Contents

Opening speech

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We have gathered here today to open the Second International Conference on Problems of Logistics, Management and Operation in the East-West Transport Corridor. As you know, the conference is organized by the Institute of Control Systems of the Azerbaijan National Academy of Sciences, Azerbaijan Technical University, Silesian Technological University (Poland), Georgian Technical University. The official sponsors of the conference are the Ministry of Digital Development and Transport of the Republic of Azerbaijan, Azerbaijan National Academy of Sciences and the Institute of Electrical and Electronics Engineers (IEEE). On behalf of the conference participants, I would like to thank the organizers and sponsors, as well as the relevant organizations of the countries that have provided us support, despite the difficulties in the time of a pandemic.

Today, with the implementation of regional and global transport and communication corridors, Azerbaijan acts not only as a producer and exporter of oil and gas, but also as a transport hub and logistics center connecting East with West and North with South.

The TRACECA (Transport Corridor Europe Caucasus Asia) program funded by the European Union involves the revival of the Great Silk Road one hundred years later, a transport and communication system connecting Europe, Caucasus and Central Asia. The East-West Corridor, which is an integral part of the One Belt One Road concept, aims to develop trade routes, transport and economic corridors and create new trade routes. The East-West Corridor is also considered the shortest trade route connecting Europe and China.

The new geopolitical situation in the region, the liberation of the occupied territories of Azerbaijan and the opening of communications through Armenia as part of the joint statement signed by the leaders of Russia, Azerbaijan and Armenia on November 10, 2020 will make it possible to attract new countries to the East-West transport corridor. Speaking about the prospects of the outcomes of the Karabakh war, the President of the Republic of Azerbaijan Mr. Ilham Aliyev, said, “One of the outcomes of the war, of course, is the Zangezur corridor, which is the subject of discussion today. The Zangezur corridor is a historic achievement. The fact that this issue is particularly specified in the trilateral statement is also our great political victory. Active work related to the Zangezur corridor is currently underway, there are many proposals, many transport and communication projects are already on the table, they are being discussed, and this will be our next historic success."

Thus, Azerbaijan today is an active participant in the cooperation in the East-West and North-South transport corridors, and significant steps have already been taken in this direction, several large infrastructure projects have been implemented. Examples include the Baku-Tbilisi-Kars railway connecting Azerbaijan, Georgia and Turkey, the Baku International Sea Trade Port complex, six international airports, modern highways throughout the country, the Free Trade Zone, etc. I would also like to point out that the Parliament adopted numerous official documents and relevant laws regulating interstate transport and communication relations.

As for international transport and communication lines, in recent years, in addition to land, air and waterways, the fourth kind of infrastructure is rapidly developing - digital information and communication infrastructure. Projects implemented by Azerbaijani companies on the transmission of information in the East-West and North-South corridors - EPEG (Europa-Persia Express Gateway), TASIM (Tran-Eurasian Information Super Highway), Trans-Caspian International Transport Route - serve to develop cooperation without borders, and these services will expand in the future. Systems operating in our country, such as AzExport (Digital Platform for International Trade Relations), Azerbaijan Digital Trade Center and Azerbaijan Digital Center under construction, also serve as international transport and communication means. Recently, our focus has also been on the Digital One Belt One Road international megaproject proposed by the Chinese Academy of Sciences. The project is aimed at gathering information about land and nature in countries located along the Silk Road, in other words, along the East-West corridor, using aerospace means, storing it in data centers, attracting powerful computing resources, bringing together scientists and solving global problems of climate change, natural disasters, water and food resources, etc. to achieve the UN Sustainable Development Goals (SDG).

Azerbaijan's space, digital resource and scientific potential makes our participation in this megaproject possible. With two telecommunications satellites and one Earth observation satellite, several TIER 3 and TIER 2 data centers, the High Performance Computing (HPC) center, transnational fiber-optic high-speed information channels and digital hubs have created a digital cluster in the full sense of the word in our country.

The main aim of our conference is the discussion and solution of scientific, technical, technological and economic problems and issues of management, logistics and operation in the East-West transport corridor and other transport and communication corridors. The papers presented here widely discuss solving transport problems by using new methods of science and technology born of the challenges of the 4th industrial revolution: artificial intelligence, unmanned aerial vehicles, Big Data, etc. I believe that the results of these discussions will be used to address issues that are of particular importance in the field of transport corridors and will make a significant contribution to bringing the desired expectations to life.

Experts and scientists from many countries and Azerbaijan will participate in our conference in a hybrid mode, both online and in person. Allow me to greet you all once again and wish you a successful conference.

Plenary papers

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Algorithms and Intelligent Technologies for Improving the Adequacy of Monitoring and Diagnostics of the Beginning of the Latent Period and Dynamics of Development of Accidents on the Rolling Stock and Railroad Tracks

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***Abstract*—Control and diagnostic systems currently used in rolling stock diagnose malfunctions in wheel-and-motor units, bearing defects, wheel-and-motor units, bearing misalignments, mounting defects, imbalance of rotating parts, gearbox defects. They also diagnose leaks in the feed and brake lines, break valve malfunctions, brake cylinder malfunctions, compressor malfunctions. In this case, parameters of vibration, pressure, force, current, voltage, resistance, pulses, time intervals are used as diagnostic indicators. The control results are primarily reflected on the driver's monitor. However, these systems do not detect the beginning of the latent period of the onset of a malfunction, which usually precedes an accident. In addition, these systems provide no information on the dynamics of its development. Therefore, the result of control is sometimes belated and does not allow taking appropriate measures in time. In addition, modern geometry cars, flaw detector cars and other track test cars are used to control the technical condition of the railroad track, which provide reliable control of the technical condition of the railroad track at "certain intervals of time". At the same time, in real life, due to the impact of various factors, such as seismic processes, certain malfunctions may occur even a day after control. Therefore, it is of great practical importance to create technologies and technical means of "continuous" control of the technical condition of the railroad track, railroad bridges, tunnels and other infrastructure elements. In this paper, the authors propose intelligent technologies and technical tools that make it possible to control the beginning of the latent period of the origin of malfunctions and the dynamics of the development of changes in the technical condition of the track. They are convenient for implementation in the form of a "black box" and can be easily installed in one of the cars of the rolling stock.**

Keywords—transport corridor, railroad tracks, rolling stock, East-West transport corridor, diagnostics, accident

I. Introduction

The main condition for ensuring the safety of train movement in railway transport is the reliable and fail-safe operation of rolling stock. To ensure the required reliability of the rolling stock, it is necessary to constantly control the technical condition of its running gear. In modern conditions, obtaining reliable information about their technical condition is impossible without technical diagnostics systems. Various diagnostic systems are currently used to assess the technical condition of the running gear of rolling stock in motion (based on the principle of their use: stationary, airborne, portable, incorporated directly into the controlled object, etc.). The main goal of technical diagnostics is to determine the type and location of defects. Vibration parameters, pressure, force, current, voltage, resistance, pulses, time intervals, etc. are used as diagnostic indicators. Receiving the information about deviations from the nominal values of the controlled parameters (temperature, vibration, noise, etc.) during movement, the driver of a high-speed passenger train informs the dispatcher, who, in turn, informs the relevant departments.

Let us consider the example of axleboxes of wheelsets, one of the critical units of the running gear of the rolling stock, which mainly consist of roller bearings. Currently, to monitor the technical condition of the axlebox bearings, automatic temperature and noise control systems with built-in sensors in the axleboxes are used. They make it possible to monitor the parameters of the technical condition of the axleboxes and generate information about deviations from the nominal readings. And this will make it possible to take timely measures and thereby prevent the development of emergency situations. For instance, the system for passenger cars allows obtaining information about the temperature of the axlebox unit using sensors built into the axlebox housing of the wheelset bearings. The control system ensures the processing and storage of the received information, as well as alerts to dangerous heating of the bearings. However, this system monitors only the unit temperature and notifies the train personnel of its value. This does not always allow controlling the beginning and dynamics of the development of bearing damage. As a result, there are challenges and difficulties in eliminating it. In this regard, the development of more effective alternative options for solving the problems of controlling the onset of the initiation and dynamics of the development of malfunctions on the running gear of the rolling stock is required.

In addition to controlling the operation of the rolling stock, it is also important to control the technical condition of the railroad track. At present, this work is carried out by modern geometry cars, flaw detector cars and other track test cars at “certain intervals of time”. Their number is limited and therefore, at present, "continuous control" of all hauls of the track practically impossible. At the same time, in real life, due to the impact of various factors, such as torrential rains, hurricane winds, seismic processes and so on, certain changes that can cause catastrophic accidents may take place even a day after control. In this regard, it is of great practical importance to create technologies and technical means of "continuous" control of the technical condition of the railroad track. It is also important to carry out continuous control of the technical condition of railroad bridges, tunnels and other infrastructure elements.

The studies carried out have shown that to solve this problem, first of all, it is necessary to create algorithms and technologies that allow ensuring the adequacy of the operation of systems for the control and diagnostics of the railroad tracks. Analysis has shown that one of the possible options for “continuous” monitoring the beginning of changes in the technical condition of the track can be implemented with intelligent tools, which allow one, by analyzing the useful signal and the noise from the soil vibrations caused by the rolling stock, to form informative attributes for identifying the technical condition of the track. Due to the simplicity and the reliability of implementation of the proposed technical tools, they can be easily installed in the form of a “black box” in one of the cars of all rolling stocks, providing control of the beginning of changes in the technical condition of the track during their movement in all hauls.

II. Problem Statement. The Importance of Ensuring the Adequacy of Control of the Beginning of the Latent Period and the Dynamics of the Development of Accidents in Rail Transport

It is known that under the normal state of operation of the rolling stock, in the signals received at the outputs of the corresponding sensors, the conditions of stationarity, normality of the distribution law and the absence of correlation between $R_{X\varepsilon}(\mu)$, $r_{X\varepsilon}$, the useful signal $X(t)$ and the noise $\varepsilon(t)$ are satisfied, i.e.,

$$\begin{cases} g(t) = X(t) + \varepsilon_1(t) \\ R_{X\varepsilon}(\mu = 0) \approx 0,\ r_{X\varepsilon} \approx 0 \end{cases} \quad (1)$$

It is also known that as a result of the initiation of malfunctions preceding the accidents, the noise $\varepsilon_2(t)$ is formed, which has a correlation with the useful signal $X(t)$. In this case, a correlation arises between the useful signal $X(t)$ and the sum noise $\varepsilon_1(t) + \varepsilon_2(t)$, i.e.,

$$\begin{cases} g(t) = X(t) + \varepsilon_{11}(t) + \varepsilon_{21}(t) \\ R_{X\varepsilon}(\mu = 0) \neq 0,\ r_{X\varepsilon} \neq 0 \end{cases} \quad (2)$$

In the first case, the estimate of the variance of the noisy signal $g(t)$ is determined from the expression

$$D_{gg} = M[g(t)g(t)] = M\big[\big(X(t) + \varepsilon_1(t)\big)\big(X(t) + \varepsilon_1(t)\big)\big] = \\ = M[X(t)X(t) + \varepsilon_1(t)\varepsilon_1(t)] = D_{XX}(0) + D_\varepsilon, \quad (3)$$

where the estimate of the variance of the noise is determined from the formula

$$M[\varepsilon_1(t)\varepsilon_1(t)] = M[\varepsilon(t)\varepsilon(t)] = D_\varepsilon. \quad (4)$$

In the second case, the estimate of the variance of the sum signal $g(t)$ is determined from the expression

$$D_{gg} = M\{[X(t) + \varepsilon_1(t) + \varepsilon_2(t)][X(t) + \varepsilon_1(t) + \varepsilon_2(t)]\} = \\ = M[X(t)X(t) + \varepsilon_2(t)X(t) + X(t)\varepsilon_2(t) + \varepsilon_1(t)\varepsilon_1(t) \\ + \varepsilon_2(t)\varepsilon_2(t)] = \\ = R_{XX}(t) + 2R_{X\varepsilon_2}(t) + D_{\varepsilon_1\varepsilon_1} + D_{\varepsilon_2\varepsilon_2}, \quad (5)$$

where the estimate of the variance of the sum noise is determined from the expression

$$D_\varepsilon = M[\varepsilon_2(t)X(t) + X(t)\varepsilon_2(t) + \varepsilon_1(t)\varepsilon_1(t) + \varepsilon_2(t)\varepsilon_2(t)] \\ = \\ = 2R_{X\varepsilon_2}(0) + D_{\varepsilon_1\varepsilon_1} + D_{\varepsilon_2\varepsilon_2} = 2R_{X\varepsilon} + D_{\varepsilon\varepsilon}\ 0. \quad (6)$$

As can be seen from expressions (4) and (6), the estimates of the result of the analysis of noisy signals in the normal state of objects coincide. However, they differ significantly at the beginning of the latent period of accidents. Because of this, the adequacy of the results of control and diagnostics at the beginning of the latent period of accidents in rolling stock using traditional technologies in most cases is not ensured. Control of the technical condition of the railrod tracks is carried out by determining the time interval by means of track test cars. Their continuous control is also a relevant and important problem. In view of the above, the detection of the occurrence of malfunctions by the rail transport control system turns out to be delayed. Occasionally, for this reason, accidents with undesirable results occur. Therefore, to improve the safety of rolling stock operation and to ensure the quality of control of railroad tracks, bridges and tunnels, we consider options for creating a technology that will improve the adequacy of the results of control in the latent period of an emergency state. The issue of controlling the dynamics of the development of accidents is also discussed in the paper.

III. Possibilities of Ensuring the Adequacy of the Results of Correlation and Spectral Control of the Beginning of Malfunctions in Rail Transport Using the Technology of Equivalent Noises

As mentioned above, according to expressions (1)-(6), the occurrence of malfunctions manifests itself in the form of noises on the noisy signals $g(t)$ received on the corresponding sensors, i.e.,

$$g(t) = X(t) + \varepsilon_1(t) + \varepsilon_2(t) \quad (7)$$

where $X(t)$ is the useful signal, $\varepsilon_1(t)$ is the noise caused by external factors, $\varepsilon_2(t)$ is the noise caused by the initiation of defects that precede malfunctions. As mentioned above for the noisy signal $g(t) = X(t) + \varepsilon(t)$, if the condition of the absence of a correlation between the useful signal and the noise is satisfied, then the analysis results obtained using traditional technologies can be considered adequate. However, when the noisy signal $g(t)$ has form (7), the following expressions take place:

$$g(t) = X(t) + \varepsilon_1(t) + \varepsilon_2(t)$$
$$\varepsilon(t) = \varepsilon_1(t) + \varepsilon_2(t)$$
$$R_{XX}(\mu) = \mathrm{M}[X(t)X(t+\tau)] \neq R_{gg}(\mu) = \mathrm{M}[g(t)g(t+\tau)]$$
$$D_\varepsilon = R_{\varepsilon\varepsilon}(\mu = 0) = \mathrm{M}[\varepsilon(t)\varepsilon(t)]$$
$$R_{X\varepsilon}(0) = \mathrm{M}\,[X(t)\varepsilon(t)]$$
$$r_{gg}(\tau) \neq r_{XX}(\tau)$$
$$a_{n_X} = \mathrm{M}[X_n \sin n\omega t] \neq a_{n_g} = \mathrm{M}[g_n \sin n\omega t]$$
$$b_{n_X} = \mathrm{M}[X_n \cos n\omega t] \neq b_{n_g} = \mathrm{M}[g_n \cos n\omega t]$$

where $R_{gg}(\mu)$, $R_{XX}(\mu)$ are the estimates of the correlation functions of the useful signal $X(t)$ and the noisy signal $g(t)$, $R_{X\varepsilon}(0)$ is the estimate of the cross-correlation function between the useful signal $X(t)$ and the noise $\varepsilon(t)$, $r_{gg}(\tau)$, $r_{XX}(\tau)$ are the normalized correlation functions of the noisy signal $g(t)$ and the useful signal$X(t)$, a_{n_X}, b_{n_X}, a_{n_g}, b_{n_g} are the estimates of the spectral characteristics of the useful signal$X(t)$, the noisy signal $g(t)$ and the noise$\varepsilon(t)$.

It is obvious from these expressions that when the correlation between the useful signal $X(t)$ and the noise $\varepsilon(t)$ differs from zero, the adequacy of the results of the analysis of noisy signals using traditional technologies will be unsatisfactory. The studies have shown that in order to eliminate the difficulty of ensuring the adequacy of the analysis of noisy signals, it is first of all necessary to create a technology for determining the estimates of the correlation characteristics of the noise $\varepsilon(t)$ of noisy signals [7-9]. For this purpose, technologies are proposed for determining the estimates of the noise variance D_ε and the cross-correlation functions between the useful signal and the noise $R_{X\varepsilon}(\mu)$.

These studies [7-9] have shown that in order to solve the problem of ensuring the adequacy of the results of control and diagnostics, it is necessary to create a technology for forming equivalent noises, in whose estimates obtained as a result of their analysis would coincide with the results of the analysis of the noises of noisy signals. In this case, by analyzing the equivalent noises, it is necessary to ensure that the obtained estimates are equivalent to the estimates of noisy signals.

Taking into account the above, various options for forming equivalent noises were considered. All of them have been tested by numerous computational experiments. Through an analysis of the proposed options, it has been found that there are few practically feasible options. The most expedient of them was replacing the non-measurable noise samples $\varepsilon(i\Delta t)$ with their approximate equivalent values $\varepsilon^e(i\Delta t)$,

$$\varepsilon(i\Delta t) \approx \varepsilon^e(i\Delta t) = \operatorname{sgn} \varepsilon'(i\Delta t) \times \sqrt{|g^2(i\Delta t) + g(i\Delta t)g((i+2)\Delta t) - 2g(i\Delta t)g((i+1)\Delta t)|} = \operatorname{sgn} \varepsilon'(i\Delta t)\sqrt{|\varepsilon'(i\Delta t)|}. \quad (8)$$

Here, assuming that the following expression is true

$$D_\varepsilon = \frac{1}{N}\sum_{i=1}^{N} \varepsilon^2(i\Delta t) \approx \frac{1}{N}\sum_{i=1}^{N} \varepsilon^{e2}(i\Delta t) = \frac{1}{N}\sum_{i=1}^{N} g(i\Delta t)[g(i\Delta t) + g((i+2)\Delta t) - 2g((i+1)\Delta t)] \quad ,(9)$$

the formula for calculating the mean value $\bar{\varepsilon}(i\Delta t)$ of samples of the noise $\varepsilon(i\Delta t)$ can be reduced to the calculation of the mean value of the equivalent samples of the noise $\varepsilon^e(i\Delta t)$, i.e.:

$$\bar{\varepsilon}(i\Delta t) \approx \overline{\varepsilon^e}(i\Delta t) = \frac{1}{N}\sum_{i=1}^{N} \varepsilon^e(i\Delta t), \quad (10)$$

$$\frac{1}{N}\sum_{i=1}^{N} \varepsilon^e(i\Delta t) \approx \frac{1}{N}\sum_{i=1}^{N} \varepsilon(i\Delta t). \quad (11)$$

The possibility of forming equivalent noises allows us to determine equivalent samples of the useful signal $X^e(i\Delta t)$ and the estimates of $R_{XX}(\mu)$, $R_{X\varepsilon}(\mu)$ and other characteristics of the noisy signal, i.e.,

$$X^e(i\Delta t) = g(i\Delta t) - \varepsilon^e(i\Delta t) \quad (12)$$

$$R^e_{XX}(\mu) \approx R^e{}_{X^eX^e}(\mu) == \frac{1}{N}\sum_{i=1}^{N} X^e(i\Delta t)X^e\big((i+\mu)\Delta t\big) \approx \frac{1}{N}\sum_{i=1}^{N} X(i\Delta t)X\big((i+\mu)\Delta t\big) \quad (13)$$

$$R^e_{X\varepsilon}(\mu) \approx \frac{1}{N}\sum_{i=1}^{N} X^e(i\Delta t)\varepsilon^e\big((i+\mu)\Delta t\big) \approx \frac{1}{N}\sum_{i=1}^{N} X(i\Delta t)\varepsilon\big((i+\mu)\Delta t\big) \quad (14)$$

where $X^e(i\Delta t)$ is the equivalent sample of the useful signal $X(t)$, $\varepsilon^e(i\Delta t)$ is the equivalent sample of the noise $\varepsilon(t)$.

Thus, using (8)-(14) makes it possible to isolate from the noisy signal an equivalent useful signal $X^e(i\Delta t)$ and an equivalent noise $\varepsilon^e(i\Delta t)$, for which the estimates of $R^e_{XX}(\mu)$ and $R^e_{X\varepsilon}(\mu)$ coincide with the estimates of the useful signal $X(i\Delta t)$ and the noise $\varepsilon(i\Delta t)$. This allows improving the adequacy of the malfunction control.

IV. Algorithms for Improving the Adequacy of Control Results Using Traditional Technologies

When considering possible options for improving the adequacy of results of control and diagnostics in rail transport, it becomes obvious that it is first and foremost necessary to create algorithms and technologies for eliminating errors in traditional technologies for analyzing noisy signals.

For this purpose, we will consider the possibility of determining the main errors of traditional technologies of correlation and spectral analysis:

$$R_{gg}(\mu) = \frac{1}{N}\sum_{i=1}^{N} g(i\Delta t)\, g((i+\mu)\Delta t) = \frac{1}{N}\sum_{i=1}^{N}(X(i\Delta t) + \varepsilon(i\Delta t))(X(i+\mu)\Delta t) + \varepsilon((i+\mu)\Delta t)) = \frac{1}{N}\sum_{i=1}^{N}[X(i\Delta t)\, X\big((i+\mu)\Delta t\big) + \varepsilon(i\Delta t)X\big((i+\mu)\Delta t\big) + X(i\Delta t)\varepsilon\big((i+\mu)\Delta t\big) + \varepsilon(i\Delta t)\varepsilon((i+\mu)\Delta t) = R_{XX}(\mu) + R_{\varepsilon X}(\mu) + R_{X\varepsilon}(\mu) + R_{\varepsilon\varepsilon}(\mu)$$

Therefore, the error $\lambda_{gg}(\mu)$ of traditional technologies can be determined from the formula

$$\lambda_{gg}(\mu) \approx \frac{1}{N}\sum_{i=1}^{N}\Big[X(i\Delta t)\varepsilon\big((i+\mu)\Delta t\big) + \varepsilon(i\Delta t)X\big((i+\mu)\Delta t\big) + \varepsilon(i\Delta t)\varepsilon((i+\mu)\Delta t)\Big]$$

which show that to eliminate it, it is necessary to determine the estimates $R_{X\varepsilon}(0)$, $R_{X\varepsilon}(\mu)$ and $R_{\varepsilon\varepsilon}(0)$, i.e.

$$\lambda_{gg}(\mu) \approx \begin{cases} 2R_{X\varepsilon}(0) + R_{\varepsilon\varepsilon}(0) & \text{when} \quad \mu = 0 \\ 2R_{X\varepsilon}(\mu) & \text{when} \quad \mu \neq 0 \end{cases}$$

It is obvious that the estimates of $R_{XX}(\mu)$ an be determined from the expression

$$R_{XX}(\mu) \approx \begin{cases} R_{gg}(0) - [2R^{e}_{X\varepsilon}(0) + R^{e}_{\varepsilon\varepsilon}(0)] & \text{when} \quad \mu = 0 \\ R_{gg}(\mu) - 2R^{e}_{X\varepsilon}(\mu) & \text{when} \quad \mu \neq 0 \end{cases} \quad (15)$$

The estimates a_{n_X} and b_{n_X}, i.e., spectral characteristics can also be determined from the expressions

$$\begin{cases} a_{n_X} = \frac{2}{T}\int_0^T [X(t) + \varepsilon(t)]\cos n\omega t\, dt = \frac{2}{T}\int_0^T [X(t)\cos n\omega t + \varepsilon(t)\cos n\omega t]\, dt \\ b_{n_X} = \frac{2}{T}\int_0^T [X(t) + \varepsilon(t)]\sin n\omega t\, dt = \frac{2}{T}\int_0^T [X(t)\sin n\omega t + \varepsilon(t)\sin n\omega t]\, dt \end{cases}$$

$$\varepsilon(i\Delta t) = \varepsilon_1(i\Delta t) + \varepsilon_2(i\Delta t)$$

which can be calculated after determining the estimates $\lambda_{a_{n_X}}$ and $\lambda_{b_{n_X}}$, from the expressions

$$\begin{cases} a_{n_g} = \frac{2}{N}\sum_{i=1}^{N} g(i\Delta t)\cos n\omega\,(i\Delta t) - \lambda_{a_n} = a_{n_X} \\ b_{n_g} = \frac{2}{N}\sum_{i=1}^{N} g(i\Delta t)\sin n\omega\,(i\Delta t) - \lambda_{b_n} = b_{n_X} \end{cases} \quad (16)$$

$$\begin{cases} \lambda_{a_n} = \sum_{i=1}^{N^+}\int_{t_1}^{t_{i+1}} \varepsilon(t)\cos n\omega t\, dt - \sum_{i=1}^{N-}\int_{t_1}^{t_{i+1}} \varepsilon(t)\cos n\omega t\, dt \\ \lambda_{b_n} = \sum_{i=1}^{N^+}\int_{t_1}^{t_{i+1}} \varepsilon(t)\sin n\omega t\, dt - \sum_{i=1}^{N-}\int_{t_1}^{t_{i+1}} \varepsilon(t)\sin n\omega t\, dt \end{cases}$$

$$\lambda_{a_n} = \left[\frac{N^{+}_{a_n} - N^{-}_{a_n}}{N}\bar{\lambda}_a(i\Delta t)\right], \quad \lambda_{b_n} = \left[\frac{N^{+}_{b_n} - N^{-}_{b_n}}{N}\bar{\lambda}_b(i\Delta t)\right]$$

$$\bar{\lambda}_{a_n}(i\Delta t) = \overline{|\sqrt{D_\varepsilon}\cos n\omega(i\Delta t)\,|}, \quad \bar{\lambda}_{b_n}(i\Delta t) = \overline{|\sqrt{D_\varepsilon}\sin n\omega(i\Delta t)\,|}$$

Thus, determining the estimates of the correlation functions $R_{XX}(\mu)$ and the spectral characteristics a_{n_X}, b_{n_X} of useful signals according to formulas (15), (16), it is possible to eliminate the errors of traditional technologies.

This opens up a possibility to improve the adequacy of solving a wide range of control and identification problems for both rolling stock and railroad tracks.

V. Correlation Technology for Noise Control of the Beginning and Dynamics of Development of the Latent Period of Accidents in Rail Transport

It is shown in [1] that at the beginning of the latent period of the initiation of accidents as a result of the appearance of the noise $\varepsilon_2(i\Delta t)$, the estimate of the cross-correlation function between the sum noise $\varepsilon_2(i\Delta t)$ and the useful signal $X(i\Delta t)$ differs from zero. At the same time, in a stable emergency state, this estimate does not change. However, as the defect develops, this estimate increases. This makes it possible to control the dynamics of the development of accidents. However, by increasing or decreasing the value of the estimates of the noise variance, it is impossible to control the dynamics of the development of accidents. As numerous experiments show, the dynamics of the development of accidents leads both to an increase in the variance of the noise $\varepsilon_2(i\Delta t)$, which leads to an increase in the correlation between the useful signal and the noise. As a result, in the presence of the dynamics of the development of a malfunction, a correlation first arises between $X(i\Delta t)$ and $\varepsilon(i\Delta t)$. Then the further development of dynamics leads to the appearance of a correlation between $X(i\Delta t)$ and $\varepsilon(i+2)\Delta t$, then between $X(i\Delta t)$ and $\varepsilon(i+3)\Delta t$, etc. Therefore, to control the dynamics of the development of accidents, it is necessary to calculate the estimates corresponding to the cross-correlation function between $X(i\Delta t)$ and $\varepsilon(i\Delta t)$. In [1], the possibility of calculating the estimate of $R_{X\varepsilon}(\Delta t)$ is considered and it is shown that if there is a correlation between $X(i\Delta t)$ and $\varepsilon(i\Delta t)$ at m different time shifts $\mu = m\Delta t$, $m = 1, 2, 3, \ldots$, it is advisable to use a generalized expression in the form

$$R_{X\varepsilon}(m\Delta t) \approx \frac{1}{2N}\sum_{i=1}^{N}\Big[\, g(i\Delta t)g\Big(\big(i + (\mathrm{m}+1)\big)\Delta t\Big) - 2g(i\Delta t)g\Big(\big(i + (\mathrm{m}+1)\big)\Delta t\Big) + g(i\Delta t)g\Big(\big(i + (\mathrm{m}+2)\big)\Delta t\Big)\Big].$$

An experimental analysis of noisy signals received at various technical facilities [1-12] showed that, depending on the degree of dynamics of the development of accidents at these facilities, a correlation appears between the useful signal $X(i\Delta t)$ and the noise $\varepsilon(i\Delta t)$ first at $\mu = 1\Delta t$, then at $\mu = 2\Delta t$, $\mu = 3\Delta t$, then at $\mu = 4\Delta t, 5\Delta t, 6\Delta t$, etc. Moreover, the values of these estimates reflect the dynamics of the development of accidents over time. Due to this, the generalized expression for calculating the estimates $R_{X\varepsilon}(\mu = 1\Delta t), R_{X\varepsilon}(\mu = 2\Delta t), R_{X\varepsilon}(\mu = 3\Delta t), \ldots, R_{X\varepsilon}(\mu = m\Delta t)$ makes it possible to control and diagnose not only the beginning, but also the dynamics of the development of rolling stock malfunctions.

As shown above, at the beginning of the latent period of malfunctions, the error $\varepsilon_2(i\Delta t)$ appeares as a result of the initiation of various defects. At the same time, in essence, the dynamics of the development of accidents, despite the indirect influence on the value of the estimate of the noise variance, uniquely manifests itself only in the estimates of the cross-correlation functions between $X(i\Delta t)$ and $\varepsilon(i\Delta t)$ at different time shifts. Therefore, as indicated above, to control the dynamics of the development of accidents, it is advisable to use the estimate of $R_{X\varepsilon}(m)$. However, quite often, to control the onset and dynamics of the latent period of accidents, it is possible to use easily implementable algorithms that make it possible to significantly simplify the solution of this problem. From this point of view, it is advisable to use estimates of relay correlation functions, which can be calculated from the formula

$$R^*_{X\varepsilon}(\mu) = \frac{1}{N}\sum_{i=1}^{N} \text{sgn } g(i\Delta t)\varepsilon^2(i\Delta t) = \frac{1}{N}\sum_{i=1}^{N} \text{sgn } X(i\Delta t)\varepsilon^2(i\Delta t).$$

However, to use this formula, it is necessary to determine the samples of the noise $\varepsilon(i\Delta t)$, which cannot be measured directly.

The following estimate can be used as informative attributes:

$$R^*_{X\varepsilon}(\mu) = \frac{1}{N}\sum_{i=1}^{N} \text{sgn } g(i\Delta t)\big[g(i\Delta t)g(i\Delta t) - 2g(i\Delta t)g\big((i+1)\Delta t\big) + g(i\Delta t)g\big((i+2)\Delta t\big)\big] = \frac{1}{N}\sum_{i=1}^{N} \text{sgn } g(i\Delta t)\varepsilon^2(i\Delta t)$$

$$\varepsilon^2(i\Delta t) = g(i\Delta t)\big[g(i\Delta t)g(i\Delta t) - 2g(i\Delta t)g\big((i+1)\Delta t\big) + g(i\Delta t)g\big((i+2)\Delta t\big)\big]$$

It is also advisable to use for these purposes simple options for the approximate calculation of estimates of the relay cross-correlation function $R^*_{X\varepsilon}(\mu)$ between the useful signal $X(i\Delta t)$ and the noise $\varepsilon(i\Delta t)$ at various time shifts $m\Delta t$:

$$R^*_{X\varepsilon}(m\Delta t) \approx \frac{1}{2N}\sum_{i=1}^{N}\Big[\text{sgn } g(i\Delta t)g\big((i+m)\Delta t\big) - 2\,\text{sgn } g(i\Delta t)g\Big(\big(i+(m+1)\big)\Delta t\Big) + \text{sgn } g(i\Delta t)g\Big(\big(i+(m+2)\big)\Delta t\Big)\Big].$$

When this formula is used, in the case of the presence of dynamics of the malfunction development, the obtained estimate will change at different time shifts [1]. At the same time, by determining the estimate of the relay cross-correlation function $R^*_{X\varepsilon}(\mu\Delta t)$ between the useful signal $X(i\Delta t)$ and the noise $\varepsilon(i\Delta t)$ at different $\mu\Delta t$, it is possible to control the dynamics of the development of the malfunction.

For instance, at $\mu = 1\Delta t$, the formula for calculating the estimate $R^*_{X\varepsilon}(\mu = 1\Delta t)$ will have the form

$$R^*_{X\varepsilon}(\mu = 1\Delta t) \approx \frac{1}{N}\sum_{i=1}^{N}[\text{sgn} g(i\Delta t)g(i+1)\Delta t - 2\,\text{sgn } g(i\Delta t)g(i+2)\Delta t + \text{sgn } g(i\Delta t)g(i+3)\Delta t].$$

At $\mu = 2\Delta t$, the formula for calculating the estimate $R^*_{X\varepsilon}(\mu = 2\Delta t)$ will have the form

$$R^*_{X\varepsilon}(\mu = 2\Delta) \approx \frac{1}{N}\sum_{i=1}^{N}[\text{sgn } g(i\Delta t)g(i+2)\Delta t - \text{sgn } g(i\Delta t)g(i+3)\Delta t + \text{sgn } g(i\Delta t)g(i+4)\Delta t].$$

It is obvious that the estimates $R^*_{X\varepsilon}(\mu = 3\Delta t), R^*_{X\varepsilon}(\mu = 4\Delta t)$, ..., can be calculated in a similar manner.

It is clear that in the absence of a correlation between $X(i\Delta t)$ and $\varepsilon(i\Delta t)$, the estimate of the cross-correlation function $R_{X\varepsilon}(\mu = 0)$ between the useful signal and the noise will be close to zero. It is also obvious that at the initiation of various defects preceding accidents at the facility, as a result of the appearance of the noise $\varepsilon_2(i\Delta t)$ $(\varepsilon(i\Delta t) = \varepsilon_1(i\Delta t) + \varepsilon_2(i\Delta t))$, the value of the estimate of the relay cross-correlation correlation function due to the presence of a correlation between $X(i\Delta t)$ and $\varepsilon(i\Delta t)$ will increase sharply. A distinctive feature of this algorithm is that at the initiation of various malfunctions, when a correlation occurs between $X(i\Delta t)$ and $\varepsilon(i\Delta t)$, the differences in the estimates $R^*_{X\varepsilon}(1\Delta t)$, $R^*_{X\varepsilon}(2\Delta t)$, $R^*_{X\varepsilon}(3\Delta t)$ unambiguously reflect the dynamics of the development of accidents, which makes it possible to provide reliable information on the dynamics of the malfunction development.

Similarly, using the corresponding formulas for other Noise characteristics of the noisy signals $g(i\Delta t)$, [1, 9-12], it is possible to increase the reliability and adequacy of control of the beginning of the latent period and the dynamics of the development of malfunctions preceding accidents in rail transport.

$$R^*_{1X\varepsilon}(0) = \frac{1}{N}\sum_{i=1}^{N} g'(i\Delta t)g'(i\Delta t) - 2g'(i\Delta t)g'\big((i+1)\Delta t\big) + g'(i\Delta t)\,g'\big((i+2)\Delta t\big)$$

$$R^*_{2X\varepsilon}(0) = \frac{1}{N}\sum_{i=1}^{N} g'(i\Delta t)g(i\Delta t) - 2g'(i\Delta t)g\big((i+1)\Delta t\big) + g'(i\Delta t)g\big((i+2)\Delta t\big)$$

$$R^*_{3X\varepsilon}(0) = \frac{1}{N}\sum_{i=1}^{N} g^2(i\Delta t)g(i\Delta t) - 2g^2(i\Delta t)g\big((i+1)\Delta t\big) + g^2(i\Delta t)g\big((i+2)\Delta t\big)$$

$$R^*_{4X\varepsilon}(0) = \frac{1}{N}\sum_{i=1}^{N} g'^2(i\Delta t)g'(i\Delta t) - 2g'^2(i\Delta t)g'\big((i+1)\Delta t\big) + g'^2(i\Delta t)\,g'\big((i+2)\Delta t\big)$$

$$R^*_{5X\varepsilon}(0) = \frac{1}{N}\sum_{i=1}^{N} sgn\ g(i\Delta t)g(i\Delta t) - 2sgn\ g(i\Delta t)g\big((i+1)\Delta t\big) + sgn\ g(i\Delta t)g\big((i+2)\Delta t\big)$$

$$R^*_{6X\varepsilon}(0) = \frac{1}{N}\sum_{i=1}^{N} sgn\ g'(i\Delta t)g'(i\Delta t) - 2sgn\ g'(i\Delta t)g'\big((i+1)\Delta t\big) + sgn\ g'(i\Delta t)\,g'\big((i+2)\Delta t\big)$$

where $g(i\Delta t)$ is the centered noisy signal, $g'(i\Delta t)$ is the non-centered noisy signal, $R_{X\varepsilon}(\mu\Delta t)$ is the cross-correlation function between the useful signal $X(i\Delta t)$ and the noise $\varepsilon(i\Delta t)$; $\mu\Delta t$ is the time shift between the samples of the useful signal $X((i+\mu)\Delta t)$ and the noise $\varepsilon(i\Delta t)$; $g((i+\mu)\Delta t)$ is the $(i+\mu)$-th sample of the centered noisy signal; $g'(i\Delta t)$ is the sample of the non-centered noisy signal; N us the number of samples.

VI. Technology for Determining the Dynamics of the Malfunction Development by Changing the Shape of the Curve of the Distribution Law of the Noise of Noisy Signals

The studies carried out have shown that to control the dynamics of the malfunction development, it is possible to use the approximate values of the estimates of the curve of the distribution law of the noise $\varepsilon(i\Delta t)$. For this purpose, first of all, the equivalent samples of the noise $\varepsilon^e(i\Delta t)$ are determined.

Numerous experiments have shown that despite the possible deviations of the approximate values of the samples of $\varepsilon^e(i\Delta t)$ from their true values $\varepsilon(i\Delta t)$ by $\varepsilon^e(i\Delta t) - \varepsilon(i\Delta t)$, the following equality holds between their estimates

$$P\left\{\frac{1}{N}\sum_{i=1}^{N}\varepsilon^{e2}(i\Delta t) - \frac{1}{N}\sum_{i=1}^{N}\varepsilon^2(i\Delta t) \approx 0\right\} = 1,$$

$$P\left\{\frac{1}{N}\sum_{i=1}^{N}\varepsilon^{e}(i\Delta t)-\frac{1}{N}\sum_{i=1}^{N}\varepsilon(i\Delta t)\approx 0\right\}=1,$$

where P is the probability sign. This equality shows that by constructing the distribution law of the equivalent noise $\varepsilon^{e}(i\Delta t)$, one can obtain results identical to the results of the analysis of the noise $\varepsilon(i\Delta t)$, i.e, the possibility of calculating the approximate values of the equivalent samples of the noise $\varepsilon^{e}(i\Delta t)$ makes it possible to construct the distribution law of the noise $\varepsilon(i\Delta t)$. It is known that the coordinates of the curve of the distribution law of the noise are determined for this purpose. Therefore, $W(\varepsilon)$ is determined corresponding values of its curve from N samples of the noise $\varepsilon(i\Delta t)$ for the time $T=N\Delta t$. For this purpose, the approximate value of the samples of the equivalent noise $\varepsilon_2^{a}(\mathrm{i}\Delta\mathrm{t})$. is used. For this, by the number of samples $N_1, N_2, \ldots, N_m$ of $\varepsilon^{e}(i\Delta t)$, given in the range from 0 to $\varepsilon_{\max}$ through equal intervals Δt, it is possible to construct the distribution law $W(\varepsilon)$.

Note that, in a similar way, by reading the square of the noise $\varepsilon^{2}(i\Delta t)$, it is possible to determine the $N_1, N_2, \ldots, N_m$ coordinates of the distribution law curve for $\varepsilon^{2}(i\Delta t)$. Obviously, this curve will be identical in shape to the curve of the distribution law of the noise $\varepsilon(i\Delta t)$. $\varepsilon^{2}(i\Delta t)$ here is determined from formula (8), (9).

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The construction of the distribution law for the equivalent noise $\varepsilon^{e}(i\Delta t)$ is carried out as follows. The minimum value ε_{min} is set, and if the condition $[\varepsilon_{min}+j\Delta x]\le\varepsilon(i\Delta t)\le[\varepsilon_{min}+(j+1)\Delta x]$ is satisfied, their number is determined. Then this value is increased by Δx for all samples of the approximate values of the noise $\varepsilon^{e}(i\Delta t)$, and this process is repeated. The construction of the curve of the distribution law for $\varepsilon^{e2}(i\Delta t)$ is carried out in a similar way.

Therefore, the construction of the distribution law $W(\varepsilon)$ for both options is carried out in a similar way. Moreover, in both cases, for the values $j=0, j=1, j=2, \ldots, j=m$, we successively determine the number of samples $\mathrm{N}_0, \mathrm{N}_1, \mathrm{N}_2, \ldots, \mathrm{N}_\mathrm{m}$, at which the specified conditions are met. It is clear that using the results obtained it is possible to construct a curve of the distribution law both for the case $W[\varepsilon^{e}(i\Delta t)]$ and for the case $W[\varepsilon^{2}(i\Delta t)]$. As the number of samples N increases, these curves tend to the distribution law of the noise itself, i.e., $W(\varepsilon)$. In the presence of dynamics of the malfunction development of the shape of both curves of the distribution laws of both $W[\varepsilon^{e}(i\Delta t)]$ and $W[\varepsilon^{2}(i\Delta t)]$ change after a certain time interval $\Delta\tau$. The difference between the samples of the distribution law curves here will depend on the dynamics of the malfunction development.

In conclusion, it should be noted that the resources of modern personal computers make it quite easy to implement the above technology in practice.

VII. Spectral Technology for the Noise Signaling of the Beginning of the Latent Period of Accidents in Rail Transport

An analysis of technologies of the possibility of using spectral noise control has shown that early diagnostics of the onset and dynamics of changes in the latent period of malfunctions is very important during the operation of rolling stock. However, the use of the technology of spectral analysis of the noisy signal $g(i\Delta t)$, usually obtained at the output of the sensors, does not provide the adequacy of the diagnostic results. Therefore, for this purpose, it is advisable to use the estimates of the spectral characteristics of the noise $\varepsilon(i\Delta t)$ of noisy signals $g(i\Delta t)$ as informative attributes, according to the expressions

$$a_{n_\varepsilon}=\frac{1}{N}\sum_{i=1}^{N}\varepsilon\,(i\Delta t)\cos n\omega(i\Delta t)$$

$$b_{n_\varepsilon}=\frac{1}{N}\sum_{i=1}^{N}\varepsilon(i\Delta t)\sin n\omega(i\Delta t)$$

However, these algorithms cannot be implemented in practice, since it is impossible to determine the samples of the noise $\varepsilon(i\Delta t)$. At the same time, as already shown above, it is possible to determine the samples of the equivalent noise $\varepsilon(i\Delta t)$ from expressions (8), (9).

$$a_{n\varepsilon}^{*}=\frac{1}{N}\sum_{i=1}^{N}\varepsilon^{e2}\,(i\Delta t)\cos n\omega(i\Delta t)$$

$$b_{n\varepsilon}^{*}=\frac{1}{N}\sum_{i=1}^{N}\varepsilon^{e2}(i\Delta t)\sin n\omega(i\Delta t)$$

where

$$\varepsilon^{e2}(i\Delta t)=g(i\Delta t)\big[g(i\Delta t)g(i\Delta t)-2g(i\Delta t)g\big((i+1)\Delta t\big)+g(i\Delta t)g\big((i+2)\Delta t\big)\big].$$

These studies have also shown that the technology of relay and sign spectral analysis of the noise using expressions can also be used for the signaling of the beginning of the initiation of malfunctions

$$a'_{n\varepsilon}=\tfrac{1}{N}\textstyle\sum_{i=1}^{N}\operatorname{sgn}\varepsilon^{e2}(i\Delta t)\operatorname{sgn}\cos n\omega(i\Delta t),$$

$$b'_{n\varepsilon}=\tfrac{1}{N}\textstyle\sum_{i=1}^{N}\operatorname{sgn}\varepsilon^{e2}(i\Delta t)\operatorname{sgn}\sin n\omega(i\Delta t),$$

$$a_{n\varepsilon}^{*}=\tfrac{1}{N}\textstyle\sum_{i=1}^{N}\operatorname{sgn}\varepsilon^{e2}(i\Delta t)\cos n\omega(i\Delta t),$$

$$b_{n\varepsilon}^{*}=\tfrac{1}{N}\textstyle\sum_{i=1}^{N}\operatorname{sgn}\varepsilon^{e2}(i\Delta t)\sin n\omega(i\Delta t).$$

The expediency of using the technology of relay and sign spectral analysis of the noise for signaling the beginning of the latent period of accidents is due to the fact that they are easily implemented by hardware.

Besides, to control the dynamics of the development of accidents, it is also advisable to use the technology of relay spectral analysis of the noise according to the expressions:

$$a_{1\varepsilon}^{*}=\tfrac{2}{N}\textstyle\sum_{i=1}^{N}\operatorname{sgn}\varepsilon^{e2}(i\Delta t)\cos n\omega(i\Delta t),$$

$$b_{1\varepsilon}^{*}=\tfrac{2}{N}\textstyle\sum_{i=1}^{N}\operatorname{sgn}\varepsilon^{e2}(i\Delta t)\sin n\omega(i\Delta t),$$

$$a_{2\varepsilon}^{*}=\tfrac{2}{N}\textstyle\sum_{i=1}^{N}\operatorname{sgn}\varepsilon^{e2}((i+1)\Delta t)\cos n\omega(i\Delta t),$$

$$b_{2\varepsilon}^{*}=\tfrac{2}{N}\textstyle\sum_{i=1}^{N}\operatorname{sgn}\varepsilon^{e2}((i+1)\Delta t)\sin n\omega(i\Delta t),$$

....

$$a_{n\varepsilon}^{*}=\tfrac{2}{N}\textstyle\sum_{i=1}^{N}\operatorname{sgn}\varepsilon^{e2}((i+m)\Delta t)\cos n\omega(i\Delta t),$$

$$b_{n\varepsilon}^{*}=\tfrac{2}{N}\textstyle\sum_{i=1}^{N}\operatorname{sgn}\varepsilon^{e2}((i+m)\Delta t)\sin n\omega(i\Delta t).$$

It is obvious that the control of the dynamics of the development of accidents can also be carried out by estimates of the sign spectral characteristics of the noise according to the formulas

$$a_{1\varepsilon}^{**} = \frac{2}{N}\sum_{i=1}^{N} \operatorname{sgn}\varepsilon^{e^2}(i\Delta t)\operatorname{sgn}\cos n\omega(i\Delta t),$$

$$b_{1\varepsilon}^{**} = \frac{2}{N}\sum_{i=1}^{N} \operatorname{sgn}\varepsilon^{e^2}(i\Delta t)\operatorname{sgn}\sin n\omega(i\Delta t),$$

$$a_{2\varepsilon}^{**} = \frac{2}{N}\sum_{i=1}^{N} \operatorname{sgn}\varepsilon^{e^2}((i+1)\Delta t)\operatorname{sgn}\cos n\omega(i\Delta t),$$

$$b_{2\varepsilon}^{**} = \frac{2}{N}\sum_{i=1}^{N} \operatorname{sgn}\varepsilon^{e^2}((i+1)\Delta t)\operatorname{sgn}\sin n\omega(i\Delta t),$$

....

$$a_{n\varepsilon}^{**} = \frac{2}{N}\sum_{i=1}^{N} \operatorname{sgn}\varepsilon^{e^2}((i+m)\Delta t)\operatorname{sgn}\cos n\omega(i\Delta t),$$

$$b_{n\varepsilon}^{**} = \frac{2}{N}\sum_{i=1}^{N} \operatorname{sgn}\varepsilon^{e^2}((i+m)\Delta t)\operatorname{sgn}\sin n\omega(i\Delta t).$$

The use of these technologies makes it possible to reliably control the dynamics of the development of accidents at $\mu = 1\Delta t$, $\mu = 2\Delta t$, $\mu = 3\Delta t$, …, $\mu = m\Delta t$. The reliability of the signaling can be ensured by duplicating these estimates with the estimates of the relay correlation functions. Due to the extreme importance of ensuring the fail-safe operation of rolling stock, duplication of the control of the beginning of initiation and dynamics of the malfunction development with several technologies can be considered justified.

VIII. Intelligent System for the Control of the Technical Condition of Railroad Tracks

Fig. 1 shows the block diagram of a system for intelligent Noise monitoring of the technical condition of railroad tracks, consisting of the following modules:

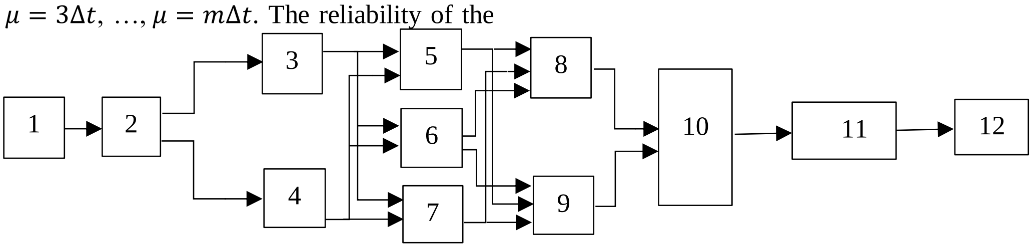

Fig. 1. Intelligent system for the control of the technical condition of railroad tracks

1. Vibration sensor.
2. Module of sampling and formation of centered samples of the noise vibration signals $g(i\Delta t)$.
3. Module of determining the equivalent samples of the useful signal $X(i\Delta t)$.
4. Module of determining the equivalent samples of the noise $\varepsilon^e(i\Delta t)$.
5. Module of determining the equivalent estimates of the correlation functions of the useful signal $R_{X^eX^e}(\mu)$.
6. Module of determining the estimates of the cross-correlation function between the useful vibration signal and the noise $R_{X^e\varepsilon^e}(\mu)$.
7. Module of determining the estimates of the spectral characteristics a_{nX^e}, b_{nX^e}, $a_{n\varepsilon^e}$, $b_{n\varepsilon^e}$ of the useful vibration signal $X(i\Delta t)$ and the noise $\varepsilon^e(i\Delta t)$.
8. Module of formation of current informative attributes consisting of current estimates $R_{X^eX^e}(\mu)$, $R_{X^e\varepsilon^e}(\mu)$, D_{ε^e}, , a_{nX^e}, b_{nX^e}, $a_{n\varepsilon^e}$, $b_{n\varepsilon^e}$, $b_{n_\varepsilon}^{*e}$.
9. Module of formation of the set of reference informative attributes $R_{X^eX^e}^{max}(\mu)$, $R_{X^e\varepsilon^e}^{max}(\mu)$, $D_{\varepsilon^e}^{max}$, $a_{nX^e}^{max}$, $b_{nX^e}^{max}$, $a_{n\varepsilon^e}^{max}$, $b_{n\varepsilon^e}^{max}$.
10. Learning module.
11. Decision-making module.
12. Module of formation of information for signaling and remote transfer.

As can be seen from the block diagram in Fig. 1, the track Noise monitoring system is an inexpensive and fairly simple device, which practically consists of a vibration sensor, a sampling tool and a controller. Therefore, it can be installed in any cars of any train, and at the same time, does not require substantial costs.

The system operates as follows. At the beginning of the operation, the learning process begins and during the movement of the rolling stock in each control cycle, by means of the appropriate modules, the sampled vibration signal $g(i\Delta t)$ is analyzed and the obtained estimates $R_{X^eX^e}(\mu)$, $R_{X^e\varepsilon^e}(\mu)$, D_{ε^e}, , a_{nX^e}, b_{nX^e}, $a_{n\varepsilon^e}$, $b_{n\varepsilon^e}$, $b_{n_\varepsilon}^{*e}$ are saved as informative attributes. In subsequent cycles, current estimates are compared with previous estimates and only those greater than the previous maximum estimates are kept. As a result, the set W_j^e forms after a certain time, which consists of maximum estimates of informative attributes, which are formed in the current cycle. They, i.e. $R_{X^eX^e}^{max}(\mu)$, $R_{X^e\varepsilon^e}^{max}(\mu)$, $D_{\varepsilon^e}^{max}$, $a_{nX^e}^{max}$, $b_{nX^e}^{max}$, $a_{n\varepsilon^e}^{max}$, $b_{n\varepsilon^e}^{max}$ are taken as reference estimates. In the following cycles, this process repeats and similarly forms the subsequent reference set. If the current informative attributes are greater than the maximum reference attributes, then it is assumed that the training for a given haul is completed, and the comparison of current combinations of informative attributes with an element of the set of reference informative attributes begins. If the current attributes are not greater than the reference ones, then the technical condition of the track is considered unchanged. If current informative features are greater than the reference ones, it is assumed that the beginning of the latent period of changes in the technical condition of the track takes place. At the same time, information is formed in Module 12 to signal the advisability of control of the technical condition of a given haul using geometry cars. In the case when no change is detected, it is also possible to form and transmit information about the safety of the track of this haul.

IX. Conclusion

Traditional technologies do not allow extracting diagnostic information sufficient to identify the onset of the latent period of the initiation of defects in the main elements of the running gear of rolling stock. This affects the delays in the detection of the onset of malfunctions, which sometimes leads to unavoidable accidents with undesirable consequences. Consequently, in order to improve the reliability of fail-safe operation and organize timely maintenance of rolling stock, it is necessary to create new, more efficient technologies for analyzing noisy signals, which allow early detection of the beginning of the initiation of malfunctions.

An analysis of malfunctions of the rolling stock undercarriage has shown that when the defects arise, the noisy signals received at the outputs of the sensors contain information about this in the form of noise of a random function. This is due to the fact that noises appear during the initiation of an accident as a result of the imposition of a large number of various dynamic effects arising in the controlled nodes. Therefore, the noises of noisy signals, which are of a chaotic random nature, contain sufficient information about the beginning of a change in the technical condition of the object. For instance, the vibration signals of the axleboxes of wheelsets contain a large number of various noises. They make it difficult to detect the onset of defect initiation when using traditional signal analysis technologies. At the same time, in some cases, it is the noise that are the only carriers of diagnostic information about the beginning of the initiation of a malfunction. Therefore, to control the beginning of the initiation of malfunctions, it is necessary to create technologies that allow calculating informative attributes not only using useful signals, but also noise [7-11]. In order to ensure the control of a defect at the beginning of its initiation, it is necessary first to choose the type and installation locations of the corresponding sensors that ensure the controllability of the object. To analyze both the sum signal $g(i\Delta t)$ and the noise $\varepsilon(i\Delta t)$, it is advisable to apply technologies that allow calculating the corresponding informative attributes.

Due to the extreme importance of ensuring fail-safe operation of the rolling stock, it is advisable to monitor the onset and dynamics of the malfunction development by duplicating several technologies of Noise control and Noise signaling proposed in [7]. The reference set of the estimates of Noise characteristics of noisy signals here will have the form

$$W_j^e = \begin{cases} D_\varepsilon^{max}, R_{X\varepsilon}^{max}(1\Delta t), R_{X\varepsilon}^{max}(2\Delta t), R_{X\varepsilon}^{max}(3\Delta t), \dots, R_{X\varepsilon}^{max}(m\Delta t) \\ R_{X\varepsilon}^{*max}(1\Delta t), R_{X\varepsilon}^{*max}(2\Delta t), R_{X\varepsilon}^{*max}(3\Delta t), \dots, R_{X\varepsilon}^{*max}(m\Delta t) \\ a_{1\varepsilon}^{max}, b_{1\varepsilon}^{max};\ a_{2\varepsilon}^{max}, b_{2\varepsilon}^{max}; a_{3\varepsilon}^{max}, b_{3\varepsilon}^{max}; \dots; a_{n\varepsilon}^{max}, b_{n\varepsilon}^{max} \\ a_{1\varepsilon}^{*max}, b_{1\varepsilon}^{*max};\ a_{2\varepsilon}^{*max}, b_{2\varepsilon}^{*max}; a_{3\varepsilon}^{*max}, b_{3\varepsilon}^{*max}; \dots; a_{n\varepsilon}^{*max}, b_{n\varepsilon}^{*max} \end{cases},$$

which, in combination with the current informative attributes, will form the basis of information support for solving the control problem. As a result, the reliability and adequacy of the results of controlling the onset and dynamics of the development of malfunctions will increase.

To ensure the safety of rail transport, it is important to increase the efficiency of control of the technical condition of the railroad tracks. Modern geometry cars, flaw detector cars and other track test cars are currently used for this purpose, providing reliable control of the technical condition of the railroad track in all hauls at certain intervals. Their number is limited and therefore "continuous control" of all hauls is practically impossible. Therefore, to ensure the safety of the track, they are used on schedule so that the control of each haul takes not less than a certain period of time. It is clear that the smaller this period, the greater the guarantee of safety. However, in reality, especially in seismically active regions, it is impossible to guarantee the complete stability of the technical condition of the track during these periods of time. Therefore, it is impossible to guarantee complete safety of the track. Obviously, to solve the track safety problem, it is necessary to take into account changes in the seismic situation in those time intervals in some hauls. This, in turn, requires a continuous monitoring of the beginning of changes in the technical condition of the track using simple and inexpensive technical tools installed in the corresponding cars of the rolling stock. This paper considers one of the possible solutions to this problem. It is known [2-5] that by analyzing soil vibration caused by the impact of the rolling stock, it is possible to form informative attributes that can be used to determine the technical condition of the track. However, the use of traditional correlation, spectral and other analysis technologies proved to be ineffective for the formation of corresponding attributes of informative attributes by analyzing vibration signals. This is due to the fact that, substantial errors caused by the effects of the noise of vibration signals arise, decreasing the adequacy of the results of track control. In this paper, the technology of separate analysis of the useful vibration signal, the noise of the vibration signal, and the relationship between them are proposed to eliminate this difficulty, and on their basis, one of the possible options for constructing intelligent technical means of Noise control is proposed, which can be easily implemented in one of the cars of all rolling stocks. Noise here is used as a carrier of diagnostic information, which is used to form a set of informative attributes that allow identifying the beginning of a change in the technical condition of railroad tracks, bridges and other track elements. For instance, with a combination of well-known technologies, it is possible to build a hybrid system for Noise signaling of the beginning of the latent period of changes in the technical condition, making it possible to prevent sudden destruction of large bridges and other elements of main traffic arteries.

In conclusion, it should be noted that, despite the influence of various factors that make it difficult to ensure fail-safe operation of the running gear of the rolling stock, currently used technologies and systems provide satisfactory control of their operation. However, due to the extreme importance of this issue, to control current state of the running gear of the rolling stock, it is advisable to duplicate traditional control algorithms with the proposed algorithms for the noise control of the onset and development dynamics of malfunctions. This can ensure early diagnostics of such malfunctions of the running gear of the rolling stock as bearing defects, lacking and insufficient lubrication, malfunctions of wheel-and-motor units, mounting defects, imbalance of rotating parts, gear defects, leakage in the feed and brake lines, break valve malfunctions, brake cylinder malfunctions, compressor malfunctions, etc. Thus, the use of algorithms and technology of noise control in combination with traditional algorithms and technologies can significantly enhance the effectiveness and reliability of ensuring fail-safe operation of the rolling stock.

REFERENCES

[1] T. Aliev, "Noise control of the Beginning and Development Dynamics of Accidents", Springer, 2019, 201 p.

[2] Машины и Оборудование для Диагностики Пути, Региональный Центр Инновационных Технологий. Путевые Машины, Применяемые ОАО "РЖД" Конструкция, Теория и Расчет, Глава 11. [In Russian: Machines and Equipment for Track Diagnostics.

Regional Center for Innovative Technologies. Track machines used by Russian Railways. Design, Theory and Calculation. Chapter 11]

[3] Е. Ашпиз, Методы и Средства Диагностики Земляного Полотна, 2013, Zheleznodorozhniy put. [In Russian: Ashpiz, Y.S. “Methods and tools of roadbed diagnostics”]

[4] И. Михалкин, О. Симаков, Ю. Седелкин, и В. Атапин, “Новые Подходы к Мониторингу Железнодорожного Пути”, NPTS INFOTRANS. [In Russian: Mikhalkin, I.K. & Simakov, O.B. & Sedelkin, Y.A. & Atapin, V.V. “New approaches to monitoring the railroad track”]

[5] “Какие бывают вагоны-лаборатории и для чего они применяются?”, https://dvizhenie24.ru/railway/kakie-byvayut-laboratorii/ [In Russian: What kinds of track test cars are there and what are they used for?]

[6] Г. Осадчий, и А. Лыков, Система Диагностики и Удаленного Мониторинга Состояния Железнодорожного Пути, 2011, Otkrytoe Obrazovaniye. Federal State Budgetary Educational Institution of Higher Education “G.V. Plekhanov Russian University of Economics”, pp. 221-224. [In Russian: Osadchiy, G.V. & Lykov, A.A. System for Diagnostics and Remote Monitoring of the State of Railroad Tracks]

[7] T. Aliev, T. Babayev, T. Alizada, and N. Rzayeva, “Control of the beginning of accidents in railroad operation safety systems in seismically active regions using the noise technology”, Transport Problems, 2019, 14.

[8] T. Aliev, Babayev, T. Alizada, and N. Rzayeva, “Noise Control of the Beginning and Development Dynamics of Malfunctions in the Running Gear of the Rolling Stock”, Transport Problems, 2020, 15.

[9] T. Aliev, Babayev, T. Alizada, N. Rzayeva, E. Alibayli, and H. Ahmedov, “Intelligent system of noise control of the technical condition of railroad tracks” Transport Problems: an International Scientific Journal, 2021, 16 (1).

[10] T. Aliev, H. Ahmedov, T. Babayev, T. Alizada, E. Manafov, N. Zohrabov, and A. Mammadova, “Using Fuzzy Set Theory and Noise Analysis Technologies to Enhance Validity and Reliability of Control of the Condition of the Running Gear of Rolling Stock”, 15-18 october 2019, “Transport Bridge Europe-Asia” V Georgian-Polish International Scientific-Technical Conference, Kutaisi.

[11] T. Aliev, T. Babayev, T. Alizada, and N. Rzayeva, “Possibilities of Application of Noise Technology in Railroad Operation Safety Systems in Seismically Active Regions”, 26-28 June 2019, The Silesian University of Technology, Transport Problems, XI International Scientific Conference, Katowice, Poland.

[12] A. Moghaddam, “A review on the current methods of railway induced vibration attenuations. International Journal of Science and Engineering Applications”, 2017, 6(04):123-128. doi:10.7753/IJSEA0604.1001

[13] Y. Bezin, “Railway turnout damage prediction and design implications”, In: International Conference on Train/Track Interaction & Wheel/Rail Interface, 20-22 June 2016, Hall of Railway Sciences (CARS), Beijing, China.

Tribological Aspects of the Wheel and Rail Interaction

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***Abstract*—For enhancing effectiveness of the wheel and rail operation, it is necessary to decrease probability of derailment, energy consumed on traction, maintenance expenses due to wear and other types of damage, pollution of the environment by friction modifiers, wear products, train accidents, vibrations and noise. All these factors, mainly depending on tribological properties of the wheel and rail contact zone are interconnected in the course of the train movement and vary under impact of various power and thermal loads. For retaining due tribological properties in various conditions of the wheel and rail interaction it is necessary to control these properties. In the work, on the base of new concept of the mechanism of variation of tribological properties of interacting bodies developed by us [George Tumanishvili, Tengiz Nadiradze, Giorgi Tumanishvili. A new Concept of the Mechanism of Variation of Tribological Properties of the Machine elements Interacting Surfaces. Chapter in the book Tribology in Materials and Manufacturing. IntechOpen, 2021. Pp. 131-150], the reasons of negative, neutral and positive friction and mild, severe and catastrophic wear are explained and the ways of providng due tribological properties of the interacting surfaces are identified. For enhancing effectiveness of the wheel and rail operation were developed ecological, heat resistant friction modifiers for the wheel and rail tread and steering surfaces and devices for their application that were tested in the laboratory and field conditions. The conditions of the wheel climbing the rail were also given definitive shape and the reasons of the rail corrugated wear, and ways for its decrease were revealed.**

Keywords—wheel, rail, tribology, third body

I. INTRODUCTION

Increasing speeds and axial loads of the modern railway transport is the result of achievements of the engineering art, where the role of tribology is essential, though it lags behind engineering in general [1]. Such indices of the rail trasport effectiveness as probability of the wheel climbing on the rail, energy consumed on traction, pollution of the environment by vibrations, noise, friction modifiers and wear prodcts, working resourse and maintenence expenses of the rail and friction brakes greatly depend on tribological properties of the corresponding contact zones. As it is specified in [2], for curved track a 33% reduction in the rolling resistance can produce a 13% reduction in total resistance, while for straight track a similar reduction produces a 3% reduction in total train resistance.

Vibrations and noise that are problems for the railway can be caused by many reasons: interaction of the wheel flange and rail lateral surface, non-roundness of the wheel, rail corrugations etc., but some aspects of this problem are not completely revealed [4].

The vague recommendations existent in the literature for prediction and control of tribological processes of the wheel, rail and friction brakes interacting surfaces are often the sources of various undesirable phenomena and wrong decisions about their prevention (railway accidents, increased energy consumption, environment pollution etc.). This also applies to selection of constructional materials and lubricants, optimal working modes according to various conditions, measures for perfection of operation of the wheels, rails and friction brakes.

In Figure 1 is shown a rail after the wheel climbing on it, where the scuffing trace is observed that is explained by the increased friction factor promoting a derailment [4, 5, 6].

Axial load of the train wheel often exceeds 25 t; contact pressure 3 GPa and nominal area of the contact zone reaches 1 sm2. Therefore, for the wheel movement is typical rolling with sliding. The wheel tread surface is of conical form and at its rolling on the rail in the contact zone with the rail are simultaneously interacting surfaces of the wheel diameters slightly differed from each other. But rolling is only possible on one diameter and on the other diameters rolling with sliding take place that causes additional shearing stresses in the contact zone. The wheel often moves on the rail in the mode of traction and braking at which its tread surface tends to slide on the rail and partial sliding in the contact zone can pass into full sliding. At interaction of the wheel flange and rail lateral surfaces the difference between the diameters interacting with the rail and value of the relative sliding increase sharply even without the traction and braking modes.

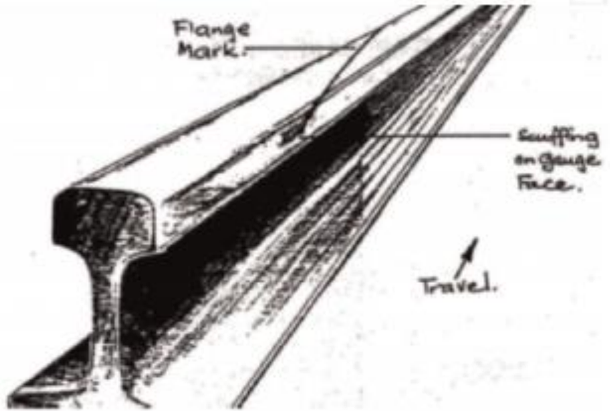


Fig. 1. The trace of the wheel climbing on the rail

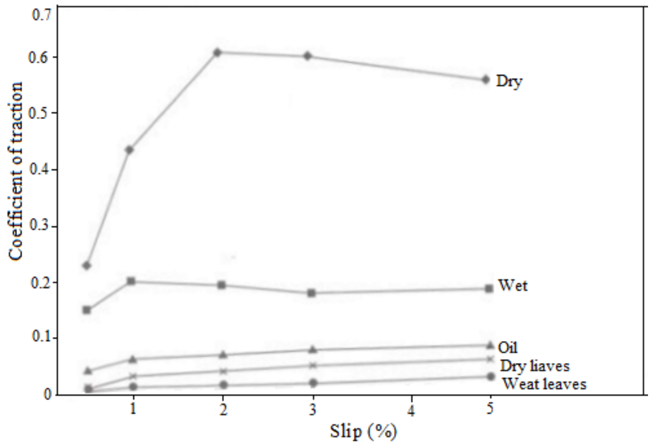


Fig. 2. Dependences of the friction coefficients on the relative sliding velocity

At modeling of the wheel-rail interaction, a friction coefficient is considered as a constant and known value. However, the results of many experimental researches show that in the wheel-rail contact zone it varies in the range 0.02-0.8 and it is influenced by many factors not all of them being known. This can become the reason of various unjustified decisions. For example: decrease of the distance between rails by 4 mm (at unchanged distance between rails) in the former Soviet Union in 1970-1980; lubrication of the wheel and rail tread surfaces and the wheel flange root (that plays the role of both, the tread and steering surfaces); at selection of the train movement mode consideration of insufficient quantity of parameters etc. All this is the reason of various negative phenomena.

Usually, the surfaces are covered with various types of natural and artificial coatings, which represent the components of the third body in the contact zone of the interacting surfaces. These surfaces are subjected to heavy power and thermal loads. This causes deformations of these coatings, their destruction, activation of the physical and chemical processes proceeding between them and the surfaces and generation of new coatings. Thus, during interaction of the surfaces, the processes of the third body destruction and restoration takes place in the contact zone continuously.

In fig. 2 is shown the dependences of the coefficient of friction on the slip ratio for different materials applied on the interacting surfaces [7].

At destruction of the third body on the separate micro asperities, they interact directly that leads to seizure. The results of laboratory tests showed that wear coefficient depended strongly on sliding velocity. The increase in the wear coefficient at increasing sliding velocity was explained by the change of wear type from mild to severe[8].

At rolling with sliding of heavy-loaded bodies, the most dangerous (dominating) kind of damage is scuffing. It arises at destruction of the lubricant film (the third body) and direct contact of bodies in extreme friction conditions. For prevention of this phenomenon, they try to minimize a sliding distance (structures of wheels and rails, dynamic characteristics of the track and a rolling stock, etc. must be improved) and to improve the tribological characteristics of the contact (to improve properties of contacting surfaces and applied lubrication). Necessary condition of scuffing is destruction of the third body and direct contact of surfaces. For formation of the third body are frequently used liquid lubricants. Consistent and solid lubricants are also used.

The wheels and rails are subjected to significant dynamic loads, transmitted from the car, that produce high stresses on the very small contact zone. Fig. 3 shows the static stress distribution at sliding at different sliding friction coefficient [9].

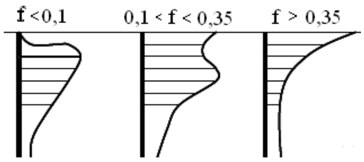


Fig. 3. Stress distribution at sliding at different sliding friction coefficient.

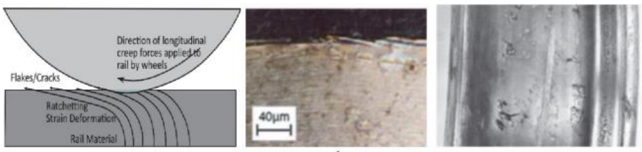
Maximum value of the shearing stress is in the subsurface area when coefficient of friction $f < 0.1$. The area of maximum pressure is shifted towards the surface when the shearing stress increases. There are two maxima: under and then on the surface when coefficient of friction $0.1 < f < 0.35$ and the maximum value of the shearing stress is in the subsurface area. When the coefficient of friction $f > 0.35$ the maximum value of the shearing stress is on the surface.

II. DEPENDENCE OF TRIBOLOGICAL CHARACTERISTICS ON THE DEGREE OF DESTRUCTION OF THE THIRD BODY

The third body is stable to the normal pressure. Increase of sliding velocity leads to increase of shearing stress, friction power and thermal loading of the contact that contributes destruction of the third body. For heavy loaded interacting surfaces is typical seizure, when continuity of the third body is destroyed in individual places and invasion of micro-asperities into each other in the contact zone and their close contact without the third body take place.

The wheel and rail contact zone are characterized by heavy operational conditions [10] (direct impact of the environmental conditions, high relative sliding and contact stresses) that enhances adhesive and fatigue processes. The unpredictable change of tribological properties - sharp increase of the friction coefficient and wear intensity, so called catastrophic wear are typical for them that is not properly studied yet [11] and whose signs are appearance of pits and scratches on the surfaces and transfer of the material from one surface on the other. As an example, can be cited interaction of the wheel and rail that occurs on: the tread surfaces during rolling, traction and braking; steering surfaces mainly in curves; flange root and rail corner at rolling, traction, braking and steering.

The shear deformation generated on the surface sharply decreases towards the depth and multiple repetition of such processes results in superficial plastic deformations, lamination and fatigue damage (Figure 4) [12, 13].



a b c

Fig. 4. The scheme of the surface plastic deformation (a); appearance of crack and lamination (b); appearance of fatigue pits (c).

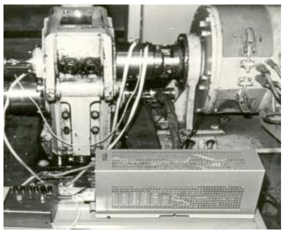
The friction forces between interacting surfaces (at lack of the third body in the places of actual contact) mainly depend on the total area of the seizure contacts. Displacement of the coupled places of surfaces relative to each other causes sharp increase of the shearing stresses and corresponding deformations (that considerably exceed the normal stresses and deformations), value and instability of the friction forces and rupture of the coupled places. This leads to increase of various kinds of damage that proceeds simultaneously with various intensity. Depending on seizure value, these deformations at multiple repeats can lead to lamination, fatigue destruction of surfaces, tearing off material from the contact zone and removal as wear product or transfer of the pulled-out material from one surface on the other and their adhesion (characterized for scuffing). It is possible in this case sharp change of roughness of these surfaces and development of the process of catastrophic wear – scuffing.

The experimental researches have shown that tribological properties (damage type and intensity, friction coefficient, vibrations, noise etc.) of interacting surfaces are especially sensitive to the relative sliding velocity and shearing stresses.

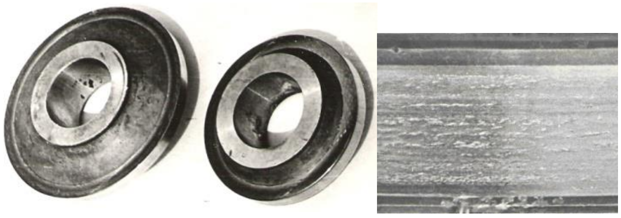
The experimental researches into the third body properties were carried out on the high-speed twin disk machine (Fig. 5) and on the twin disk machine MT-1 (Fig. 6) in the broad range of operational factors with the use of existing lubricants and ecologically friendly friction modifiers, developed by us.

In the field of railway simulation, it is a general assumption to consider the coefficient of friction as a known and constant value. This hypothesis is clearly not correct as many factors can change the friction coefficient.

The various dominant damage types, wear rates, and friction coefficients are typical for various relative sliding. In Figure 6 is shown dependence of the friction coefficient on the relative sliding and expected kind of surface damage. Three zones can be distinguished in Figure 4. In zone 1 and at the beginning of zone 2, deformations of the subsurface layers reach the maximum values, and the interacting surfaces undergo cyclic deformations. With the rise of relative sliding, the contact temperature gradually increases, decreasing viscosity of the third body [14] and the friction factor that reaches the minimum value. At full separation of the interacting surfaces by the third body, the tribological properties of the contact zone mainly depend on the properties of the third body, and they provide high wear resistance of the interacting surfaces and relatively stable friction coefficient.



a



b c

Fig. 5. High speed twin disk machine (a), experimental pieces (b) and a working surface of the roller with traces of scuffing (c) at total speed of rolling 7 m/s, sliding speeds of 3 m/s, linear load 100 N/m

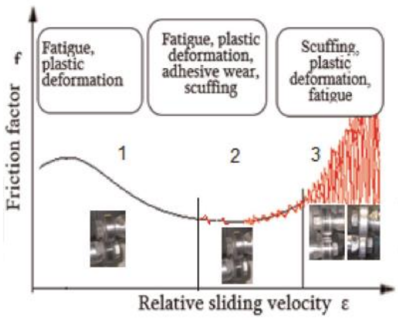


Fig. 6. Dependence of the friction coefficient (f) on the relative sliding (ε) and expected kinds of surface damage.

In zone 2 the separate small impulses of the friction moment and adhesive wear of low intensity correspond to destruction of the third body in the separate unique and multiple places. The first point marks of scuffing appear on the interacting surfaces and balance between destruction and restoration of the third body is observed, that stipulates the “mild” and “sever” wear [15]. In zone 3 destruction of the third body takes place in the narrow strips that pass then into whole area of interacting surfaces, the surface roughness changes correspondingly to working conditions (rolling speed, sliding rate, contact pressure etc.) resulting in rise of the friction coefficient, its instability, wear rate (reaching “catastrophic” wear), and scuffing.

Therefore, we have three stages of variation of the tribological characteristics of interacting surfaces (friction coefficient, roughness and wear): at continuous third body, at reversible discontinuous third body and at irreversible discontinuous third body. The first stage is characterized by minimal wear rate and change of roughness and stable friction factor. The second stage is characterized also by the minimal but slightly unstable friction coefficient, roughness, and wear rate. In terms of tribological characteristics, the stage 1, as well as stage 2 can be considered as the acceptable working conditions of the tribological system. In contrast to this, stage 3 is characterized by the sharp rise of the constant and variable components of the friction coefficient, wear rate (“catastrophic wear”), vibrations, and noise and operation in this zone is not admissible.

The signs of beginning of the third body destruction are instability of the friction (coefficient) moment, vibrations, and noise, and at visual observation in the laboratory conditions, the signs of scuffing are noticeable. Its prediction is possible with the use of the tables and graphs considering the given friction modifier, working conditions and environment properties, as well as the criterion of destruction of the third body [16].

III. Some features of wheels and rails interaction in the curves

In the straight, a wheel-set performs a zigzag movement close to the sinusoid, which is accompanied by creeping.

In curves, the inner wheel passes the shorter distance, which causes deviation of the wheel set axis from radial disposition. It leads to increase of the angle of attack, lateral force and rolling resistance of outer wheel of the front wheel-set of the bogie and promotes problems of wheel-flange climbing on the rail and derailment, squealing noise, wear of the wheel flange and gauge face of the high-rail and corrugations basically of the low-rail. In such conditions, for prevention of derailment and returning the wheel-set into initial position it is necessary that one of the wheels of the wheel-set slide on the rail in the longitudinal direction. There are many attempts to obtain radial position of the wheel-set [17, 18].

The movement of the wheel-set in the curve commonly leads to periodical advancing of the inner wheel relative to the outer wheel and the further return of the wheel-set symmetry axis near initial position by sliding of the wheel on a rail. That is the cause of periodic torsional deformations of the wheel-set axle and wear of the wheel and rail. The intermittent slipping of one of the wheels of the wheel-set can produce torsional vibrations of the wheel-set and longitudinal vibrations of the vehicle (that have been identified as flange noise [19]) and the respective wear of wheels and rails, like corrugation. In Fig. 7 is shown movement of a wheel-set in the curved track and a corrugated inner rail.

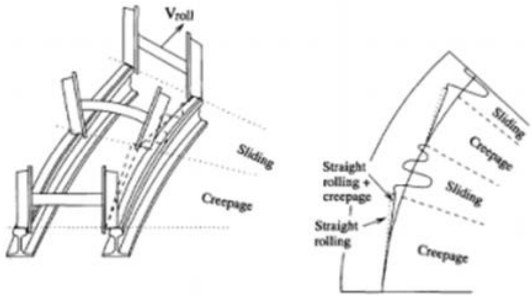


Fig.7. Movement of a wheel-set in the curved track and a corrugated inner rail [20]

The similar picture would be at movement of the wheel-set in the straight track with the wheels of different diameters or one wheel having ellipticity [21].

The researches have shown that a dominating type of deterioration of working surfaces for the given conditions is the scuffing. The high sensitivity and limited stability of used lubricants to the thermal loads have been also shown. The experimental researches have shown high sensitivity of the third body destruction to the sliding rate. For heavy loaded interacting surfaces is typical seizure. Certain part of micro-asperities of the heavy loaded interacting surfaces are in direct contact with each other causing their seizure and the remaining part interact with each other through the third body.

The smoothness of interacting surfaces is especially influenced by their velocity. At low velocity time of thermal impact on the surface part, depth of the heated layer and damage and amplitudes of variation of the friction force and noise are great in the actual contact zone. With increase the velocity these parameters decrease and at high velocities amplitudes of variation of the friction force and noise, as well as scales of individual damages of the surfaces and roughness decrease (when total rolling velocity exceeds 50-60 m/s the noise passes into high frequency whistle and at further increase of the velocity it exceeds the limits of human ear perception) [21], though high wear rate is retained. Thus, roughness of the surfaces of heavy loaded friction contact differs from their initial roughness and depends on their working mode.

Our experimental researches have shown that at the same friction modifier variation of the friction coefficient depends on degree of destruction of the third body: negative friction takes place at continuous third body; neutral friction – at partly destroyed and restorable third body, and positive friction – at progressively destroyed discontinuous and non-restorable third body.

It should be noted that various types of damage take place simultaneously and with various intensity in the heavy loaded contact and visually they are seen as dominant types of damage. The experimental researches have shown that the type of degradation of interacting surfaces mainly depends on the combination of the relative sliding velocity and shearing stress. For example, the main type of damage at low relative sliding is fatigue wear [13] (generation of cracks, plastic deformations and exfoliation), though adhesive wear takes place in parallel. Such phenomenon takes place on the rolling surface of the train wheel, near the pitch point of the gear drive, in rolling bearings etc. The portion of adhesive wear and scuffing increases at increase of the relative sliding and they frequently become dominant type of damage.

The researches were carried out in the field conditions on the electro-train ER2-631 with the use of the existent and developed by us ecological friction modifiers (which were fed respectively on the steering and tread surfaces) meant for steering and tread surfaces and their feeding devices. The noise was measured near the contact zone during the studies with the use of the noise meter (model SL 5868P, Fig. 8).

From the noise sensor installed near the wheel flange, the signal was transmitted with the help of noise meter to the PC where it was registered and processed.

a b c

Fig.8. a) Electro-train ER2- 631 with modified steering and tread surfaces and noise measuring devices installed near the wheel flange; b) Device for modification of the wheel steering surface; c) The noise sensor installed near the wheel flange.

In Fig. 9 are shown the results of the noise measurements of the modified and non-modified wheel rolling with velocity 60 km/h, from where is seen decrease of the noise level for the modified wheel.

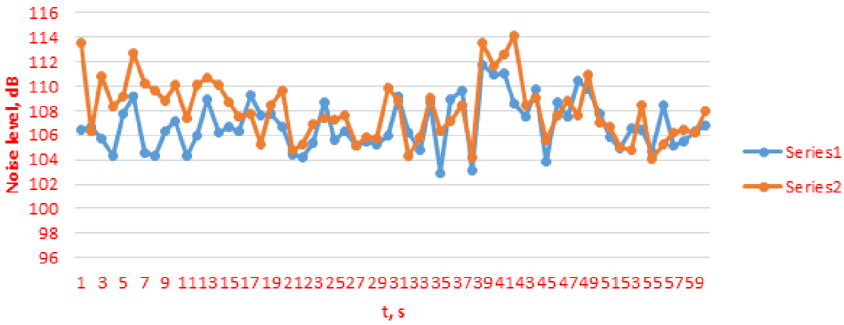


Figure 9. The results of the noise measurements of the modified and non-modified wheel: series 1 –modified wheel, series 2 – non-modified wheel.

At interaction of the wheel and rail, the noise level is stipulated by many factors, including the processes proceeding in the contact zone. As it is seen from Fig. 1 for modified wheel the noise level at its rolling on the rail, is decreased. Weakening of influence of the friction modifier at some places is explained by interference of external disturbing factors.

Conclusions

Velocity and safety of the railway traffic, energy consumed on traction, ecological compatibility and maintenance expenses greatly depend on tribological properties of the wheel and rail contact zone. The experimental researches carried out in laboratory conditions have shown dependence of the contact zone tribological properties on degree of destruction of the third body. For wheels and rails, destruction of the third body, direct interaction of juvenile parts of the surfaces lead to their seizure and scuffing, that stipulates the vibrations, noise and catastrophic wear.

Number of parameters influencing interaction of the wheel and rail rises in the field conditions that generates additional sources of noise having negative influence on precision of measurement of the contact zone noise.

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References

[1] K.C Ludema. FRICTION, WEAR, LUBRICATION. A TEXTBOOK IN TRIBOLOGY. 1996 CRC Press LLC. ISBN 0-8493-2685-0.Printed in the United States of America, 263 p.

[2] Railroad and Locomotive Technology Roadmap, Centre for Transportation Research Argonne National Laboratory, by Frank Stodolsky, Roadmap Coordinator, December 2002.

[3] Controlling of wheel squeal on rapid transit systems. IRJ, October, 2004, pp.30-31.

[4] Engineering Manual Track and Rolling Stock. TMC 213 Derailment 16 Transportation Systems Analysis and Assessment Investigation - Track and Rolling Stock. Version 1.0; August 2011.

[5] Engineering Manual Track andRolling Stock. TMC 213 Derailmentransportation Systems Analysis and AssessmentInvestigation - Track and Rolling Stock.Version 1.0; August 2011

[6] George Tumanishvili, Tengiz Nadiradze, Giorgi Tumanishvili. A new Concept of the Mechanism of Variation of Tribological Properties of the Machine elements Interacting Surfaces. pp. 131-150, In the book “Tribology in Materials and Manufacturing – Wear, Friction and Lubrication”. IntechOpen, Edited by Amar Patnaik, Tej Singh and Vikas Kurshal. London, 2021.

[7] Ulf Olofsson at all. Tribology of the wheel-rail contact – aspects of wear, particle emission and adhesion. Vehicle System Dynamics; Special Issue: State of Art Papers of the 23rd IAVSD in 2013. http://dx.doi.org/10.1080/00423114.2013.800215.

[8] U. Olofsson∗, T. Telliskivi. Wear, plastic deformation and friction of two railsteels—a full-scale test and a laboratory study. Wear 254 (2003) 80–93.

[9] Vidaud M., Zwanenburg W-J., Current situation on rolling contact fatigue – rail wear phenomenon. 9th Swiss transport research conference. Monte Verita / Ascona, September 9 – 11, 2009, pp. 1-27. Widaud http://www.strc.ch/conferences/2009/Vidaud.pdf.

[10] ASM Handbook, Friction, Lubrication and Wear Technology, 10th ed., Vol. 18, 1992. M. ISHIDA, M.AKAMA, K. KASHIWAYA and A. KAPOOR. The current status of theory and practice on rail integrity in Japanese railways-rolling contact fatigue and corrugations. 2003 Blackwell Publishing Ltd. Fatigue Fract Engng Mater Struct 26, 909–919.

[11] Kenneth C. Ludema. Review of Scuffing and Running in of Lubricated Surfaces, with Asperities and Oxides in Perspective. Wear, 100 (1984) 315 – 69 331.

[12] F. Braghin a, R. Lewis b, R.S. Dwyer-Joyce b, S. Bruni. A mathematical model to predict railway wheel profile evolution due to wear. Wear 261 (2006) 1253–1264.

[13] [31] Lewis R., Dwyer-Joyce R.S., Bruni S., Ekberg A., Cavalletti M., Bel Knani K.. A New CAE Procedure for Railway Wheel Tribological Design. 14th International Wheelset Congress, 17-21 October, Orlando, USA.

[14] Eadie DT, Kalousek J, Chiddik KC.The role of high positive friction (HPF)modifier in the control of short pitchcorrugations and related phenomena.Wear. 2002;253:185-192.

[15] Lewis R, Dwyer-Joyce RS. Wearmechanisms and transitions in railwaywheel steels. Proceedings of theinstitution of mechanical engineers, partJ. Journal of Engineering Tribology.2004;218(6):467-478.

[16] Tumanishvili G, Natriashvili T, Nadiradze T. Perfection of technical characteristics of the railway transport system Europe-Caucasus-Asia (TRACECA) in the book. In: Sladkowski A, editor. Transport Systems and Delivery of Cargo on East-West Routes, Springer. 2018. pp. 303-368.

[17] Curt A. Swenson. Locomotive Radial Steering Bogie Experience in Heavy Haul Service. IHHA'99. 1999, pp. 79-86.

[18] C. Yang, F. Li, Y. Huang, K. Wang, B. He. Comparative study on wheel-rail dynamic interactions of side-frame cross-bracing bogie and sub-frame radial bogie. J. Mod. Transport. 21(1) c1-8. DOI 10.1007/s40534-013-0001-3.

[19] D.T. Eadie, M. Santoro & W. Powell: Local control of noise and vibration with KELTRACK™ friction modifier and Protector® trackside application: an integrated solution, Journal of Sound and Vibration, Vol. 267, Issue 3, October 23, 2003, pp. 761-772.

[20] Christophe Collette, Mihaita Horodinca and Andre Premont. Rotational vibration absorber for the mitigation of rail rutting corrugation. Vehicle System Dynamics Vol. 00, No. 0, Month 2008, 1–19.

[21] George TUMANISHVILI, Tamaz NATRIASHVILI, Tengiz NADIRADZE, Giorgi TUMANISHVILI. Estimation of Parameters of the Rail Corrugation. International Journal Of Advancement In Engineering Technology, Management and Applied Science (IJAETMAS). ISSN: 2349-3224, www.ijaetmas.com. Volume 04 - Issue 09, September-2017. PP. 94-102.

Section #1

Possibilities of Enhancing the Safety of Rail Transport in Seismically Active Regions with the Application of Intelligent Seismic-Acoustic Technologies and Systems

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***Abstract*—The specific features of solving the problem of ensuring safety of railroads in seismically active regions necessitates taking into account seismic information across large territories. This, first of all, requires determining the area of the focus of the expected earthquake. It is also necessary here to take into account the information accumulated earlier by ground seismic services. The authors consider technologies for obtaining and analyzing seismic-acoustic signals from deep strata of the earth and versions of a network of seismic-acoustic stations for noise monitoring of the beginning of an earthquake preparation based on the analysis of seismic-acoustic signals. It has been established that the results of the analysis of seismograms obtained from deep strata of the earth by means of hydrophones allows detetcing the beginning of the earthquake preparation with sufficient reliability 10-25 hours in advance. Experiments have shown that the reliability and adequacy of these results can be increased by integrating the operation of seismic-acoustic stations of neighboring seismically active regions. The location of the earthquake focus area using the proposed decision-making system is determined as follows. Based on the results of the monitoring by the network of stations, the current combination of informative attributes is formed. They are saved and used in the learning process to form the corresponding reference sets, and in the process of further analysis of the current data, it is compared with all elements of the specified sets. Thus, during the training process of the system, new combinations of informative attributes of seismic-acoustic signals are constantly saved. When the system operates in the monitoring mode, if the current informative attributes match the elements in the reference set, the location of the expected earthquake area is identified by its number. Thus, the network of stations operates in combination with the monitoring center and the decision-making system as a whole. The stations are built on wells of different depths and make it possible to use an intelligent seismic-acoustic system in seismically active regions to warn about the area of the focus of an expected earthquake. In this case, saving, i.e., archiving of the relevant information from all stations is carried out using cloud technology. An integration of networks of stations of the countries in several seismically active regions can, in the long term, allow increasing the validity and reliability of determining the coordinates of an expected earthquake. Due to this, the railroad traffic safety service can get all necessary information on the seismic situation in the region, which will allow them to take appropriate measures in a timely manner.**

***Keywords*—rail transport, seismically active regions, safety, seismic technologies, intelligent systems, early warning systems**

I. Introduction

An analysis of the literature [1, 2] devoted to control technologies and control systems taking into account the specific characteristics of railroads has shown the importance of taking into account the specifics of seismic processes, which will allow improving the safety of this mode of transport in seismically active regions. To do this, it is reasonable to create warning systems that alert to the beginning of seismic processes, as well as appropriate technologies for the control of the latent period of the beginning of malfunctions in the railbed, bridges, tunnels and communications throughout the entire railroad track.

In this case, the traffic control service to receive additional information in advance, which allows taking appropriate actions to improve traffic safety in general

It is known that one of the main requirements for a railroad track is that all its elements, track superstructure, artificial structures, as well as the roadbed, must have adequate strength, stability and condition to ensure safe and smooth movement of trains at the speeds established for this particular section [1-6]. The control of the condition of the railroad track superstructure is mainly carried out under dynamic load [2-4].

In recent years, self-propelled flaw detectors [3-5] equipped with radio communications have been actively introduced to transmit information about detected violations to the duty officers at stations on both ends of a haul. In the end all the information is sent to the track maintenance department [2-5]. However, despite these efforts, wrecks of freight and passenger trains still occur frequently. This is due to the fact that it is currently impossible to carry out continuous control of the technical condition of the railway. As our studies have shown, by solving such problems as ensuring continuous control of the latent period of changes in the technical condition of railroad tracks, railroad bridges, tunnels, crossings, etc., it is possible to enhance the safety of rail transport. This is particularly important for rail transport in the countries located in seismically active regions. This is due to the fact that weak, 1–3-point earthquakes often occur in these regions, affecting the technical condition of the railroad tracks, bridges, tunnels and communications. As a rule, they do not result in great destruction. But each such earthquake is a potential factor contributing to the beginning of the latent period of changes in the facility's technical condition. In this regard, the new technologies and systems to ensure the safety of rail transport in seismically active regions is of undoubted practical interest [2-4].

II. Problem statement

With the development of high-speed train traffic, the requirements for objects and devices of railroad infrastructure are becoming more stringent, both for the quality of determining the occupancy of the track and for the condition of the rail line, the track superstructure (ballast), on which the qualitative characteristics of performance, safety and uninterrupted operation of trains depend. To ensure the safety of the track, it is necessary to obtain sufficient information to monitor the technical condition of the track ballast, the subgrade, under the ballast and sloping areas of the roadbed during the movement of the rolling stock. Control of the technical condition of the railroad track is practically performed by geometry cars of each haul on schedule, i.e., "in turns", as it is believed that no significant changes occur between the checks, when no control is carried out. At the same time, in real life, due to the impact of various factors, such as seismic processes, certain changes take place even a day after control. Therefore, the issue of creating new alternative solutions in the field of improving the control of the technical condition of tracks is relevant. This is of particular importance for railroads in seismically active regions. It is advisable to take into account that one of the most effective methods of diagnostics of the technical condition of railroad tracks is based on the use of vibrations of the soil of embankments caused by the rolling stock [2-5]. The prerequisite for the application of the vibration method is that a certain condition of embankments corresponds to a group of diagnostic signs of a dynamic process that occur during the movement of trains.

The result of the dynamic process reflecting the beginning of changes in the technical condition of the railroad track during the movement of the rolling stock affects the vibration signal $g(i\Delta t)$, which consists of the useful vibration signal $X(i\Delta t)$ and the sum noise $\varepsilon(i\Delta t)$ of the vibration signal, i.e.,

$$g(i\Delta t) = X(i\Delta t) + \varepsilon(i\Delta t).$$

It can be assumed that due to the impact of the technical condition of the track, due to the enormous weight of the car and rolling stock, low-frequency vibrations occur. At the same time, it can also be assumed that high-frequency components are mainly caused by other factors related to the technical condition of the rolling stock. Therefore, it can be assumed that in the sum noisy vibration signal $g(i\Delta t)$, the high-frequency components of the noise $\varepsilon(i\Delta t)$ are mostly indicative of the technical condition of the car of the rolling stock, and the useful signal consisting of low-frequency components of $X(i\Delta t)$ and the relationship coefficient between $X(i\Delta t)$ and $\varepsilon(i\Delta t)$ rather reflect the information about the technical condition of the track

The problem this paper aims to solve is obtaining information about the seismic state of the train's route and creating new intelligent technologies and means of monitoring the technical condition of railroad tracks, which allow, by analyzing vibration noisy signals, to identify its pre-failure states in real time without restrictions on the speed of train movement.

III. Main Components of Creating a Railroad Operation Safety System in Seismically Active Regions

It is known that a prerequisite for achieving highly competitive ability in the transportation market is the compliance of rail transport with the growing demands for speed, safety and comfort. The significant advantages of this mode of transport in comparison with other types offer great prospects in increasing the volume of traffic and at the same time require the improvement of this mode of transport [2-5]. There are great achievements in this area at present. However, seismic activity in the large territories of some regions can create problems. The most important and vulnerable element of rail transport is the railroad track, the insufficient monitoring of the condition of which does not ensure the proper safety of the rolling stock [1-5]. In view of the above, as the railroad passes through seismically active regions, additional requirements for traffic safety appear. This particularly applies to the problems of controlling the onset of the emergency condition of wheels and rails, their vulnerability, derailment conditions.

An analysis of the literature [3-7] devoted to control technologies and control systems taking into account the specific characteristics of railroads of seismically active regions has shown that the use of intelligent technologies and systems [1] can indeed improve the safety of this mode of transport. To do this, it is reasonable to create seismic hazard warming subsystems, as well as subsystems for control of the onset of the initiation and dynamics of development of changes in the technical condition of railroad tracks to incorporate in the existing railroad control systems. In view of the above, the issues of ensuring the safety of railroad tracks, taking into account the characteristics of seismically active regions along the route of the train, is an extremely relevant problem. Our studies have shown that in order to ensure an adequate level of safety of operation of rail transport in seismically active regions, it is necessary to create [1], [2]:

- ✓ a system of intelligent analysis of the level of seismic activity and prompt notification of seismic hazard along the main line;
- ✓ a system to control malfunctions of railroad tracks, bridges, tunnels and communication hubs of the entire route;
- ✓ a system to control the adequacy of the results of operation of the rolling stock diagnostic systems.

These subsystems will allow the driver and the traffic control service to receive additional information in advance and take appropriate measures to ensure traffic safety in general.

The first component includes the creation of a network of seismic-acoustic stations located along the route, as well as the development of software and equipment for transmitting, collecting, processing and analyzing seismic-acoustic information. Using a network of seismic-acoustic stations, the structural principle of which is given in [1], [2], this subsystem allows calculating in real time the probability of occurrence of dangerous earthquakes on the territory of the railroad route based on noise analysis of seismic-acoustic signals. The obtained information can be used to make appropriate decisions.

It is known that widely used seismic stations nowadays allow registering the moment of the beginning of an earthquake, determining the coordinates of its focus and magnitude. Various methods and technologies of spectral analysis are used to analyze seismic signals obtained from seismic sensors [1-4]. It is also known that many variants of short-term earthquake forecasting have been proposed over several decades [3-8].

In the considered version, solving the given problem first of all requires obtaining seismic-acoustic noise from the deep strata of earth, it being the primary immediate carrier of information on the incipient earthquake [3], [8], [9-15].

Thus, another important problem comes down to the development of a technology that takes into account the peculiarities of a heavily noisy seismic-acoustic signal in the period of the beginning of earthquake preparation (BEP). Here, the analysis of noise in the seismic-acoustic signal as a carrier of useful diagnostic information is of particular significance.

An experimental analysis of seismic processes occurring in deep strata of the earth during the preparation of earthquakes has shown that a systematic recording of seismological data in the territories of the entire region is necessary to monitor the beginning of an earthquake and to determine its focus area. In view of this, the appropriate technologies for obtaining and analyzing seismic-acoustic signals from deep strata of the earth were discussed.

Experimental versions of five seismic-acoustic stations were built on Gum Island in the Caspian Sea, in Shirvan District, in Neftchala District, in Siyazan District and in the resort town of Naftalan. A joint examination of the results of the analysis of seismograms of these stations allowed recording estimates of their characteristics related to the beginning of earthquake preparation with sufficient reliability 10-25 hours in advance. In this regard, a decision was made on the feasibility of creating an experimental version of the network of seismic-acoustic stations for noise monitoring of the beginning of earthquake preparation based on the analysis of seismic-acoustic signals received from deep strata of the earth by means of hydrophones.

These experiments have once again shown that to solve the problem of monitoring the earthquake preparation during its beginning, it is advisable to use noise technology for analyzing the noise of seismic-acoustic signals. It was also established that to determine the area of the focus of an expected earthquake, it is advisable to use modern intelligent technologies for analyzing the results of monitoring.

These experiments have also shown that the reliability and validity of the obtained results can be achieved by integration of seismic-acoustic stations of all seismic regions. Thus, the conducted experimental work made it obvious that it is necessary to create a system for Noise monitoring of the beginning of earthquake preparation and warning of its focus area.

Fig. 1 shows a seismic-acoustic system for noise monitoring of the beginning of earthquake preparation and warning of its focus area.

As can be seen from the block diagram in Fig. 1, the proposed system consists of the following components.

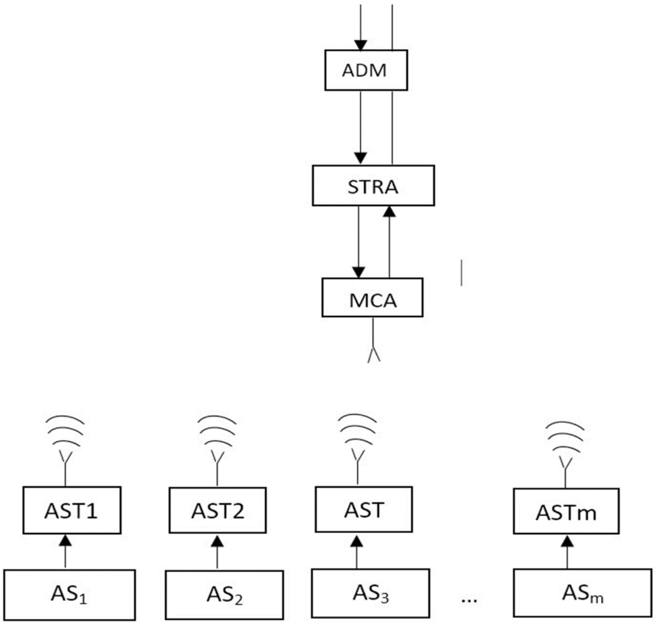

Fig. 1. Block diagram of the intelligent seismic-acoustic system

1. AS_1-AS_m – seismic-acoustic stations for Noise monitoring of the beginning of earthquake preparation;

2. AST1- ASTm – systems for transmitting the seismic-acoustic information from seismic-acoustic stations to respective monitoring centers;

3. MCA – centers of Noise monitoring of the beginning of earthquake preparation;

4. STRA – systems for transmitting and receiving information on the results of Noise monitoring of the beginning of earthquake preparation;

5. U'AS (sam) – unit of archiving samples of seismic-acoustic signals during earthquake preparation by means of cloud technology.

6. ADM – decision-making systems about the beginning of the earthquake preparation time, its focus area and possible intensity.

Let us now consider the main functions performed by these components (1-5).

AST1 and ASTm transmit recorded information about the start of earthquake preparation as a result of Noise monitoring of the noise of the seismic process. The information is transmitted in the form of an estimate of noise characteristics to the monitoring center in two versions. In the first version, the information is transmitted via the "Internet channel". In the second version, information is transmitted via satellite communication.

The monitoring centers form the sets of corresponding reference informative attributes only in the periods of the beginning and preparation of the earthquake on the basis of the results obtained from the respective Noise monitoring stations. Subsequently, knowledge bases are formed on their basis, by means of which the the process of registration of the beginning of earthquake preparation is studied. Ultimately, in the future they are used to determine possible focus areas and the beginning of the time of the expected earthquake.

The system for transmitting and receiving information STRA, when registering the start of earthquake preparation by the respective stations, transmits and receives information between monitoring centers. This information is also transmitted to ADM decision-making systems.

Studies devoted to this problem in recent years have shown that with the advent of a new, more efficient technology for the analysis of noisy signals, more accurate methods for their identification and more advanced methods for determining the location of the earthquake focus, their application it requires the availability of experimental data obtained at seismic-acoustic stations and recorded during earthquake preparation. Unfortunately, in the monitoring centers of the above-described seismic stations, only estimates of the noise characteristics obtained as a result of Noise analysis of seismic-acoustic noise are saved. This was due to the fact that storing all data consisting of samples of seismic-acoustic signals, even with one earthquake, requires an enormous amount of memory. Storing it for several years even for one station requires even a much larger amount of memory. At the same time, storing, i.e. archiving relevant data from all stations is very important. Our analysis of achievements and opportunities related to this problem has shown that using cloud technology it is possible to create a unit for archiving samples of seismic-acoustic signals received by Noise monitoring stations during earthquake preparation periods. For this reason, the system includes a unit of archiving seismic-acoustic signals by means of cloud technology.

Decision-making systems operate as follows.

At the beginning of earthquake preparation, estimates of Noise characteristics obtained as a result of analysis of seismic-acoustic noise by respective stations via the communication channel are synchronously transmitted to the server of the respective monitoring center MC. Based on the obtained monitoring results, the combinations of the sequence of indication times T_{1i}, T_{1j} and the combinations of their difference $\Delta\tau_{ij}$ are formed, which can be used as source data to determine the location of the expected earthquake.

The experiments have demonstrated that the combinations of the sequence of the times of indication by the stations practically repeat themselves for each earthquake focus area. Our analysis of the recorded charts has demonstrated that each sequence combination of time of indication of current BEP corresponds to one of the concrete earthquake areas. Employees of the laboratories studying the problem of interpretation of the experimental materials for over 2 years have learned to identify the location of the area of an expected earthquake intuitively and practically error-free, using these time combinations. It then became obvious that the problem of identifying the location of an expected earthquake should be solved by using expert systems (ES). This, in its turn, demonstrated the possibility of creating an ES which in the future will allow seismologists to use the network of the proposed stations as a toolkit to determine the location of the area of an expected earthquake.

The proposed experimental version of the expert system for identifying the location of the focus area will be based on a knowledge base (KB) formed from the totality of corresponding sets consisting of the combination of sequence of times of BEP indication by the stations T_{1i}, T_{1j}, the combination of the differences in times of their indication $\Delta\tau_{ij}$, and the combination of the estimates of the noise characteristics of the noise of the seismic-acoustic signal. The value of magnitude M_i determined during the corresponding earthquakes by ground seismic stations can also be entered in the KB.

Thus, the identification of the location of earthquake areas by the decision-making system after training is carried out as follows. The current combination is formed on the basis of the results of monitoring carried out by the network of stations. After that, the current element is compared with all elements of the indicated sets. If it matches any element of any set, the location of the area of an expected earthquake is identified based on the number of that set. At the same time, the current combination is entered into that set of the KB. New combinations of informative attributes of seismic-acoustic signals are continuously written into the KB during the operation of the system. Thus, the network of stations, the monitoring center and the decision-making system operate as a single whole.

To check the validity and reliability of the identification of the location of the earthquake focus area, the experimental version was tested during all several earthquakes. The obtained results have demonstrated the real possibility of practical application of this version of the system to identify the location of the earthquake focus area, which creates prerequisites for using it as a toolkit for determining the location of the area of an expected earthquake. Taking this prospect into account, a function of forming and providing the following information to railroad personnel can be included in the list of key functions of the decision-making block:

1. Date of the beginning of preparation and the number of the area of the expected earthquake.
2. Results of the current monitoring performed by the stations.
3. Estimated lead time at the beginning of BEP monitoring compared with the time of registration of the expected earthquake by ground seismic stations.
4. Magnitudes of previous earthquakes.
5. Minimum magnitude of the expected earthquake.

If the knowledge base contains no elements matching at least some of the elements in the sets, information on the impossibility of identifying the earthquake area is formed.

Our analysis of the results of experiments to determine the location of the BEP area has shown that, knowing the current values of the estimate of the noise of the seismic-acoustic signal and the distance from the area to the stations, the approximate minimum magnitude of the expected earthquake can be calculated.

IV. The Structural Principle of a Seismic Acoustic Noise Monitoring Station

The diagram of the seismic station for noise monitoring of BEP is given in Fig. 2.

The station includes the following equipment:

1. System unit;
2. Fastwell Micro PC type station controller;
3. GURALP LTD CMG 5T seismic accelerometer;
4. BC 321 hydrophone made in Zelenograd;
5. Amplifying and normalizing elements;
6. Siemens MC35i terminal forming an Internet channel via GPRS;
7. Antenna;
8. Voltage regulator;
9. UPS;
10. Monitor;
11. Connector

An experimental version of the station was installed at the head of a 3 500 m deep suspended oil well No 5 on 01.07.2010. The well is filled with water, and for this reason a BC 312 hydrophone is used as the sensor.

Experimental research has demonstrated that in the analysis of the noise $\varepsilon(i\Delta t)$ of the seismic-acoustic signal $g(i\Delta t)$, clear identification of the time of the beginning of earthquake preparation by means of traditional technologies is impossible. At the same time, using the robust technologies for noise analysis of the estimates of the noise characteristics of the cross-correlation function between the useful signal, the noise $R_{X\varepsilon}(\Delta t)$ and the noise variance D_ε, the system detects the beginning of earthquake preparation reliably and adequately.

$$D_\varepsilon \approx \frac{1}{N}\sum_{i=1}^{N}\left[g^2(i\Delta t) + g(i\Delta t)g\big((i+2)\Delta t\big) - 2g(i\Delta t)g\big((i+1)\Delta t\big)\right]$$

$$R^*_{X\varepsilon}(\mu=0) \approx \frac{1}{N}\sum_{i=1}^{N}\left[\mathrm{sgn}g(i\Delta t)g(i\Delta t) - 2\mathrm{sgn}g(i\Delta t)g\big((i+1)\Delta t\big) + \mathrm{sgn}g(i\Delta t)g\big((i+2)\Delta t\big)\right]$$

The first results of experiments show that it is possible to register the beginning of an earthquake within a radius of over 300-500 km 10-25 hours before the earthquake by means of these stations. These results have shown that the time of earthquake preparation changes depending on the location of the earthquake focus.

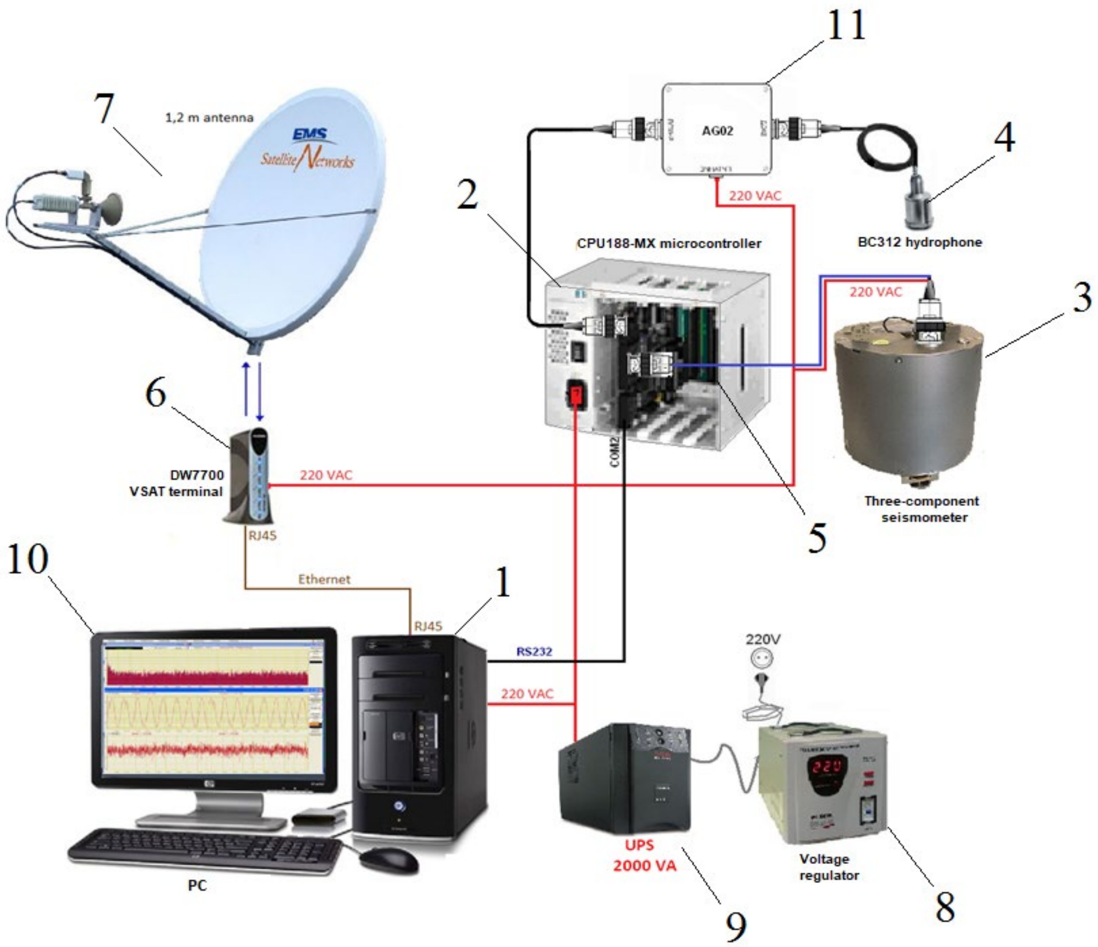

Fig. 2. Diagram of the station

Based on the obtained results, one can also assume that, when spreading from the earthquake focus, seismic-acoustic waves are reflected due to the resistance of certain upper strata of the earth, and for this reason they propagate horizontally. One can also assume that sufficient intensity of those waves allows them to travel to long distances (300-500 km).

The research conducted on these stations has demonstrated that to determine coordinates and magnitudes of expected earthquakes, we need to build networks consisting of at least 18-20 stations located across large areas along the entire route of the railroad. It was also obvious that they should be integrated with networks of similar seismic stations.

During the operation of all these seismic stations, as was indicated earlier, the results of noise analysis of seismic-acoustic signals at the moment of the beginning of earthquake preparation are transmitted from each station to the server at the Monitoring Center. As a result, sets of corresponding informative attributes form there.

Similarly, using the corresponding formulas for other Noise characteristics of the noisy signal $g(i\Delta t)$ given below [1, 9-12], it is possible to increase the reliability of the analysis results, which will allow controlling seismic processes across the entire region along the route of rail transport.

$$R_{1X\varepsilon}^{*}(0)=\frac{1}{N}\sum_{i=1}^{N}g'(i\Delta t)g'(i\Delta t)-2g'(i\Delta t)g'\big((i+1)\Delta t\big)+g'(i\Delta t)\,g'\big((i+2)\Delta t\big)$$

$$R_{2X\varepsilon}^{*}(0)=\frac{1}{N}\sum_{i=1}^{N}g'(i\Delta t)g(i\Delta t)-2g'(i\Delta t)g\big((i+1)\Delta t\big)+g'(i\Delta t)g\big((i+2)\Delta t\big)$$

$$R_{3X\varepsilon}^{*}(0)=\frac{1}{N}\sum_{i=1}^{N}g^{2}(i\Delta t)g(i\Delta t)-2g^{2}(i\Delta t)g\big((i+1)\Delta t\big)+g^{2}(i\Delta t)g\big((i+2)\Delta t\big)$$

$$R_{4X\varepsilon}^{*}(0)=\frac{1}{N}\sum_{i=1}^{N}g'^{2}(i\Delta t)g'(i\Delta t)-2g'^{2}(i\Delta t)g'\big((i+1)\Delta t\big)+g'^{2}(i\Delta t)\,g'\big((i+2)\Delta t\big)$$

$$R_{5X\varepsilon}^{*}(0)=\frac{1}{N}\sum_{i=1}^{N}sgn\,g(i\Delta t)g(i\Delta t)-2sgn\,g(i\Delta t)g\big((i+1)\Delta t\big)+sgn\,g(i\Delta t)g\big((i+2)\Delta t\big)$$

$$R_{6X\varepsilon}^{*}(0)=\frac{1}{N}\sum_{i=1}^{N}sgn\,g'(i\Delta t)g'(i\Delta t)-2sgn\,g'(i\Delta t)g'\big((i+1)\Delta t\big)+sgn\,g'(i\Delta t)\,g'\big((i+2)\Delta t\big)$$

where $g(i\Delta t)$ is the centered noisy seismic-acoustic signal, $g'(i\Delta t)$ is the non-centered noisy signal, $R_{X\varepsilon}(\mu\Delta t)$ is the cross-correlation function between the useful signal $X(i\Delta t)$

and the noise $\varepsilon(i\Delta t)$; $\mu\Delta t$ is the time shift between the samples of the useful signal $X((i+\mu)\Delta t)$ and the noise $\varepsilon(i\Delta t)$; $g((i+\mu)\Delta t)$ is the $(i+\mu)$-th sample of the centered noisy signal; $g'(i\Delta t)$ is the sample of the non-centered noisy signal; N us the number of samples.

As a result of experiments conducted at these stations, it has been established that during the initiation of ASP there is indeed a cross-correlation between the useful signal and the noise of the seismic-acoustic information.

The results of the experimental operation of these stations has shown that based on changes in the estimate of the cross-correlation function between the useful signal and the noise, each of them individually reliably indicates the start of earthquake preparation processes within a radius of 300-500 km with sufficient reliability. Using intelligent technologies, by means of a network of these stations located across large areas, it is possible to identify the location of the earthquake focus area.

Analyzing the seismic data obtained by means of acoustic sensors installed at well heads, we find that during ASP initiation, seismic-acoustic noise traveling in the earth's deep layers anticipates expected earthquakes by dozens of hours T_1. Experiments have established that seismic-acoustic stations can quite reliably monitor the beginning of the time T_1 by the above-described technology.

In the following paragraphs, we consider the results of the development of the intelligent technology for locating the ASP area, using the data from the stations installed in seismically active regions of the Caspian Sea (Fig. 3). The geographical coordinates and well depths of the stations are as follows:

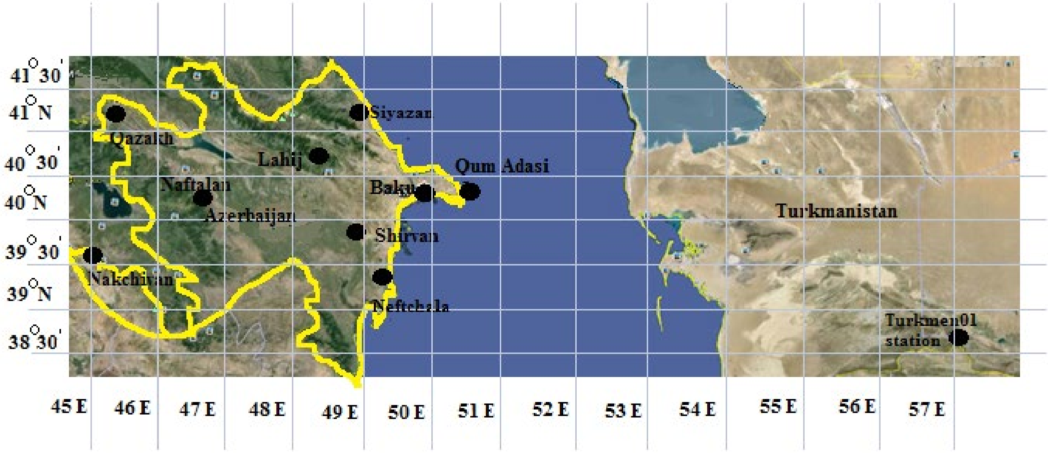

Fig. 3 Map of the locations of RNM ASP stations in the seismically active Caspian region

TABLE 1 GEOGRAPHIC COORDINATES AND DEPTHS OF STATIONS

1	Qum Island	40.310425°	50.008392°	3500 m	July	2010
2	Siazan	41.046217°	49.172058°	3145 m	November	2011
3	Naftalan	40.609521°	46.791458°	4000 m	May	2012
4	Shirvan	39.933170°	48.920745°	4900 m	November	2011
5	Neftchala	39.358333°	49.246667°	1430 m	June	2012
6	Nakhchivan	39.718000°	44.876000°	1800 m	March	2013
7	Qazakh	41.311889°	45.100278°	200 m	August	2013
8	Turkmenistan	38.530089°	56.654472°	300 m	August	2013
9	Baku (Cybernetics)	40.375700°	49.810833°	10 m	February	2014

Our experiments on these stations (Fig. 2) have shown that the seismic-acoustic noises received by hydrophones installed at the head of wells from the earth's deep layers are immediate precursors of the earthquake preparation process.

The results of the measurement and analysis of those noises are transmitted from every station to the server of the Center for Seismic-acoustic Monitoring (CM) via the Internet or satellite communication. The system also has the feature of forwarding the obtained results to the serves of CMs in neighboring countries in seismically active regions.

Starting from 01.07.2010, Qum Island (Caspian Sea), Shirvan, Siazan, Naftalan, Neftchala, Nakhchivan (on the borders with Iran and Turkey), Qazakh (on the border with Georgia), and Cybernetic (Baku) stations were put into operation one by one to conduct large-scale experiments in the monitoring of anomalous seismic processes. The last three stations were built on 300 m, 200 m, and 10 m deep water wells, respectively. Those wells are filled with water by gravity flow. Hydrophones are placed in the water at the depth of 10-20 m from the water level. Our analysis of the seismic-acoustic signals received by these stations shows that during ASP initiation seismic-acoustic noises emerge spreading tens of hours earlier than seismic waves that are registered by the ground stations during an earthquake.

A synchronous robust noise analysis of the seismic-acoustic signals received from all stations via radio communication channels is performed during the operation of the network. The estimates of the noise characteristics $R_{X\varepsilon}(1\Delta t)$, $R_{X\varepsilon\varepsilon}(2\Delta t)$ and D_ε are sent to the server of the CM from the stations every 5 seconds. Based on the changes in those estimates, the identification of the starting points T_{1i} and T_{1j} of ASP initiation for the i-th and j-th stations, respectively, is carried out.

The result of the operation of these stations has shown that each of them individually makes it possible to reliably perform the indication of the process of initiation of ASP preceding an earthquake. It also became clear that we can use the results obtained by means of the network of these stations to create an intelligent technology for identifying the location of the area of an anticipated earthquake. For this purpose, by means of the network, we first determine the combinations of indication moments T_{1i} and T_{1j}, which together with the location coordinates of the stations represent the initial data for the solution of the problem of locating the ASP area. For the results to be more adequate and trustworthy, it is appropriate to use, in addition to the combinations of indication moments, time differences T_{1i}-T_{1j} for each chosen pair of stations. In other words, to solve the problem at hand, we should determine not only the combination T_{1i}, T_{1j} but also the difference in time of ASP indication between the stations, i.e. the differences $\Delta\tau_{ij} = (T_{1i} - T_{1j})$.

According to the results of our experiments, it is not easy to determine the start of the time of indication T_{1i} with sufficient accuracy by means of the estimates of noise characteristics. For this reason, taking into account the importance and necessity of improving its accuracy, the proposed system duplicates the process of determining $\Delta\tau_{ij}$. To this end, it was found expedient to also determine the time difference $\Delta\tau_{ij} = (T_{1i} - T_{1j})$ using the extreme value of the estimate of the cross-correlation function $R_{g_i g_j}(\mu_{max})$ between the signals $g_i(i\Delta t)$ and $g_j(i\Delta t)$ obtained from different combinations of RNM ASP stations, using the following expressions:

$$R_{g_i g_j}(\mu_{max}) = \frac{1}{N}\sum_{i=1}^{N} g_i(i\Delta t) g_j(i+\mu)\Delta t,$$

$$R^*_{g_i g_j}(\mu_{max}) = \frac{1}{N}\sum_{i=1}^{N} g_i^2(i\Delta t) g_j^2(i+\mu)\Delta t,$$

$$R^{**}_{g_i g_j}(\mu_{max}) = \frac{1}{N}\sum_{i=1}^{N} g_i(i\Delta t) g_j^2(i\Delta t).$$

In this case, the procedure for determining the difference in monitoring time between different stations on the CM server comes down to the following:

1. finding the time of registration of the start of the period T_{1i} of ASP initiation by the first station (Qum Island);
2. finding the time of registration for the second (Shirvan), third (Siazan), fourth (Naftalan) station, etc.;
3. calculating the sets of estimates of the cross-correlation functions $R_{g_i g_j}(i\Delta t)$, $R^*_{g_i g_j}(i\Delta t)$ and $R^{**}_{g_i g_j}(i\Delta t)$ from the corresponding expressions, choosing from the results the time shifts $\mu\Delta t$, at which the curve of the cross-correlation function has the peak (extreme) value and using those time shifts to calculate $\Delta\tau_{ij} = (T_{1i} - T_{1j})$, i.e., the difference in ASP registration time by the i-the and the j-the station, respectively
4. using the found time differences $\Delta\tau_{1i} = (T_{1i} - T_{1j})$ as the source data to identify the location of ASP area.

Thus, in the proposed system, the estimates of the noise characteristics $R_{X\varepsilon}(1\Delta t)$, $R_{X\varepsilon\varepsilon}(2\Delta t)$ and D_ε obtained as a result of ASP monitoring by RNM ASP stations Qum Island, Shirvan, Siazan, Naftalan, Neftchala and Nakhichevan, Qazakh and Cybernetic (Baku) are synchronously transmitted via the communication channel to the server of the CM. On the basis of the obtained monitoring results, combinations of sequences of indication times T_{1i} T_{1j} and combinations of time differences $\Delta\tau_{ij}$ are formed and used as the source data for identifying the location of the area of an expected earthquake.

After the above results were obtained, three more stations were built to increase the reliability and accuracy of determining the coordinates of the focus area of the expected earthquake:

- ✓ in the village of Lagich, Ismayilli District (seismically active zone – the southern border of the Republic of Dagestan, Russian Federation) in 2015;
- ✓ in Lerik District (the northern border with the Islamic Republic of Iran) in 2016;
- ✓ in Sheki District (seismically active zone bordering with the Mingachevir reservoir) in 2017.

All these stations are built on 40-100 m deep wells. Our experiments after the inclusion of additional seismic-acoustic stations in the network confirmed the advisability of using the intelligent seismic-acoustic system in the warning mode to inform about the area of the focus of the expected earthquake [1, 16, 17].

V. Correlation Technology for Noise Control of the Beginning and Dynamics of Development of the Latent Period of Accidents in Rail Transport

It is shown in [1] that at the beginning of the latent period of the initiation of accidents as a result of the appearance of the noise $\varepsilon_2(i\Delta t)$, the estimate of the cross-correlation function between the sum noise $\varepsilon_2(i\Delta t)$ and the useful signal $X(i\Delta t)$ differs from zero. At the same time, in a stable emergency state, this estimate does not change. However, as the defect develops, this estimate increases. This makes it possible to control the dynamics of the development of accidents. However, by increasing or decreasing the value of the estimates of the noise variance, it is impossible to control the dynamics of the development of accidents. As numerous experiments show, the dynamics of the development of accidents leads both to an increase in the variance of the noise $\varepsilon_2(i\Delta t)$, which leads to an increase in the correlation between the useful signal and the noise. As a result, in the presence of the dynamics of the development of a malfunction, a correlation first arises between $X(i\Delta t)$ and $\varepsilon(i\Delta t)$. Then the further development of dynamics leads to the appearance of a correlation between $X(i\Delta t)$ and $\varepsilon(i+2)\Delta t$, then between

$X(i\Delta t)$ and $\varepsilon(i+3)\Delta t$, etc. Therefore, to control the dynamics of the development of accidents, it is necessary to calculate the estimates corresponding to the cross-correlation function between $X(i\Delta t)$ and $\varepsilon(i\Delta t)$. In [1], the possibility of calculating the estimate of $R_{X\varepsilon}(\Delta t)$ is considered and it is shown that if there is a correlation between $X(i\Delta t)$ and $\varepsilon(i\Delta t)$ at m different time shifts $\mu = m\Delta t$, $m = 1, 2, 3, \ldots$, it is advisable to use a generalized expression in the form

$$R_{X\varepsilon}(m\Delta t) \approx \frac{1}{2N}\sum_{i=1}^{N}[\ g(i\Delta t)g\left(\left(i+(\mathrm{m}+1)\right)\Delta t\right) \\ -2g(i\Delta t)g\left(\left(i+(\mathrm{m}+1)\right)\Delta t\right)+g(i\Delta t)g\left(\left(i+ (\mathrm{m}+2)\right)\Delta t\right)].$$

An experimental analysis of noisy signals received at various technical facilities [1-12] showed that, depending on the degree of dynamics of the development of accidents at these facilities, a correlation appears between the useful signal $X(i\Delta t)$ and the noise $\varepsilon(i\Delta t)$ first at $\mu = 1\Delta t$, then at $\mu = 2\Delta t$, $\mu = 3\Delta t$, then at $\mu = 4\Delta t, 5\Delta t, 6\Delta t$, etc. Moreover, the values of these estimates reflect the dynamics of the development of accidents over time. Due to this, the generalized expression for calculating the estimates $R_{X\varepsilon}(\mu = 1\Delta t), R_{X\varepsilon}(\mu = 2\Delta t), R_{X\varepsilon}(\mu = 3\Delta t), \ldots, R_{X\varepsilon}(\mu = m\Delta t)$ makes it possible to control and diagnose not only the beginning, but also the dynamics of the development of rolling stock malfunctions.

As shown above, at the beginning of the latent period of malfunctions, the error $\varepsilon_2(i\Delta t)$ appeares as a result of the initiation of various defects. At the same time, in essence, the dynamics of the development of accidents, despite the indirect influence on the value of the estimate of the noise variance, uniquely manifests itself only in the estimates of the cross-correlation functions between $X(i\Delta t)$ and $\varepsilon(i\Delta t)$ at different time shifts. Therefore, as indicated above, to control the dynamics of the development of accidents, it is advisable to use the estimate of $R_{X\varepsilon}(m)$. However, quite often, to control the onset and dynamics of the latent period of accidents, it is possible to use easily implementable algorithms that make it possible to significantly simplify the solution of this problem. From this point of view, it is advisable to use estimates of relay correlation functions, which can be calculated from the formula

$$R^*_{X\varepsilon}(\mu) = \frac{1}{N}\sum_{i=1}^{N}\operatorname{sgn} g(i\Delta t)\varepsilon^2(i\Delta t) = \\ \frac{1}{N}\sum_{i=1}^{N}\operatorname{sgn} X(i\Delta t)\varepsilon^2(i\Delta t).$$

However, to use this formula, it is necessary to determine the samples of the noise $\varepsilon(i\Delta t)$, which cannot be measured directly.

The following estimate can be used as informative attributes:

$$R^*_{X\varepsilon}(\mu) = \frac{1}{N}\sum_{i=1}^{N}\operatorname{sgn} g(i\Delta t)\left[g(i\Delta t)g(i\Delta t) - \\ 2g(i\Delta t)g\left((i+1)\Delta t\right) + \\ + g(i\Delta t)g\left((i+2)\Delta t\right)\right] = \frac{1}{N}\sum_{i=1}^{N}\operatorname{sgn} g(i\Delta t)\varepsilon^2(i\Delta t)$$

$$\varepsilon^2(i\Delta t) = g(i\Delta t)\left[g(i\Delta t)g(i\Delta t) - 2g(i\Delta t)g\left((i+1)\Delta t\right) \\ + g(i\Delta t)g\left((i+2)\Delta t\right)\right]$$

It is also advisable to use for these purposes simple options for the approximate calculation of estimates of the relay cross-correlation function $R^*_{X\varepsilon}(\mu)$ between the useful signal $X(i\Delta t)$ and the noise $\varepsilon(i\Delta t)$ at various time shifts $m\Delta t$:

$$R^*_{X\varepsilon}(m\Delta t) \approx \frac{1}{2N}\sum_{i=1}^{N}[\operatorname{sgn} g(i\Delta t)g\left((i+m)\Delta t\right) \\ -2\operatorname{sgn} g(i\Delta t)g\left(\left(i+(m+1)\right)\Delta t\right) + \\ + \operatorname{sgn} g(i\Delta t)g\left(\left(i+(m+2)\right)\Delta t\right)].$$

When this formula is used, in the case of the presence of dynamics of the malfunction development, the obtained estimate will change at different time shifts [1]. At the same time, by determining the estimate of the relay cross-correlation function $R^*_{X\varepsilon}(\mu\Delta t)$ between the useful signal $X(i\Delta t)$ and the noise $\varepsilon(i\Delta t)$ at different $\mu\Delta t$, it is possible to control the dynamics of the development of the malfunction.

For instance, at $\mu = 1\Delta t$, the formula for calculating the estimate $R^*_{X\varepsilon}(\mu = 1\Delta t)$ will have the form

$$R^*_{X\varepsilon}(\mu = 1\Delta t) \approx \frac{1}{N}\sum_{i=1}^{N}[\operatorname{sgn} g(i\Delta t)g(i+1)\Delta t \\ -2\operatorname{sgn} g(i\Delta t)g(i+2)\Delta t + \operatorname{sgn} g(i\Delta t)g(i+3)\Delta t].$$

At $\mu = 2\Delta t$, the formula for calculating the estimate $R^*_{X\varepsilon}(\mu = 2\Delta t)$ will have the form

$$R^*_{X\varepsilon}(\mu = 2\Delta) \approx \frac{1}{N}\sum_{i=1}^{N}[\operatorname{sgn} g(i\Delta t)g(i+2)\Delta t \\ -\operatorname{sgn} g(i\Delta t)g(i+3)\Delta t + \operatorname{sgn} g(i\Delta t)g(i+4)\Delta t].$$

It is obvious that the estimates $R^*_{X\varepsilon}(\mu = 3\Delta t), R^*_{X\varepsilon}(\mu = 4\Delta t), \ldots$, can be calculated in a similar manner.

It is clear that in the absence of a correlation between $X(i\Delta t)$ and $\varepsilon(i\Delta t)$, the estimate of the cross-correlation function $R_{X\varepsilon}(\mu = 0)$ between the useful signal and the noise will be close to zero. It is also obvious that at the initiation of various defects preceding accidents at the facility, as a result of the appearance of the noise $\varepsilon_2(i\Delta t)$ $(\varepsilon(i\Delta t) = \varepsilon_1(i\Delta t) + \varepsilon_2(i\Delta t))$, the value of the estimate of the relay cross-correlation correlation function due to the presence of a correlation between $X(i\Delta t)$ and $\varepsilon(i\Delta t)$ will increase sharply. A distinctive feature of this algorithm is that at the initiation of various malfunctions, when a correlation occurs between $X(i\Delta t)$ and $\varepsilon(i\Delta t)$, the differences in the estimates $R^*_{X\varepsilon}(1\Delta t)$, $R^*_{X\varepsilon}(2\Delta t)$, $R^*_{X\varepsilon}(3\Delta t)$ unambiguously reflect the dynamics of the development of accidents, which makes it possible to provide reliable information on the dynamics of the malfunction development.

Similarly, using the corresponding formulas for other Noise characteristics of the noisy signals $g(i\Delta t)$, [1, 9-12], it is possible to increase the reliability and adequacy of control of the beginning of the latent period and the dynamics of the development of malfunctions preceding accidents in rail transport.

$$R^*_{1X\varepsilon}(0) = \frac{1}{N}\sum_{i=1}^{N} g'(i\Delta t)g'(i\Delta t) - 2g'(i\Delta t)g'\left((i+1)\Delta t\right) \\ + g'(i\Delta t)\, g'\left((i+2)\Delta t\right)$$

$$R^*_{2X\varepsilon}(0) = \frac{1}{N}\sum_{i=1}^{N} g'(i\Delta t)g(i\Delta t) - 2g'(i\Delta t)g\left((i+1)\Delta t\right) \\ + g'(i\Delta t)g\left((i+2)\Delta t\right)$$

$$R^*_{3X\varepsilon}(0) = \frac{1}{N}\sum_{i=1}^{N} g^2(i\Delta t)g(i\Delta t) - 2g^2(i\Delta t)g\left((i+1)\Delta t\right) \\ + g^2(i\Delta t)g\left((i+2)\Delta t\right)$$

$$R_{4X\varepsilon}^*(0) = \frac{1}{N}\sum_{i=1}^{N} g'^2(i\Delta t)g'(i\Delta t) - 2g'^2(i\Delta t)g'\big((i+1)\Delta t\big) + g'^2(i\Delta t)\, g'\big((i+2)\Delta t\big)$$

$$R_{5X\varepsilon}^*(0) = \frac{1}{N}\sum_{i=1}^{N} sgn\; g(i\Delta t)g(i\Delta t) - 2sgn\; g(i\Delta t)g\big((i+1)\Delta t\big) + sgn\; g(i\Delta t)g\big((i+2)\Delta t\big)$$

$$R_{6X\varepsilon}^*(0) = \frac{1}{N}\sum_{i=1}^{N} sgn\; g'(i\Delta t)g'(i\Delta t) - 2sgn\; g'(i\Delta t)g'\big((i+1)\Delta t\big) + sgn\; g'(i\Delta t)\, g'\big((i+2)\Delta t\big)$$

where $g(i\Delta t)$ is the centered noisy signal, $g'(i\Delta t)$ is the non-centered noisy signal, $R_{X\varepsilon}(\mu\Delta t)$ is the cross-correlation function between the useful signal $X(i\Delta t)$ and the noise $\varepsilon(i\Delta t)$; $\mu\Delta t$ is the time shift between the samples of the useful signal $X((i+\mu)\Delta t)$ and the noise $\varepsilon(i\Delta t)$; $g((i+\mu)\Delta t)$ is the $(i+\mu)$-th sample of the centered noisy signal; $g'(i\Delta t)$ is the sample of the non-centered noisy signal; N us the number of samples.

VI. Conclusion

On the basis of the experimental studies on the development and use of networks of seismic-acoustic stations for the warning of the focus area of expected earthquakes, the following can be pointed out:

1. The intelligent system consisting of the network of seismic-acoustic stations and an expert system combined with a neural network can be used in a rail transport safety system as a toolkit for identifying the location of the area of an expected earthquake in advance. The obtained information will allow railroad workers, after a certain amount of experience, to take necessary measures to ensure safety due to having enough time before the expected earthquake. If there is any doubt, they can consult professional seismologists, ruling out possible mistakes in taking rolling stock safety measures.

2. The seismic-acoustic stations in the proposed network are built on wells with different depths. Based on the results of the experiments, we recommend forming a network of stations built in 50–100-m deep water wells in the future, with hydrophones placed in the water column at a depth of 10–20 m. To improve the validity and reliability of the identification of the location of the area of the expected earthquake, we found it appropriate to build a network consisting of a large number of stations (over 10–15) in wells of equal depth located at an equal distance from one another. An integration of networks of stations of the countries in several seismically active regions via satellite communication can, in the long term, allow increasing the validity and reliability of determining the coordinates of the location of the focus of an expected earthquake.

3. Our experiments have demonstrated that the reliability of the ASP monitoring results and the validity of the results of identification of the location of the area of the focus of an expected earthquake grow with the growth in earthquake strength. With the strength exceeding 5 points, the results of the identification of the earthquake location proved to be valid in almost all cases. The value of the estimate of the cross-correlation function $R_{X\varepsilon}(\mu)$ between the useful signal $X(i\Delta t)$ and the noise $\varepsilon(i\Delta t)$ decreases as the distance from the earthquake area grows. In contrast, the value of the estimate of noise variance D_ε, increases as the distance from the area grows. The propagation velocity of the seismic-acoustic noise in different types of medium, e.g., water, sand or clay, significantly varies. There is a correlation between the well depth and the radius of ASP monitoring.

4. The experiments at the Qum Island station in the Caspian Sea have demonstrated that the monitoring range of that station is much wider than that of the stations located far from the Caspian Sea. Other stations in Siazan and Neftchala located near the Caspian Sea also have a wide monitoring range compared with other stations. Practically all seismic processes reaching the Caspian Sea are clearly registered by those stations. Therefore, in building networks of new stations, one should consider the fact that the sea is a "perfect conductor" for seismic-acoustic noises emerging during the initiation of BEP in the region.

5. The results obtained from the experimental data give us reason to assume that the lead time of the registration of the initiation of BEP by a seismic-acoustic station over standard seismic equipment is due to two factors.

First, seismic-acoustic waves that arise at the onset of BEP do not reach the earth's surface due to the frequency characteristics of certain upper strata, which furthers their horizontal spread in deep strata as noise. Reaching the steel pipes of the well, seismic-acoustic waves transform into acoustic signals and go to the ground surface at the velocity of sound, where they are detected by a hydrophone. At the same time, low frequency seismic waves from seismic processes are perceived at the surface after a certain amount of time, when the earthquake is already in progress, and are registered by seismic receivers of standard ground equipment much later.

Second, the use of noise technologies by analyzing seismic-acoustic noise allows, when a correlation appears between the useful signal and the noise, registering BEP at its onset.

These two factors make it possible for seismic-acoustic stations to indicate the time of the onset of BEP much earlier than is done by standard ground stations.

References

[1] T. Aliev, "Noise Control of the Beginning and Development Dynamics of Accidents", Springer, 2019, pp. 201.

[2] T. Aliev, "İntelligent Seismic-Acoustic System for identifying the Area of the Focus of an Expected Earthquake", Earthquakes tectonics, Hazard and risk mitigation, edited by Taher Zouaghi., Published by in Tech, Janeza Trdine 9, 51000 Rijeka, Croatia, The Editor(s) and the Author(s), 2017, pp. 293-315.

[3] T. Aliev, and A. Abbasov, "Digital Technology and System of Interference Monitoring of the Technical State of Building Structures and Generation of Warnings of Anomalous Seismic Processes", Avtom. Vychisl. Tekh., 2005, no. 6, pp. 3–10.

[4] A. Abbasov, T. Aliev, Q. Guluyev, F. Pashayev, and U. Sattarova, "System of robust noise monitoring of anomalous seismic processes", Soil Dynamics and Earthquake Engineering Volume (s) 53, 07 jul-2013, p.11-25.

[5] T. Aliev, A. Abbasov, E. Aliev, and G. Guliev, "Digital technology and systems for generating and analyzing information from deep strata of the Earth for the purpose of interference monitoring of the technical state of major structures", Automatic Control and Computer Sciences, Vol. 41, 2007, pp. 59-67.

[6] T. Aliev, and E. Aliev, "Multichannel telemetric system for seismo-acoustic signal interference monitoring of earthquakes", Automatic Control and Computer Sciences, 2008, 42(4):223-228. doi:10.3103/S0146411608040093

[7] T. Aliev, N. Musayeva, and U. Sattarova, "Noise technologies for operating the system for monitoring of the beginning of violation of seismic stability of construction objects", In: Zadeh L., Abbasov A., Yager R. et al (eds) Recent Developments and New Directions in Soft Computing. Studies in Fuzziness and Soft Computing, 2014, vol 317, Springer, Cham, pp 211-232. doi:10.1007/978-3-319-06323-2_14

[8] T. Aliev, A. Alizade, G. Etirmishli et al, "Intelligent seismoacoustic system for monitoring the beginning of anomalous seismic process. Seismic Instruments", 47(1):15-23. doi:10.3103/S0747923911010026

[9] R. Collacott, "Mechanical fault diagnosis and condition monitoring", Dordrecht: Springer, 1977, Available at: www.doi.org/10.1007/978-94-009-5723-7

[10] J. Bendat, A. Piersol, "Random data: analysis and measurement procedures", 4th edn. Hoboken: Wiley, 2010, Available at: www.doi.org/10.1002/9781118032428.ch11

[11] G. Papagiannopoulos, and D. Beskos, "On a modal damping identification model for non-classically damped linear building structures subjected to earthquakes", Soil Dynamics and Earthquake Engineering, 2009, 29(3):583-589

[12] H. Zafarani, A. Noorzad, A. Ansari et al, "Stochastic modeling of Iranian earthquakes and estimation of ground motion for future earthquakes in Greater Tehran", Soil Dynamics and Earthquake Engineering, 200929(4):722-741. doi:10.1016/j.soildyn.2008.08.002

[13] V. Sokolov, C. Loh, and K. Wen, "Evaluation of hard rock spectral models for the Taiwan region on the basis of the 1999 Chi–Chi earthquake data", Soil Dynamics and Earthquake Engineering, 2003, 23(8):715-735. doi:10.1016/S0267-7261(03)00075-7

[14] J. Stankiewicz, D. Bindi, A. Oth et al, "Designing efficient earthquake early warning systems: case study of Almaty, Kazakhstan", Journal of Seismology, 2013, 17(4):1125-1137. doi:10.1007/s10950-013-9381-4

[15] P. Rydelek, and J. Pujol, "Real-time seismic warning with a two-station subarray", Bulletin of the Seismological Society of America, 2004, 94(4):1546-1550. doi:10.1785/012003197

[16] A. Moghaddam, "A review on the current methods of railway induced vibration attenuations", International Journal of Science and Engineering Applications, 2017, 6(04):123-128. doi:10.7753/IJSEA0604.1001

[17] Y. Bezin, "Railway turnout damage prediction and design implications", In: International Conference on Train/Track Interaction & Wheel/Rail Interface, 2022 June 2016, Hall of Railway Sciences (CARS), Beijing, China.

Causes and Probability of Premature Fatigue Cracks in Railway Axles

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***Abstract*—Fatigue is one of the most common forms of damage to structures, moving parts of machines, devices and vehicles. It is estimated that over 80% of all cracks are due to fatigue. The axle is considered to be the most heavily loaded element in a railway vehicle. Despite the fact that there is progress in the field of computational methods and technological processes of axle production and their acceptance, diagnostic methods during inspection, these elements are exposed to fatigue fracture, which is often the cause of serious railway accident. The article presents cases of fatigue cracks in railway axles and discusses their causes.**

***Keywords*—railway vehicle, wheelset, axle, fatigue, cracking**

I. Introduction

Fatigue of materials is the failure due to a crack that slowly develops over time, or cracks under the influence of cyclically changing loads. Fatigue is a dangerous form of failure because it usually occurs below the yield point and occurs suddenly and without warning. Fatigue is one of the most common forms of destruction of structures, moving parts of machines, devices and vehicles. It is estimated that over 80% of all cracks are due to fatigue.

Three types of fatigue failures can be distinguished:

a / for materials (structures) that do not contain preliminary cracks:

- high cycle fatigue failure; occurs at stresses much lower than the yield point and a sufficiently large number of cycles (10^5-10^8),

- low cycle fatigue failure; occurs in structures and components exposed to temporary overload above the yield point and with the number of cycles lower than 10^4-10^5,

b / for large structures containing cracks in the initial state (especially welded structures); the process controlling the failure of such structures is the rate of crack propagation under cyclic loads, not the crack initiation process.

Fatigue failure of metals and alloys begins with the nucleation (initiation) of the crack, followed by the phase of the crack development (propagation, growth). The number of cycles to failure N_f is the sum of the cycles to nucleation N_n of the crack and the cycles during which the crack develops N_p.

$$N_f = N_n + N_p \qquad (1)$$

The number of cycles necessary to initiate a fatigue crack, in the case of high-cycle fatigue of smooth laboratory samples, is up to 80% of the number of cycles necessary to failure the material. For low-cycle fatigue at high stress levels, the range of crack propagation ($N_p > N_n$) is dominant. In the case of high stress amplitude, approx. 90% of the element/structure life phase is the fracture development stage. If an element/structure has a pre-fracture (notch), this percentage is even greater.

The following factors affect fatigue strength:

- presence of a notch (cavities, scratches, subsurface non-metallic inclusions or precipitations of hard phases),
- average stresses in the cycle σ_m,
- environment (corrosion pits),
- microstructure,
- residual stresses (due to the influence of the average cycle stress σ_m).

The fatigue life is particularly sensitive to the surface condition and hence most of the fatigue cracks are initiated on the surface of samples/components /structures.

II. Fatigue Failure of the Axles of Railway Wheelsets

Wheelset axles are one of the critical elements of a rail vehicle, decisive for the operational safety of wagons and locomotives. The axle is considered to be the most heavily loaded element in a railway vehicle.

Despite the fact that there is progress in the field of computational methods and technological processes of axle production and their acceptance, diagnostic methods during inspection, these elements are exposed to fatigue fracture, which is often the cause of serious railway accidents, causing significant material losses and fatal accidents.

The axle is designed for high cycle fatigue, which means the axle can operate with unlimited fatigue strength.

Railway axles are designed for high cycle fatigue, with no mileage and no limitations on service life. Therefore, they are used until the inspection proves that the product is unfit for further safe performance of its function.

Due to the distribution of cyclic stresses in rotational bending in the axis, the greatest bending moments occur in the section axle journal – dust collar – wheel seat - a radius of transition from the seat to the body of an axle. This is also where fatigue cracks initiated on the axle surface occur most frequently (Fig. 1). These cracks appear in particular in freight wagons after long use.

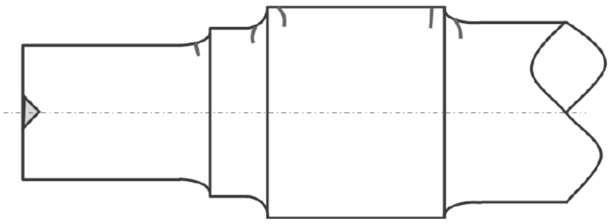

Fig. 1. The places of the railway axle most exposed to the occurrence of fatigue cracks [1]

The sources of the emergence of additional hazards in the operation of the axles of rail freight wagons and the formation of fatigue cracks can be divided into the following groups:

- overloading the wagon,
- dropping the load while loading/unloading,
- corrosion and pitting,
- poor condition of infrastructure (dynamic loads).

A new axle is equally exposed to fatigue cracks as an operating axle, if it has subsurface defects caused in the process of its manufacture, or surface defects such as scratches, microcracks and other discontinuities in materials that appear during operation and are initiation places of fatigue cracks.

Taking into account the service life of an axle showing no defects, the life to failure is an essential part of the overall fatigue life of a wheelset axle. This phase of a wheelset axle service life can be shortened by surface or subsurface defects that occurred during the manufacturing stage and were not detected, or due to damage during operation - by corrosion or mechanical impact - and contribute to the formation of fatigue cracks.

III. MAXIMUM PERMISSIBLE STRESSES OF AXLES

Railway axles of wheelsets (non-powered and powered) can be classified as highly stressed elements due to the safety factors adopted in their design. According to EN 13103: 2009, concerning the design of the axles of rolling wheelsets, for calculations with static loads for EA1N steel, the safety factor S = 1.2 is assumed (Table 6 on page 28 of the standard).

According to the standard, all calculations are made on the basis of analytical calculations without the use of FEM. The value of the safety factor at the level of 1.2 means that the axis has only a 20% margin to reach the yield point, with the assumed allowable stresses. In the event of unforeseen loads or additional stresses, the yield point can easily be reached locally, which can lead to its permanent deformation (excessive axial runout) or initiation of low-cycle fatigue.

Achieving local stresses in the railway axis close to the yield point of the material may be caused by:

- exceeding the permissible load capacity of a freight wagon,
- one-sided axle overload as a result of asymmetrically distributed loads in the wagon or overcoming bends with excessive speed,
- stresses resulting from operational loads summing up with the stresses resulting from the wheel press-in on the hub, the stresses remaining in the axis after the manufacturing process,
- additional dynamic loads as a result of the interaction of the wheels with the uneven track surface,
- the scatter of mechanical properties of the axle material (especially a yield point) on the cross-section and longitudinal section, which is typical for large-size forgings. In practice, the yield point spread may be from 50 to 70 MPa.

Fig. 2 shows the distribution of the maximum stresses in the tested axle, after applying a load in accordance with the EN 13103 standard, and their reference to the permissible stresses [3]. The diagram shows that the design stresses locally within the wheel seat have reached the level of allowable stresses (the area marked in green).

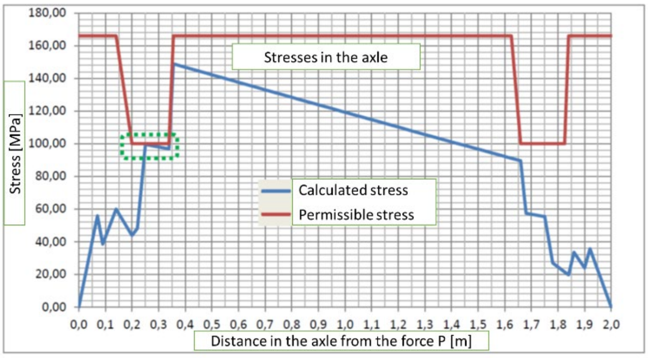

Fig. 2. Stresses in the tested railway axis [3]

Safety factor - a unitless number used in the strength of materials and construction calculations, indicating how many times the allowable stress for a given structure is lower than the dangerous stress.

The dangerous stress for elastic-plastic metallic materials is usually the yield point for static loads, and the fatigue strength for cyclic loads.

The value of the safety factor is assumed depending on the type of metallic material (steel, cast steel, cast iron, aluminum alloys, copper alloys) and the type and responsibility of the structure from the point of view of its operational safety.

The values of the safety factors are given in the relevant standards, and range from 1.1 to 20, for example in typical applications the following values are assumed:

- aviation 1.5
- chains 4.0
- ropes of lifting and hoisting devices 6.0-12.0.

IV. PROBABLE CAUSES OF FATIGUE CRACKING OF RAILWAY AXLES

The causes of fatigue cracks in railway axles include:

- mechanical damage to the axle surface due to errors in assembly and disassembly of axle boxes, bearings, wheels, brake discs,
- mechanical damage to the axle surface as a result of impact during the operation of a railway vehicle,
- initiation of high-cycle fatigue crack as a result of long-term (many years) operation of the axle; in this case, it may be the mechanism of the formation of slip bands in the surface grains, or differences in the deformability of non-metallic inclusions or particles of a different phase and the metallic matrix,

- initiation of low-cycle fatigue crack as a result of axle overload and local stress increase to the yield point.

The probable hypotheses for accelerated breakage of the railway axle between the repairs of the wagon according to the MSD (maintenance system documentation) of a railway wagon and the ultrasonic tests seem to be:

- mechanical damage to the surface during operation (e.g. stone impact from the ballast)
- and/or axle overload.

As fatigue cracks most often nucleate on the surface, the surface condition has a significant influence on the fatigue strength. Increasing the roughness and depth of micro-irregularities reduces the fatigue resistance of the material. Machined scratches and cuts as well as microcracks are especially dangerous when placed perpendicular to the main tensile stress direction as they act as stress concentrators. Deep scratches and dents on the surface dramatically reduce the fatigue life of components subjected to cyclic loads.

V. EXAMPLES OF FATIGUE CRACKING OF RAILWAY AXLES

From 2016 to 2019 twenty three B11 accidents occurred in Poland (Fig. 3) in which the direct cause was the fatigue crack of the axle (data derived from reports of State Railway Accident Investigation Commission). The scope of data submission starts in 2016, as from this year all infrastructure and siding managers are required to report incidents to the Commission.

Accordin to Polish national act on railway transport “accident” (B) is an unintentional sudden event or sequence of such events involving a railway vehicle, causing negative consequences for human health, property or the environment; accidents include in particular:
a) collisions,
b) derailments,
c) events at level crossings,
d) incidents involving persons caused by a moving railway vehicle,
e) fire of a railway vehicle.

According to Regulation of the Minister of Infrastructure and Construction of 16 March 2016 on serious accidents, accidents and incidents in rail transport – “B11” accident is damage or poor technical condition of the wagon.

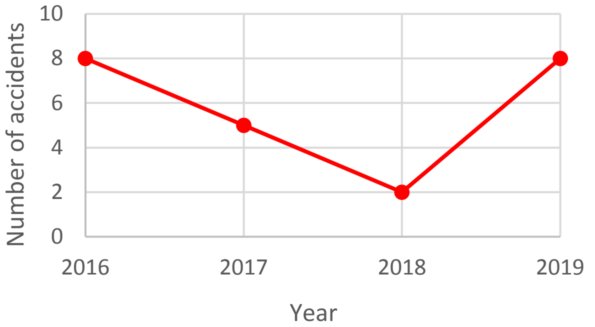

Fig. 3. Number of category B11 accidents, in which the axle fatigue cracking took place

The fatigue crack shown in Figure 4 and Figure 5 derives from the B11 accident of the freight wagon in 2015 [4]. The immediate cause was a fatigue crack in the middle part of the first axle of the first wheelset, while the primary cause was an old surface defect of the axle. A crack has taken place on the axle body. The origin of the crack was the surface defect unnoticed during inspection. The smaller area of the fatigue zone and the larger area of the rapid fracture zone indicate high loads on the axle. The lack of stop and radial lines indicates the rapid development and propagation of the crack that took place on the presented fracture surface. Numerous defects and pitting can be seen on the axle surface, moreover, the shape of the axle is deformed as a result of a derailment of the train.

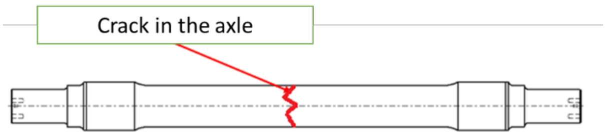

Fig. 4. The place of the axle fatigue crack

Fig. 5. Fatigue cracking surface of the axle of the freight wagon [4]

Another example of fatigue cracking classified as B11 accident is from the derailment of a freight wagon in 2019 [4]. The immediate cause of the incident was a fatigue fracture in the middle of the axle body of the third axle in a wagon. The origin of the crack was the surface defect of the wheelset axle. This axis was subjected to lower bending and rotational loads, which indicates a larger area of the fatigue zone compared to the rapid fracture zone and the presence of stop lines (Fig. 6). The development of the fracture progressed slowly, as indicated by the stop lines.

Fig. 6. Fatigue cracking surface of the axle of the freight wagon [4]

Last example of B11 accident with fatigue cracking is from the derailment of a freight wagon in 2019 [5]. The immediate cause of the incident was a fatigue fracture in the journal of the axle (Fig. 7). It can be seen from Fig. 8 that about 40% of the cross-section is fatigue area, which indicate high loads on the axle. The primary cause is improper machining of the axle surface (Fig. 9), i.e. undercut, which resulted in an unfavorable distribution of stresses in the axle and initiation and development of fatigue crack.

Fig. 7. The place of the axle fatigue crack

Fig. 8. Fatigue cracking surface of the axle of the freight wagon [5]

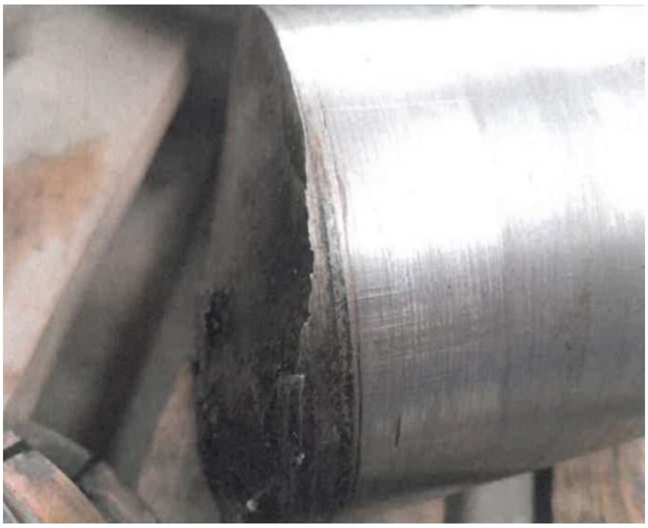

Fig. 9. The fatigue fracture area of the axle journal with visible undercutting [5]

VI. CONCLUSIONS

Despite the fact that railway axles are designed for unlimited fatigue strength, they often fail due to fatigue, which leading to rail accidents.

Fatigue cracking of railway axles is initiated in the places of stress concentration and/or the occurrence of geometric notches.

Notches on the surface are caused by mechanical damage, improper machining, pitting corrosion and fretting.

During inspection and repair of wheelsets, particular attention should be paid to detecting even slight scratches and surface cracks, which may cause initiation and development of fatigue cracks.

REFERENCES

[1] Ł. Antolik, “Methodology of Fatigue Cracks Detection in Railway Axles in Comparison with European Standards Requirements” (in Polish), Railroad Problems, Vol. 165, pp. 7-19, 2014.

[2] EN 13103:2009 Railway applications. Wheelsets and bogies. Non-powered axles. Design method.

[3] A. Mańka, “Design calculations for railway axles in accordance with PN-EN 13103” (research report in Polish), Department of Railway Transport, Faculty of Transport, Silesian University of Technology, Katowice 2009.

[4] Report No. PKBWK/07/2019 of the Polish State Railway Accident Investigation Commission.

[5] Report No. PKBWK/06/2020 of the Polish State Railway Accident Investigation Commission.

Reducing the Level of Nitrogen Oxides in Exhaust Gases of a High-Speed Hydrogen-Powered Diesel Engine

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***Abstract*—The relevance of the widespread introduction of hydrogen as fuel for the transport and stationary engines is obvious. The proposed paper describes the working process of a still little studied hydrogen-powered diesel engine with direct injection of hydrogen gas. The study was carried out using a 3D mathematical model based on the fundamental equations of the Navier-Stokes type, which were solved by the numerical method of control volumes using the CRFD code AVL FIRE. Numerical experiments have shown that with an increase in the amount of hydrogen injected into the cylinder at a constant value of the excess air ratio, the quantities of nitrogen oxides generated in the combustion chamber can increase. An explanation is given for the reason for this phenomenon, which is not characteristic of the traditional diesel engines. It was found that by changing the regulating (moment of hydrogen injection) and design (shape of the combustion chamber, diameter and number of nozzle holes) parameters, it is possible to achieve a significant reduction in the emission of nitrogen oxides. The values of these parameters, contributing to a significant reduction in the emission of nitrogen oxides, have been determined.**

Keywords—hydrogen-powered diesel engine; 3D modeling; shape of the combustion chamber; nozzle design.

I. INTRODUCTION

The widespread use of hydrogen, as an alternative to petroleum-derived traditional fuels in transport and stationary energy production, is the way forward for solving environmental and energy-related problems. The main advantages of using hydrogen as a motor fuel lie in its remarkable thermophysical properties, such as high values of the heat of combustion, flame propagation velocity, the minimum ignition energy, a wide range of inflammability in terms of the excess air factor, as well as in complete decarbonization of exhaust gases. The only harmful component of the latter are nitrogen oxides NOx, the reduction of which by controlling the injection moment (ignition dwell angle) and changes in the shape of the combustion chamber, as well as the design of the nozzle, and this is what this paper focuses to.

All of the research completed so far has been mostly on the hydrogen engines with carburation and positive ignition. The hydrogen-powered diesel engine with direct injection of the gas hydrogen into the cylinder has obvious advantages, both from an environmental point of view (NOx emissions) and in terms of fuel efficiency (engine efficiency). Despite this, the first incisive pilot studies proving the long-term benefits of developing the hydrogen-powered diesel engine were conducted by H. Rottengruber and others at the Technical University of Munich [1, 2]. Later, it's where the pilot studies were conducted on the ignition delay of various hydrogen-containing fuels [3]. On the basis of the experimental data obtained, the 3D mathematical models were developed [4, 5, 6], allowing to monitor the change in the local parameters of the working fluid in the cylinder, which determine the environmental performance of the engine, which is in turn very difficult and time-consuming, and sometimes impossible in the process of a pilot study. It should also be noted that recently the problem of developing the hydrogen-powered diesel engine has become even more urgent in connection with the desire to drastically reduce CO_2 emissions [7, 8, 9]. Let us emphasize that the question of the influence of a number of design parameters on the combustion process and the formation of nitrogen oxides in the hydrogen-powered diesel engine has not been practically studied using the mathematical modeling methods.

The proposed study is aimed at 3D modeling of the working process of the hydrogen-powered engine and the generation process of nitrogen oxides, as well as the determination of those values of regulated and design parameters of the engine that can reduce the emissions nitrogen oxides.

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II. A BRIEF DESCRIPTIN OF THE ENGINE UNDER STUDY AND A 3D MATHEMATICAL MODEL OF THE WORKING PROCESS

The object of investigation was a high-speed hydrogen-powered diesel engine, which is a hydrogen-converted modification of the base four-stroke, V-shaped, 24-valve water-cooled diesel engine with the following technical data: number of cylinders i=6; cylinder diameter/piston stroke D/S=130/140 mm/mm; compression ratio ε=16,5; effective power Ne=315 kW; crankshaft speed n=2000 min^{-1}, the combustion chamber shape of YaMZ type.

The mathematical model is based on the fundamental equations of conservation of momentum (Navier-Stokes equations), energy (Fourier-Kirchhoff equations), diffusion (Fick equation) and continuity, describing unsteady three-dimensional turbulent motion in the gas exchange systems and in the cylinder of the hydrogen-powered diesel engine. After averaging with respect to Favre, these equations are written in the Reynolds form and supplemented by the equations of the k-f-ζ model of turbulence. The combustion process is simulated using the Magnussen-Hjertager model, and the generation process of nitrogen oxide is based on the extended Zeldovich mechanism. For a numerical solution, the semi-implicit method SIMPLER (Semi-Implicit Method for Pressure-Linked Equations-Revised) is used, which was designed for a step-by-step calculation of the "predictor-corrector" type. Numerical experiments were carried out using the 3D CRFD code AVL FIRE. A detailed description and analysis of these equations, models and methods of solution are published in [4, 5, 6, 10, 11].

When converting the traditional serial diesel engines running on the hydrocarbon diesel fuel to hydrogen, a comparative analysis of the processes occurring in the combustion chambers of the base diesel and the hydrogen-converted diesel engines was carried out under conditions formulated in [6]: 1) Identity of the main dimensions D and S, as well as ε and the shape of the combustion chamber; 2) Identity of the available amount of heat entering the combustion chamber with the inject fuel. The latter condition is satisfied on the basis of the ratio of the mass cyclic hydrogen inlets and the diesel fuel [6]. It was shown that under these conditions in the combustion chamber of the hydrogen-powered diesel engine, the local temperatures have relatively high (compared to the base diesel engine) values and lead to increased (by about ~ 10%) values of the total mass amount of nitrogen oxides per cycle.

Reducing the level of nitrogen oxides in the exhaust gases of the hydrogen-powered diesel engine would be achieved through the successful selection of regulating (the hydrogen injection timing angle) and designing (CC shape, number of nozzle openings in the injection nozzle) parameters.

III. THE INFLENCS OF THE HYDROGEN INJECTION TIMING ANGEL (HITA)

The HITA defines the moment of fuel injection and, obviously, its value significantly affects the efficient and environmental performance of the engine [3]. The flame propagation velocity during the combustion of the stoichiometric mixtures with air in the case of hydrogen is approximately 5-6 times higher than in the case of a diesel fuel, gasoline or natural gas [12]. In this regard, small changes in the hydrogen gas emission ratio can affect the course of the combustion and NOx generation. The modeling of the generation process of NOx, carried out when changing the HITA by 1^0 of crankshaft degree, showed a significant effect of the moment of direct injection of hydrogen into the cylinder. This is confirmed by the results obtained for three different values of the HITA – 7^0, 6^0 and 5^0 of crankshaft degree (or the corresponding injection moments φ_{inj} = 353^0, 354^0 and 355^0 of crankshaft degree (Fig. 1). Note that the quantities of nitrogen oxides indicated in Figure 3 in the cylinder of the hydrogen-powered diesel engine correspond to the moment of opening of the exhaust valves, that is, these are the total concentrations in the cylinder for the working cycle. In the investigated range of variation of φ_{inj}, a decrease in the injection lead angle by 1^0 of crankshaft degree leads to a decrease in the total amount of nitrogen oxides per cycle by about 7-8%.

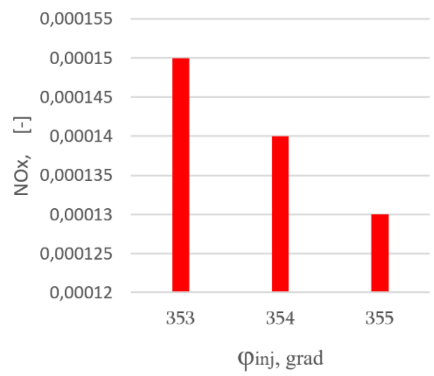


Fig.1. *Total nitrogen content per working cycle (mass portion), depending on the moment of hydrogen injection* φ_{inj}.

However, this process is accompanied by a decrease in the maximum cycle pressure pz and a deterioration in the effective performance of the working process.

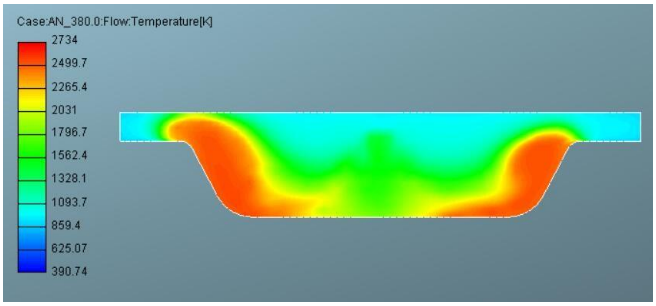
Modeling the change in the local temperatures of the working fluid in the combustion chamber, depending on the moment of hydrogen injection, demonstrated that with a relatively large injection lead angle (that is, with early injection, when φ_{inj} = 353°), the first sources in the combustion chamber manage to form already by the time when the piston is in the position of top dead centre (TDC), and with relatively late injection (φinj = 355°), these sources are not so visible. Note that the intensity of local generation of nitrogen oxides depends on the intensity of the growth of local temperatures and, obviously, it changes in a similar way depending on the moment of hydrogen injection. In addition, with early injection, the rate of pressure rise dp/dφ increases, which is caused by a sharper increase in the rate of heat generation at the initial stage of combustion, and, accordingly, the noise level increases when operating the engine.

Such different developments of the combustion processes depending on φinj leads to the fact that with early injection (φinj = 353°), the maximum values of the heat release rate (dQx/dφ)max, pressure pz and temperature Tz are higher, and their corresponding crankshaft degrees φ are closer to TDC (φ = 360°) than with late injection (φinj = 355°). This explains the fact that a decrease in NOx concentration with a later injection (Figure 1) can lead to a decrease in the efficiency of the cycle.

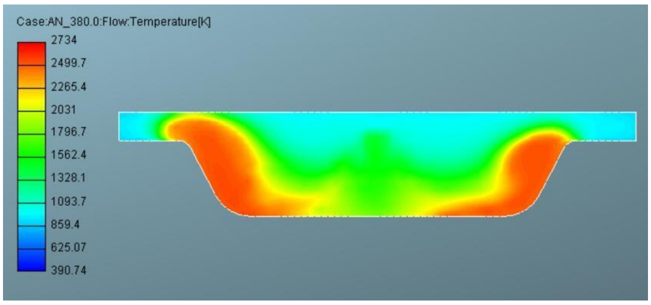
IV. THE INFLUENCE OF THE SHAPE OF THE COMBUSTION CHAMBER

When converting the serial compression-ignition diesel engines to the positive-ignition gas engine in order to prevent knocking, the compression ratio needs to be reduced. It is usually achieved through changing the shape and size of the combustion engine located in the piston. In the hydrogen-powered compression-ignition diesel engine, compared to a serial base diesel engine, higher compression ratio may be required, which is due to a higher autoignition temperature of hydrogen (585°C under atmospheric conditions) compared to a diesel fuel (250°C under the same conditions) [12]. In any case, the transition from the liquid to gaseous fuel is often associated with change in the compression ratio associated in turn with change in geometry of the combustion chamber.

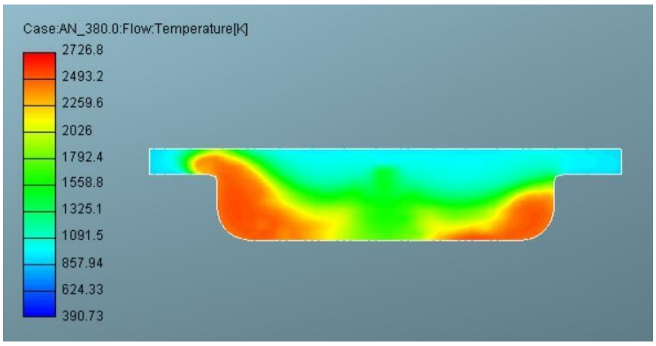
The invalidity of the prevailing opinion that in the gas-powered engines with spark ignition it is important to provide the compression ratio required for knock-free operation, and the shape of the combustion chamber is immaterial, was proved in [13]. The results of the numerical experiments carried out for the three different shapes of the combustion chamber of the hydrogen-powered diesel engine show a noticeable influence of the shape of the combustion chamber on change in the local temperatures of the working fluid (Figure 2).



a



b



c

Fig.2. *The instant temperature fields of working fluid in the volume of the combustion chamber depending on its shape, at crankshaft degree is φ=3800 : a – base combustion chamber (CC) of YaMZ type; b – conical (asymmetrical) CC; c – cylindrical (symmetrical) CC.*

We can see that in the cylindrical combustion chamber, when φ = 380° of crankshaft degree are the high-temperature zones, that is, the zones with intensive combustion occupy significantly less volume of the combustion chamber than in the conical or the base combustion chamber. It is obvious that the base combustion chamber of the YaMZ type, which is w-shaped (Figure 3), further contributes to an increase in the kinetic energy of turbulence (KET) of the working fluid in the cylinder, especially when the piston approaches the TDC, that is, to the moments of hydrogen injection and the start of ignition. This causes the effect of KET on the rate of heat release, depending on the shape of the combustion chamber, which has the appearance shown in Figure 3. As you can see, in the case of a base (w-shaped, YaMZ type) combustion chamber, the heat release rate is not only higher, but also its maximum instantaneous magnitude is closer to TDC (φ=360° of crankshaft degree, Figure 3) than in the case of the conical or cylindrical combustion chamber.

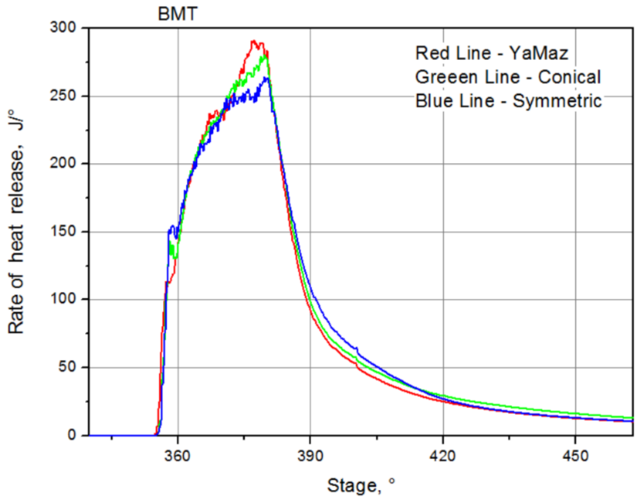


Fig. 3. *Change of rate of heat release (J/0crankshaft degree) in the cylinder of the hydrogen powered diesel engine depending on the shape of the combustion degree.*

It is obvious that the cycle maximum pressure p_z and its correspondence maximum value of the temperature T_z of the cylinder averaged by volume, as well as the total cyclic concentrations (mass portion) of nitrogen oxides in the case of a base combustion chamber is higher compared to the cylindrical and conical combustion chambers (Figure 4). Thus, the base combustion chamber, giving the best effective indicators of the cycle among the three study shapes of the combustion chamber, in terms of the emission of nitrogen oxides, remains below according to the meaning of nitrogen oxide is established (but not too far, see Figure 5) the other combustion chambers.

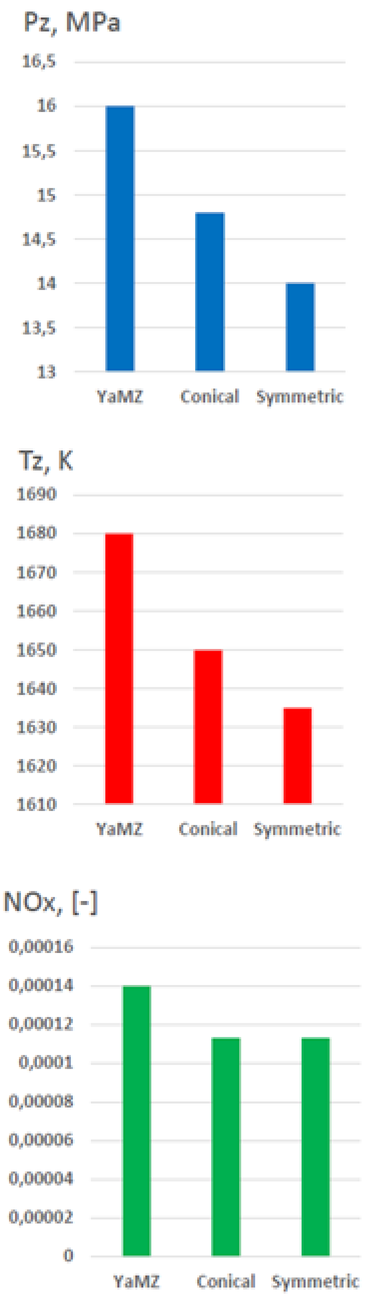


Fig. 4. *The influence of the shape of the combustion chamber on maximum pressure p_z and the temperature T_z averaged in terms of volume of the cylinder, and the total cycle concentration (mass portion) of nitrogen oxides NOx.*

Note that the reduction in NOx emissions in the hydrogen-powered diesel engine could be reduced significantly with the help of the exhaust gas recirculation methods proven in the traditional diesel engines [14], or by means of the homogenization of the combustion process in the diesel engine. The latter could be carried out, for example, by increasing the number of nozzle holes in the nozzle [15].

V.THE INFLUENCE OF THE NOZZLE DESING

The results of a pilot study, given in [12], demonstrate that the nozzle design, specifically the number and diameters of nozzle holes, can have a significant impact on the process of nitrogen oxide generation. In this work, the task is solved with the help of 3D CRFD programs AVL FIRE [11], allowing the turbulent combustion of hydrogen in the cylinder of the engine. Figure 5 illustrates the instant temperature fields and concentrations (mass portions) of nitrogen oxides in cylinder capacity.

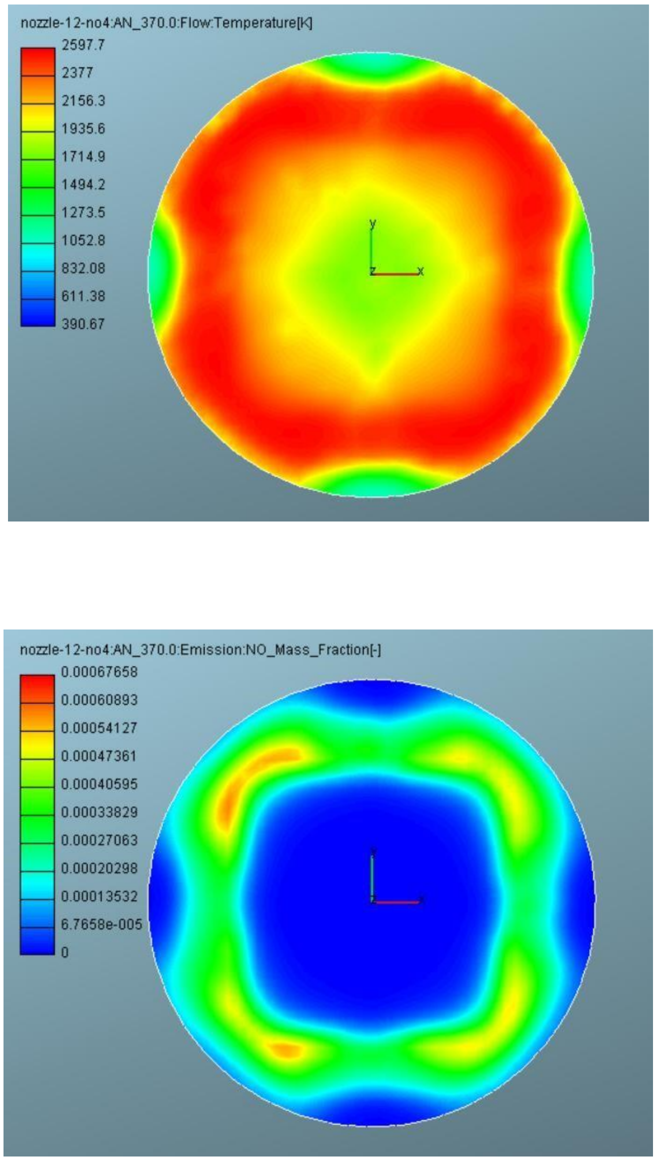
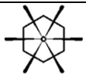
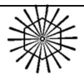


Fig. 5. *Instant values of the local temperatures and concentration (mass portion) of NOx in the combustion chamber of the hydrogen-powered combustion engine with a nozzle №2 (z=18, dc=0,42 mm, see Table 1), when crankshaft degree is φ=370°.*

The schemes of the nozzles under study, their geometrical parameters, as well as the cyclic values of the total quantities (mass portions) of nitrogen oxides, depending on the design of the nozzle end of the nozzle burner, are presented in Table 1.

TABLE I.

№	Nozzle diagram	Number of nozzles Holes, z	Diameters of nozzle holes, dc, mm	Total open flow area of holes, ΣF, mm^2	share of NOx (total mass portion per cyle)
1		6	0,24	0,27	0,0012
2		18	0,17	0,41	0,00022

As the number of nozzle holes increases, there occurs homogenization of the hydrogen-air mixtures, in which the flame from the first combustion sources spreads rapidly to the adjacent zone in cylinder capacity and covers more rapidly the volume of the combustion chamber (Figure 5). The rapid growth of heat release rate in the initial phase leads to an increase in pressure rise rate, which in turn contributes to increasing noise of the hydrogen-powered diesel engine. With other factors, the homogenization of mixtures leads to the regulation of local temperatures in the upper zones (Fig. 5) and lowering of the temperature cycle as a whole, and particularly the local temperatures themselves, which reflects the total cyclic concentration of nitrogen oxides (see Table 1).

VI. CONCLUSIONS

Numerical experiments performed during modeling of intra0cylinder processes of the traditional (base) and hydrogen-powered diesel processes showed significant difference between the natures of the conduct of these processes n the traditional and hydrogen-powered diesel engines during the injection and combustion of fluid diesel fuel. In the case of a diesel fuel, the processes of evaporation and carburation begin and occur on the outer surface of the injected fuel spray, where the first combustion sources appear. Hydrogen is more rapidly mixed with air by volume of the combustion chamber and ignites faster, the flame rapidly spreads to the volume of the combustion chamber.

An increase in the cyclic hydrogen consumption, when the aggregate excess air ratio remains constant, increases the mass of the hydrogen-air mixture in the cylinder and leads to higher density of working fluid. Provided that hydrogen injection pressure, limited by critical value, leading to a constant magnitude of hydrogen discharge through the nozzle, remains constant, hydrogen throw (the depth of penetration into the cylinder decreases). Hydrogen will accumulate near the nozzle, and due to lack of oxygen in this zone, the combustion process can be stretched out. This leads to a decrease in local temperature in the combustion chamber, and as a result, to an increase in local NOx concentrations. This phenomenon, earlier noted in the pilot studies on the hydrogen-powered diesel engines, conducted by H. Rottengruber and others [1, 2], has no place in the traditional diesel engines.

By changing the moment of hydrogen injection (injection timing angle φinj), it is possible to increase the effective performance of the hydrogen-powered diesel engine so that an increase in nitrogen oxides remains relatively small. In this regard, the value φinj = 353° should be taken as optimal for the investigated hydrogen-powered diesel engine. The conical combustion chamber from an environmental point of view has an advantage over the base chamber of the YaMZ type (reduces the emission of nitrogen oxides by about 15-18%) and leads to practically the same results as the cylindrical (symmetrical) chamber. As a result, it is recommended to choose the conical chamber, which, however, in terms of effective performance is not much inferior to the YaMZ-type chamber, but surpasses the symmetrical (cylindrical) chamber. According to the results of the study of two different designs of the nozzle end, it was found that the nozzle with an increased number of nozzle holes (18x0,17 mm) significantly reduces the emission of nitrogen oxides, does not significantly decrease the effective performance, and its use is advisable.

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REFERENCES

[1] Rottengruber H. , Wiebicke U., Woschni G., Zeilinger K. Investigation of a Direct Injecting Hydrogen Diesel-Engine. World Hydrogen Conference XII. Buenos Aires. 1999.

[2] Rottengruber H., Wiebicke U., Woschni G., Zeilinger K. Wasserstoff-Dieselmotor mit Direkteinspritzung, hoher Leistungsdiechte und geringer Abgasemission. Teil 3: Versuche und Berechnungen am Motor. MTZ, N2.-2000. S.122-128.

[3] Kavtaradze R.Z., Zeilinger R., Zitzler G. Ignition Delay in a Diesel Engine Utilizing Differenz Fuels. High Temperature. Vol. 43, N6, 2005. pp. 951-960.

[4] Кавтарадзе Р.З., Зеленцов А.А., Краснов В.М., Климова Е.В. Исследование локального образования оксидов азота в водородном дизеле. //Транспорт на альтернативном топливе, № 2(32). 2013. С. 34-40. (in Russian).

[5] Kavtaradze, R., Natriashvili, T., and Gladyshev, S. Hydrogen-Diesel Engine: Problems and Prospects of Improving the Working Process. SAE (Society of Automotive Engineers, USA) Technical Paper 2019-01-0541, 2019.-15 p.

[6] Natriashvili T., Kavtaradze R., Glonti M., Chilashvili G. Ecological Characteristics of the Direct Injection Hydrogen Diesel with the Use of the 3D Model. Bulletin of the Georgian National Academy of Sciences. Vol. 14, № 3, 2020. Pp.56-63.

[7] Laiminger St., Url M., Payrhuber K., Schneider M. Wasserstoff für Gasmotoren – Kraftstoff der Zukunft. MTZ, №5, 2020. S. 66-71.

[8] Cernat A., Pana C., Negurescu N., Lazaroiu G., Nutu C., Fuiorescu D. Hydrogen—An Alternative Fuel for Automotive Diesel Engines Used in Transportation. MDPI, Sustainability, N12. – 2020.- P. 1-21.

[9] Koch D., Ebert T., Sousa A. Transformation vom Diesel zum H2-Hoch-AGR-Magerkonzept. MTZ, №5, 2020. S. 30-38.

[10] Babayev R., Andersson A., Dalmau A. S., Im Hong G., Johansson B. Computational Characterization of Hydrogen Direct Injection and Nonpremixed Combustion in a Compression-Ignition Engine. International Journal of Hydrogen Energy. April 2021. -16 p.

[11] FIRE. Users Manual. Version 2020. AVL List GmbH Graz, Austria, 2020.

[12] Кавтарадзе Р.З. Теплофизические процессы в дизелях, конвертированных на природный газ и водород. Изд-во МГТУ им. Н.Э. Баумана, 2011.- 238 с. (in Russian).

[13] Леонтьев А.И., Кавтарадзе Р.З., Шибанов А.В., Зеленцов А.А., Сергеев С.С. Влияние формы камеры на нестационарные процессы переноса и турбулентного сгорания в дизеле,

конвертированном в газовый двигатель. Известия РАН, «Энергетика», №2. -2009. С. 49-63.

[14] Kavtaradze R.Z., Sergeev S.S. New Alternative (Partially Homogeneous) Combustion Process as a Method for Reduction of Concentrations of Nitric Oxides and Soot in Combustion Products of Diesel. High Temperature. Vol.52, №2,-2014. Pp. 285-299.

[15] Кавтарадзе Р.З., Натриашвили Т.М., Сахвадзе Г.Ж., Ван Ичунь (Wang Yichun), Лю Сяохао (Lyu Xiaohao). Влияние формы камеры сгорания и конструкции форсунки на образование оксидов азота в водородном дизеле. Проблемы машиностроения и надежности машин. №7, 2019. С. 105-112.

Individual Educational Trajectory Ensuring Professionogram-Careerogram Compatibility in the Sphere of Logistics

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***Abstract*—The paper presents the working principle of the model checking the compatibility of professionogram-careerogram to ensure the compatibility of knowledge, skills and personal characteristics of university graduates applying to work in the sphere of logistics with the position they apply for. With the help of the proposed model, compatibility of professionogram-careerogram is first verified by referring to fuzzy sets' theory. If the result is positive, the model decides on the suitability of the applicant for the position. If the professionogram-careerogram compatibility is below the acceptable limit, the model identifies the "weak points" of the applicant in relation to job requirements and generates an individual educational trajectory consisting of these "points". The paper presents a method to select the most relevant content on the topics covered by the individual educational trajectory for the applicant's requirements from the global educational resources.**

***Keywords*—logistics services, human resources, professionogram, careerogram, individual educational trajectory, fuzzy logic, intelligent management**

I. INTRODUCTION

In modern times, logistics services play an exceptional role in the development of domestic and global economy, increasing the pace of production and ensuring competitiveness in the world market. The development of information technology, the Internet and web tools necessitates increasing the level of services provided in this area and reducing human labor, as well as ensuring intelligence and transparency in management. In the society operating in terms of the Fourth Industrial Revolution, the concept of logistics (the service of transporting any cargo from one point to another for a certain fee) becomes more diverse, losing some of its traditional scope. Today, to determine the amount of service fee required for logistics services, the decision that will satisfy all the actors, i.e., the sending, transporting and receiving parties should be made taking into account the physical, chemical, geometric, environmental and strategic characteristics of cargo to be transported, the type of transport to implement the transportation, the vehicle, route and duration of transportation, insurance issues, customs authorization, etc. The functioning of the logistics service market in uncertainty conditions leads to the changes in its structure, the multifaceted, multiple, quantitative and qualitative nature of the indicators to be considered, and the impossibility of its unambiguous definition. These features identify the issue of supply and demand management in the logistics services market as a poorly structured and difficult to formalize [1], [2]. Obviously, the use of fuzzy logic mathematical apparatus is more effective in solving the problems requiring intelligent management.

For example, the RELOG Web tool is designed to provide intelligent management in urban logistics. The software tool is capable to make optimal decisions in the route selection and cargo placement, taking into account 40 parameters for cargo transportation [3]. Blockchain technology is developed for the management of domestic and international cargo transportation [4], [5]. Seco toolkit, together with its POU, SupplyPad, SecoPoint, VIM subsystems, performs the functions of assembly, virtual storage and virtual tracking [6]. One of the important issues to ensure the provision of logistics services meeting the requirements of rapidly changing labor market in the industry 4.0 environment is the training of competitive personnel in this field. In modern times, the study of the structure and requirements of the labor market in professions and specialties section is one of the most pressing and unexplored issues in the world, including in Azerbaijan. Today, the inertia of education system is also in the spotlight of the developed countries, various tools for the integration of labor and education markets are being developed, verified and submitted for discussion on various platforms.

We believe that one of the areas ensuring the flexibility and dynamism of education system may be the personalization of education and the development of individual educational trajectories. Note that the assessment of supply and demand for professions and specialties, the need for education meeting the labor market requirements to shift to narrow specializations' are specified in many political documents as priority issues [7] [8].

II. SPECIALTIES AND PROFESSIONS IN LOGISTICS

To provide the logistics sphere with human resources, staff training on bachelor's and master's degree is implemented in various universities on specialties, such as sales agents, transport service agents, transport service engineers, transportation and transport management engineers, logisticians, transportation managers, customs service managers, warehouse managers, logistics trainers, warehouse process automation specialist, green logistics specialist, delivery chain specialist, transport planner, consignor, etc. [9]. In some universities, these specialties are generalized and called management.

Occupations in the sphere of logistics are hierarchically structured and often generalized as top management in logistics, senior/middle management staff and operational management staff. In Europe, this hierarchy is classified as Supervisory/Operational level, senior level and master level accordingly [10]. Studies show that the problem of certification in logistics sphere is still a priority. In this context, the development of an individual educational trajectory to ensure professionogram-careerogram compatibility for optimal management in logistics sphere is one of the important issues to be addressed.

III. DETERMINATION OF PROFESSIONOGRAM-CAREEROGRAM COMPATIBILITY

Professionogram (lat. Professio - specialty, gramma - describe) is a description of the features of a particular profession, including the requirements for a specialist realizing himself/herself in this area. Taking into account the uniqueness and specificity of the requirements put forward to various specialists by employers in the Industry 4.0 environment, in this work, a competency-based approach is taken as the basis for compiling a professionogram. This approach allows for creating a unified formal model both for describing the requirements for specialists set by employers, and to describe and evaluate the potential of the specialists themselves through the prism of employers' requirements.

Thus, the model of specialty (position) and specialist implies the presence of requirements for at least two generalized types of competencies: 1) professional (functional) competencies related to a certain area of work (specialty) and including everything a specialist should be aware of (knowledge) and capable to perform (skills and abilities) at a specific workplace; 2) personal competencies, including behavioral, communicative, ethical, etc. (team work ability, creativity, transfer of knowledge and skills, responsibility, desire to acquire new knowledge (ability to learn), etc.)

A careerogram is a set of parameters representing the competencies (knowledge, skills, individual characteristics, work experience, etc.) of each applicant.

The Individual Education Trajectory (IET) is a purposeful educational program comprising educational standards and choices to meet them, including open (global) educational resources, which are constantly adapted to the professionogram of the specialty covered by the position [12].

This paper proposes a model and method for determining professionogram-careerogram compatibility, as well as a method for selecting an individual educational trajectory to ensure the maximum compatibility.

The block diagram of the model is presented in Figure 1.

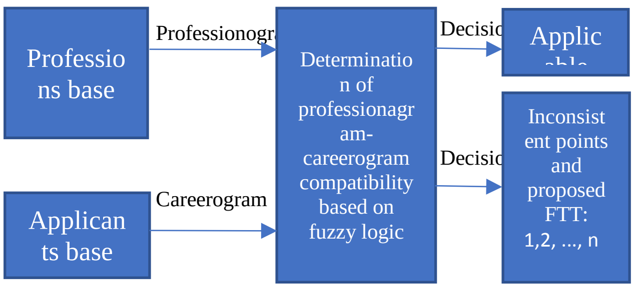

Figure 1. Structural scheme of the model for determination of professionogram-careerogram compatibility.

For more accurate determination of professionogram-careerogram compatibility in the logistics sphere, it is appropriate to view the field of logistics services as an uncertain intelligent environment. In this case, provision of competencies is taken as the basis for achieving the result [13].

A. Fuzzy situation model of supply and demand for applicants

If we conditionally denote the positions required in the enterprises providing services in the field of logistics by "P", then we can describe the requirements for the positions as follows:

$P = \{P_1, P_2, \dots, P_d\}$ or $P = \{P_b\}, b = \overline{1, d}$ denotes a set of tasks or professionograms;

$V = \{v_1, v_2, \dots, v_y\}$ or $V = \{v_z\}, z = \overline{1, y}$ denotes a set of personal characteristics (competencies) that a candidate applying for a profession (position) must have; $F = \{f_1, f_2, \dots, f_r\}$ or $F = \{f_o\}, o = \overline{1, r}$ denotes a set of competencies that a candidate applying for a position must have; $E = \{e_1, e_2, \dots, e_x\}$ or

$E = \{e_t\}, t = \overline{1, x}$ denotes the required level of knowledge that an applicant must have in individual subjects and themes.

Thus, the demand model for each position is described by three matrices P = (V, F, E): $P_V = \|v_{bz}\|_{dy}, P_F = \|f_{bo}\|_{dr}, P_E = \|e_{bt}\|_{dx}$. Here, each $b = \overline{1, d}$ line of Pb defines the specific tasks required by the logistics service company, and the columns (vdy,fdr,edx) represent the applicant's personal characteristics, professional competencies and ever-expanding base of required knowledge. The elements Vdy,fdr denote the level of possessing separate indicators required to function in particular position, edx denotes the knowledge level in individual subjects required for a particular position. Compliance with the knowledge level is determined by oral, written or test examinations, depending on the theoretical and practical requirements. The degree of the position$P_b\left(b = \overline{1, d}\right)$ to fulfill the indicators vdy, fdr and edx is determined by fuzzy sets, expressed by the following affiliation functions:

$$\mu_{v_{bz}}(P_b): P \times V \to [0,1], \mu_{f_{bo}}(P_b): P \times C \to [0,1], \mu_{e_{bt}}(P_b): P \times E \to [0,1] \quad (1)$$

and represents the level of affiliation required by the company for selected position in terms of individual indicators.

If the candidates for any position in the company are conditionally indicated as "A", then a set of applicants can be $A = \{A_1, A_2, \dots, A_s\}$ or

$A = \{A_\square\}, \square = \overline{1, s}$. In this case, $V = \{v_z\}, z = \overline{1, y}$ denotes a set of personal competencies possessed by the applicant for the position, $F = \{f_o\}, o = \overline{1, r}$ denotes a set of open professional competencies possessed by the applicant for the position, and $E = \{e_t\}, t = \overline{1, x}$ denotes a set of indicators of the applicant's initial knowledge on individual subjects and themes or the careerograms.

In this case, the supply model A = (V, F, E) is also described by three matrices: $A_V = \|v_{\square z}\|_{sy}, A_F = \|f_{\square o}\|_{sr}, A_E = \|e_{\square t}\|_{sx}$. Here, each line $\square = \overline{1, s}$ of Ah characterizes the individual candidates for the claimed profession/position, and the columns (vy,fr,ex) represent the ever-expanding database of applicants' personal and professional competencies and their required knowledge level. The elements Vhy , fhr denote level of possessing separate indicators of the applicant for a particular position, and ehx denotes the knowledge level in several subjects required for a particular position. The degree of affiliation of a specific candidate Ah of ($\square = \overline{1, s}$) V personal characteristics, F competencies and E knowledge levels in subjects is determined by the following affiliation functions:

$$\mu_{v_{hz}}(A_h): A \times V \to [0,1], \mu_{f_{ho}}(A_h): A \times C \to [0,1], \mu_{e_{ht}}(A_h): A \times E \to [0,1] \quad (2)$$

Consequently, there are two fuzzy sets describing the conditions of demand $\tilde{P}_b$ and supply $\tilde{A}_\square$ to determine the occupation/position compatibility of the applicant.

$$\tilde{P}_b = \left\{< \mu_{v_{bz}}(P_b) >, < \mu_{f_{bo}}(P_b) >, < \mu_{e_{bt}}(P_b) >\right\} = \{\mu_{p_b}(y)/y\} \quad (3)$$

$$\tilde{A}_h = \left\{< \mu_{v_{hz}}(A_h) >, < \mu_{f_{ho}}(A_h) >, < \mu_{e_{ht}}(A_h) >\right\} = \{\mu_{A_h}(y)/y\} \quad (4)$$

Here, a set$\tilde{P}_b = \{\mu_{p_b}(y)/y\}, b = \overline{1, d}$ is the fuzzy reference situations required by the enterprise for occupations/positions or sought fuzzy images of demand, and $\tilde{A}_\square = \{\mu_{A_\square}(y)/y\}, \square = \overline{1, s}$ is a set of real situations possessed by the applicant, that is sought fuzzy images of supply.

In this case, the goal of the proposed methods is to recognize their similarity and to identify a pair with a greater similarity by comparing the fuzzy image of each real supply with the fuzzy reference images of demand for the intelligent management of demand and supply compatibility in the process of verifying professionogram-careerogram compatibility [14].

B. Recognition of fuzzy images of supply and demand for applicants

Thus, the goal and purpose of making decisions related to professionogram-careerogram compatibility is based on determining the degree of similarity of the two fuzzy situations and managing the situations using the proximity value. Determination of the degree of fuzzy inclusion of a fuzzy situation $\tilde{A}_\square$into a fuzzy situation $\tilde{P}_b$; and the determination of the degree of fuzzy equality $\tilde{A}_\square$and $\tilde{P}_b$can be used as a method for assessing the degree of similarity of a random real situation with the relevant reference situation [14]:

1. The degree of fuzzy inclusion$\theta\left(\tilde{A}_\square, \tilde{P}_b\right)$ of a fuzzy situation $\tilde{A}_\square$into a fuzzy situation $\tilde{P}_b$ is defined as follows:

$$\theta(\tilde{A}_h, \tilde{P}_b) = \&\theta(\mu A_h(y), \mu P_b(y)) = \underset{y \in Y}{\&} \left(\max\left(1 - \mu A_h(y), \mu P_b(y)\right)\right) = \min\left(\max\left(1 - \mu A_h(y), \mu P_b(y)\right)\right) \quad (5)$$

If the degree of fuzzy inclusion of a situation $\tilde{A}_\square$into $\tilde{P}_b$ is not less than the limit of fuzzy inclusion ψ accepted in accordance with the terms of management, i.e., $\theta\left(\tilde{A}_\square, \tilde{P}_b\right) \geq \psi$, then the situation $\tilde{A}_\square$is fuzzy included into the situation$\tilde{P}_b$, i.e.,

$\left(\tilde{A}_\square \subseteq \tilde{P}_b\right)$. More precisely, if the fuzzy values of the indicators of the situation $\tilde{A}_\square$are fuzzy included into the fuzzy values of the indicators of the situation$\tilde{P}_b$, then the situation $\tilde{A}_\square$ is fuzzy included into the situation$\tilde{P}_b$.

To make a decision, the fuzzy image (real situations) of each candidate is compared to the reference image of the claimed specialty and the degree of fuzzy inclusion is determined. The specialty with the maximum compatibility is selected as a result of specialty search based on the following expression:

$$\theta(\tilde{A}_h, \tilde{P}_b) = max[min(max(1 - \mu A_h(y), \mu P_b(y)))],$$
$$h = \overline{1,s}, b = \overline{1,d} \qquad (6)$$

2. As a measure of the similarity degree of two random fuzzy situations, the fuzzy equality degree is defined as follows. Assume that a fuzzy equality limit $\psi$is specified for two situations, and if there are situations mutually included into each other, i.e., $\widetilde{A}_{\square} \subseteq \tilde{P}_b$and $\tilde{P}_b \subseteq \tilde{A}_{\square}$, $\square = \overline{1,s}, b = \overline{1,d}, \square \neq b$, then the situations $\tilde{A}_{\square}$ and $\tilde{P}_b$ are considered to be approximately the identical. Such similarity degree called fuzzy equality of situations, is calculated according to the following expression:

$$\mu(\tilde{A}_h, \tilde{P}_b) = \vee(\tilde{A}_h, \tilde{P}_b) \vee (\tilde{P}_b, \tilde{A}_h) = \& \mu(\mu A_h(y), \mu P_b(y)) =$$
$$= \min_{y \in Y}[\min(\max(1 - \mu A_h(y), \mu P_b(y)), \max(\mu A_h(y), 1 - \mu P_b(y)))] \qquad (7)$$

If $\mu(\tilde{A}_{\square}, \tilde{P}_b) \geq \psi$, when $\psi$is included into a certain limit, then the situations $\tilde{A}_{\square}$ and $\tilde{P}_b$ are considered to be fuzzy equal, i.e., $\tilde{A}_{\square} \approx \tilde{P}_b$.

As the Figure 1 shows, the system makes two decisions as a result of verification of the professionogram-careerogram.

In the first case, the applicant is considered suitable for the position as he/she meets the requirements. If we denote the compatibility degree by any of the matrices $U = \{U_1, U_2, \ldots, U_l\}$or $U = \{U_l\}, l = \overline{1,m}$, then all the elements of the matrix U in the first case will get the values less than the limits set.

$$\text{Ul} \leq \psi \qquad (8)$$

In the second case, the system will provide the applicant with the points inappropriate for the position he or she is applying for, and it can be assessed as an individual educational trajectory as a set of topics and skills and abilities needed for learning.

In other words, for each violation of the condition Ul ≤ ψ, l denotes the “points” for which the applicant is not suitable for the position, i.e., the missing competencies (knowledge, skills, abilities, etc.). The combination of these “points” generates an individual educational trajectory.

Of course, in a rapidly changing Industry 4.0 environment, flexible curriculum change is often impossible due to formal bureaucratic barriers and lack of appropriate staff. The most effective solution may be to select training materials from open virtual educational resources on topics covering the individual educational trajectory. However, due to a large number of open contents covering the same topic, the question of choosing the one that best suits the applicant’s current potential becomes relevant.

IV. SELECTION OF TRAINING MATERIAL IN ACCORDANCE WITH THE APPLICANT’S REQUIREMENTS FROM OPEN EDUCATIONAL RESOURCES WITH FUZZY MULTI-CRITERIA GROUP DECISION METHOD

As mentioned above, to meet the requirements of ever-changing labor market, each person, graduate and specialist is now faced with the need for lifelong (continuous) education. That is, along with formal education, the role of non-formal and informal education and training, determination, the importance of learning skills become important factors in the realization of self-education opportunities. Today, anyone willing to achieve a certain status can be considered a “continuous learner.”

From this point of view, even if the candidate is not considered suitable for the position (i.e., the violation of condition Ul ≤ ψ is identified), the applicant must advance himself to achieve his/her goal and pursue education on an independently determined individual educational trajectory. In this case, the applicant’ status becomes the learner’s status.

One of the most important issues for the applicant, who has already become a learner, to show more successful results in the next stages, is to find a training methodological kit that meets his/her needs. To provide the learner with the necessary content, the diversity of the subject-content structure in terms of individual parameters and the position as a whole must be taken into account. Thus, when selecting contents for each parameter, the learner’s current potential is taken into account, and after mastering each topic, the learner’s potential already changes anyway. This reveals the diversity of selection conditions.

Given that the content on the topics is developed at different levels, each content to be presented to learner should lead to a positive change in its potential. Therefore, the developed method should constantly monitor the learner’s current potential.

To assess the compatibility degree of the content selected according to the learner’s requirements, a set of contents can be arranged from complex to simple, taking into account the elements of the set of characteristics by levels in the topic-content sphere [15]. When constructing a set of content compatibility by topic, the main point is the equal distribution by level, rather than the number of content topics. Expert knowledge is needed to select the most appropriate content for the individual educational trajectory. In the current situation, the issue can be brought to the issue of arranging the alternatives, taking into account the number of references to the content by learners previously studied on this trajectory and achieved successful results in the next stage, and their advantage relations in accordance with their success in subsequent periods. In this case, the issue can be stated as follows.

Assume that the alternatives, i.e., a set of content covering subjects and topics, a set of criteria for evaluating alternatives (content), and a decision-maker or -makers (learners previously chosen this content), are given. Depending on the nature of objectives, a choice is required, i.e., it can be one of the best alternatives (a content more appropriate to the learner’s position in the trajectory) or a group of alternatives divided into several classes.

The problem of selecting a subset from a set of complex objects refers to decision-making by its nature. Since the presentation of content to learners and the acceptance of this content as the most appropriate content is the decision made by individuals, in such situation, the opinions of experts, success indicators, the author, volume, type of content, etc. are important.

In this case, it is assumed that, depending on the situation, the intelligent support of selection policy can be performed in two ways: 1) the content is presented in accordance with the general potential of learner according to former learners' opinion; 2) the learner finds the content appropriate to certain characteristics.

The main issues in solving the problem of content selection and determination of their relevance include:

1. Most accurate determination of learner's current rating.
2. Formation of a set of possible alternatives (files with different attributes).
3. Description of a set of criteria (type, size, language, author of the content, number of references, success indicator of learners selecting this contend) important for evaluating alternatives.
4. Preparation of criteria scale.
5. Selection of an expert or group of experts (may include former learners as experts).
6. Determination of experts' competence (based on success indicators).
7. Determination of decision-making on the most appropriate content selection.
8. Solution of selection problem using the most appropriate decision-making method for the given problem (decision-making method allowing for the transition from individual assessments to integrated assessment of results is beneficial).
9. Possibility of verifying the adequacy of the decisions made by alternative methods.

Experience shows that, the evaluation of each alternative in the set of alternatives and the expression of an opinion are performed in consultation with a decision-maker or experts who have no a clear judgement. In such cases, a fuzzy opinion may be more comfortable and acceptable to the reality of the initially presented information rather than an ordinary opinion. The fuzzy approach, i.e., an important mathematical concept, allows to analyze and formulate mathematical models of real decision-making problems and is defined as follows:

The subset of the fuzzy Cartesian product X × X characterized by the affiliation function μR : X× X→[0,1] is called the fuzzy relation R in the set X. The value μR(x,y) of this function is understood as a subjective measure or the fulfillment degree of the relation xRy [16]. We use the method of alternatives' selection, taking into account the fuzzy multi-criteria assessment and the preferences of expert team on each criterion in determining the compatibility of content on the parameters within the framework of ensuring professionogram-careerogram compatibility.

Assume that X={x1, x2, ... , xn}={xi, i= $\overline{1,n}$ } is a set of alternatives out of which the best one should be selected, and K={k1, k2, ... , km}={kj, j= $\overline{1,m}$ } is a set of criteria, signs and indicators specific to alternatives. The set of possible alternatives is expressed by a two-dimensional matrix, where the level of the alternative xi to fulfill the criterion kj is determined by the following affiliation function:

φkj(xi):X×K→[0,1]. (9)

Given the set of signs and those preferred by some experts, we use a group decision-making method proposed by Orlovski S.A. [17].

The value of the function ψ (xi, xj, g) expresses the preference relation put forward by the g-th expert out of the set of alternatives, i.e., the advantage of the alternative xi proposed by the g-th expert over the alternative xj.

In this case, ψ(xi, xj, g) has a reflexiveness feature, i.e., ψ(xi, xj, g)=1 for any ∀xi∈X. There is no equation ψ(xi, xj, g)=0, which means that the alternatives xi, xj are not comparable between each other, because we believe that all the alternatives are comparable.

ψ(xi, xj, g) is defined as follows:

$$\psi(x_i, x_j, \mathrm{g}) = \begin{cases} 1 - |\varphi(x_j, \mathrm{g}) - \varphi(x_i, \mathrm{g})|, \varphi(x_j, \mathrm{g}) > \varphi(x_i, \mathrm{g}) \\ 1, \varphi(x_j, \mathrm{g}) < \varphi(x_i, \mathrm{g}) \end{cases} \quad (10)$$

In this formula, φ(xi,g)=min{φkj(xi,g), j=$\overline{1,m}$} and on its basis the matrix of fuzzy preference relations of alternatives for each expert is determined.

On the other hand, the competence of experts evaluating the alternatives (success level of previous learners) differs, and this factor is expressed by the competency coefficient of experts □(g)□[0,1]. Given this and using the following expression

$$\nu(\mathrm{g}_1, \mathrm{g}_2) = \begin{cases} 1 - [\gamma(\mathrm{g}_2) - \gamma(\mathrm{g}_1)], & \gamma(\mathrm{g}_2) \geq \gamma(\mathrm{g}_1) \\ 1, & \gamma(\mathrm{g}_2) \leq \gamma(\mathrm{g}_1) \end{cases} \quad (11)$$

ν:G×G→[0,1] fuzzy competence relations of experts are defined. The quantity ν(g1, g2) is referred to as at which extend the expert g1 is more competent than the expert g2.

The problem is then brought to a rational selection of alternatives out of the set X, taking into account the information described above. For the mentioned g∈G, the fuzzy subset ψn.d.(x,g) of non-preferred alternatives corresponding to the fuzzy preference relationship ψ(xi, xj, g) is determined:

$$\psi^{\text{n.d.}}(\mathrm{x_i}, \mathrm{g}) = 1 \sup_{\mathrm{x_j} \in \mathrm{X}} \left| \psi(\mathrm{x_i}, \mathrm{x_j}, \mathrm{g}) - \psi(\mathrm{x_i}, \mathrm{x_j}, \mathrm{g}) \right| \quad (12)$$

The alternatives giving the highest possible value to the affiliation function ψn.d. (x,g) in the set X coincide with the individual decision of the g-th expert.

Then the fuzzy relations ν(g1,g2) are generalized in the fuzzy subsets of the set G. The following expression for fuzzy relations is used in the set X:

$$\eta(\mathrm{xi, xj}) = \sup_{g_1, g_2 \in G} \min\{\psi\text{n.d. (xi,g1)}, \psi\text{n.d. (xj,g2)}, \nu\text{(g1,g2)}. \quad (13)$$

The obtained fuzzy preference relationship is the result of "gathering" a set of fuzzy relations y(xi,xj,g) into a single final fuzzy preference relationship, taking into account the information on the experts' competence in the subject field. The generalization of preference relationships in the set X allows shifting to the alternatives' selection based on the basis of a single preference relationship, and the set of relevant non-preferred alternatives is determined:

$$\tilde{\eta}^{'n.d.}(x_i) = 1 - \sup_{x_j \in X}\left[\eta(x_j, x_i) - \eta(x_i, x_j)\right]$$

(14)

Finally,

$$\eta^{'.n.d..}(x_i) = min\{\tilde{\eta}^{'.n.d..}(x_i),\ \eta(x_i, x_j)\}$$

(15)

corrected fuzzy set of non-preferred alternatives is determined from the abovementioned expression and more effective alternative is selected according to the function hn.d.(x) with maximum value.

$$\eta^{'.n.d.}(x) = \sup_{x_j \in X} \eta(x_i) \qquad (16)$$

The alternative selected is the final group decision and coincides with one of the individual decisions.

Based on the proposed approach, [18] describes an empirical experiment for obtaining an arranged list of contents by occupation group in the logistics sector and for determining the most priority content.

V. CONCLUSION

The fuzzy situation model presented in the article for assessing the compatibility of supply and demand for professions and specialties can be used as a tool for adequate decision-making in the human resources management in the field of logistics services. Another advantage of the model is the possibility of its implementation in practice.

The proposed method for selecting training materials from open educational resources according to the applicant's needs with the fuzzy multi-criteria group decision-making method allows for more flexible access to content in this field that is more relevant to current knowledge and learning potentials in recruitment, reassignment and self-education stages.

REFERENCES

[1] H. A. Simon, "The stucture off ill structured problems," Artificial İntelligence, vol. 4, no. 3-4, pp. 181-201, 1973.

[2] M. H. Mammadova, Intelligent managenet of the labor market of IT specialists, Baku: "Information Technologies" publishing house, 2019, p. 298.

[3] "RELOG - Consulting and Infrastructure design," https://www.relog.co.za.

[4] "Blokchain. Develop, test and deploy secure blockchain apps," Microsoft Azure Official site, http://azure.microsoft.com/en-us/solutions/blockchain.

[5] N. Khsteri, "Blokckchain's roles in meeting key supply chain management objectives," International Journal of Information Management, vol. 39, pp. 80-89, 2018.

[6] "About SECO tools," https://www.secotools.com/article/54588?language=en.

[7] "National Strategy for the Development of Information Society in the Republic of Azerbaijan for 2014-2020", Order of the President of the Republic of Azerbaijan dated April 2, 2014, http://president.az/articles/11312.

[8] "Strategic Roadmap for Vocational Education and Training in Azerbaijan Republic," http://edu.gov.az/upload/file/serencama-elave/2016/peshe-tehsil-yol-xeritesi.pdf.

[9] "Jobs and Carrier Path in Supply Chain and Logistics," People,Supply,Chain, 19 April 2019. http://www.logisticbreau.com/jobs-and-career-path-in-supply-chain-and-logistics/.

[10] "Empowering logistics," www.elalog.org.

[11] M. Mammadova and F. Mammadzadeh, "Formation of supply and demand for İT Specialists on the base of competency model.," in IV International Conference "Problems of Cybernetics and Informatics" , Baku, 2012.

[12] V. V. Shcherbakov, "Modeling professional educational training of a logistician of digital economy," in Digital Technologies in Logistics and Infrastructure, St. Petersburg, 2019.

[13] M. G. Mammadova, Z. G. Jabrailova and F. R. Mammadzada, "Fuzzy multi-scenario approach to decision-making support in human resource management," Studies in Fuzzines and Soft Computing, vol. 342, pp. 19-36, 2016.

[14] A. N. Melikhov, L. S. Brenstein and S. Y. Korovin, Situational counseling systems with fuzzy logic, Moscow: Nauka, 1990, p. 272.

[15] T. Jurubescu, "Learning Content Management Systems," Informatica Economica Journal, vol. 4, no. 48, pp. 90-94, 2008.

[16] L. A. Zadeh, "Fuzzy logic and approximate reasoning," Synthese, vol. 30, pp. 407-428, 1975.

[17] S. A. Orlovsky, Problems of Decision Making with Fuzzy Initial Information, Moscow: Nauka C. A., 1981, p. 212.

[18] M. Mammadova, "Methods for fuzzy demand assessment for It specialities," EUREKA: Physics and Engineering, vol. 4, pp. 23-33, 2019.

Analysis of the Engine Start-Up Process

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***Abstract*—The article describes, based on the author's own research, four different stages of a diesel engine start-up. In stage 1, the driving mechanisms of the engine are set in motion and there is a systematic increase in the angular velocity of the crankshaft as a result of driving it with a starter. Stage 2 is the rotation of the engine crankshaft with an almost constant angular speed using the starter itself. Stage 3 begins with the first ignition of the combustible mixture and the last stage (stage 4) only covers the occurrence of ignitions of the combustible mixture and results in starting the combustion engine. Then, the duration of the particular stages of the diesel engine start-up was analyzed.**

***Keywords*—engine, process, start-up**

I. Introduction

Successful start-up of a vehicle internal combustion engine is a necessary process in order to achieve its independent operation at idle speed [2,5]. During the independent operation, the engine internally generates mechanical energy by converting the chemical energy contained in the fuel via combustion. This energy enables to overcome all resistances during engine operation [9]. Each start-up process of a vehicle internal combustion engine is accompanied by numerous negative phenomena and processes that influence both the engine itself, as well as its environment. These negative phenomena and processes are particularly visible in the case of starting a diesel engine [3, 5, 11].

During engine start-up, the wear intensity of its tribological pairs increases as a result of insufficient lubrication due to the lubrication system inertia, high viscosity of the lubricating oil (especially at low ambient temperatures) and insufficient relative speed of the moving elements, [4, 10, 16]. Secondly, during the start-up of a diesel engine, insufficient atomization and evaporation of the first doses of fuel result in auto-ignition as well as incomplete combustion of the fuel-rich combustible mixture in engine cylinders [1, 3, 8]. Therefore, an increased emission of toxic components can be observed in the exhaust gases during the start-up [7, 14, 15]. When starting an internal combustion engine, the significant resistance to motion results in the high values of current consumed by the starter in a short time, thus causing sudden overloads in the vehicle electrical system. In addition, malfunctions in other electronic systems of the vehicle may occur due to the corresponding voltage drops at the battery terminals [12, 13].

Hence, special attention must be devoted to the start-up process of a diesel engine. This is shown in the research and published scientific articles on the topic [3,5,11,13]. This paper analyzes the duration of a four-stage transitional process, i.e. the start-up of a vehicle diesel engine. The considerations found in this article result from numerous years of research carried out by the author under the actual vehicle operation conditions [5,6].

II. Start-up stages of a diesel engine

The analysis of the angular velocity of the engine crankshaft and the amperage draw by the starter during the meshing phase of the starter with the flywheel of the crankshaft indicates that the start-up of a diesel engine should be considered as a multi-stage process. On the basis of the author's own research, four different stages of diesel engine start-up were distinguished [5]:

1. **Stage 1**, in which the moving mechanisms of an engine are put into motion and there is a systematic increase in the angular velocity of the crankshaft as a result of driving it with a starter.
2. **Stage 2** constitutes the engine crankshaft rotation at an almost constant angular speed with the help of the starter itself.
3. **Stage 3** is initiated with the first ignition of the combustible mixture. Intermittent operation of the starter as well as irregular combustion of the mixture in the engine cylinders occur in this stage.
4. **Stage 4**, involves only the occurrence of the combustible mixture ignitions and results in the start-up of the combustion engine.

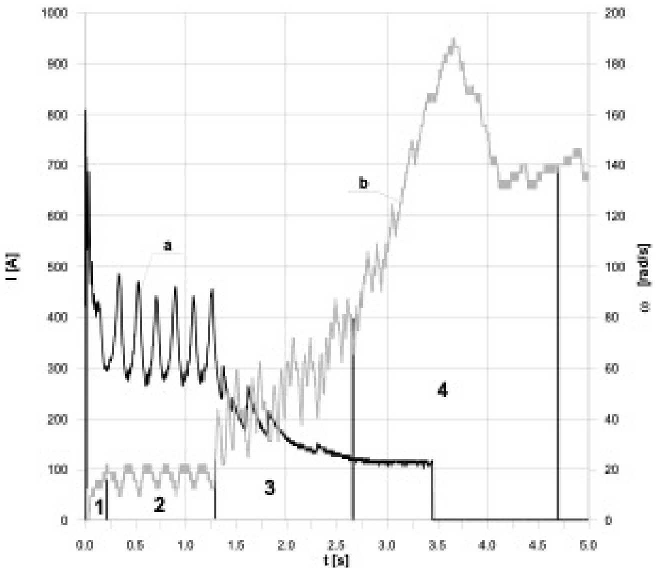

Fig. 1. The course of the angular velocity of the crankshaft and the amperage draw by the starter during the "model" start-up of a vehicle diesel engine with four distinguished stages; a – current intensity, b – angular speed of the crankshaft, 1 – starting stage 1, 2 – starting stage 2, 3 – starting stage 3, 4 – starting stage 4 [5].

In Figure 1, attention should be drawn to a clear increase in the amperage value and a decrease in the angular velocity of the crankshaft when individual cylinders enter the compression stroke. This is due to the moment of resistance to compression of the fuel-air mixture.

It should be noted that under the actual conditions of vehicle use, the situation where a diesel engine is started, e.g. without stage 2, or where a return to stage 2 occurs following stage 3, is possible. Other transitions between the afore-mentioned stages can occur as well. This is discussed in greater detail in [5]. The duration of each of the four distinguished stages of starting a vehicle diesel engine, based on the author's own research, will be analyzed in the further part of this paper [5, 6].

III. Analysis of the Duration of Individual Stages of the Diesel Engine Start-up

During the stage 1 of diesel engine start-up, the moving mechanisms of the engine are put into motion and a systematic increase (see Fig. 1) in the angular velocity values of the crankshaft occurs under the influence of driving it with a starter. The course of changes in the angular velocity during stage 1 depends mainly on the crank mechanism inertia [5].

In line with the author's own research carried out under the actual vehicle operation conditions, it is stated that the average duration of stage 1 of diesel engine start-up is 0.115 s [6]. Figure 2 shows a histogram of the statistical distribution for the duration of stage 1 of engine start-up.

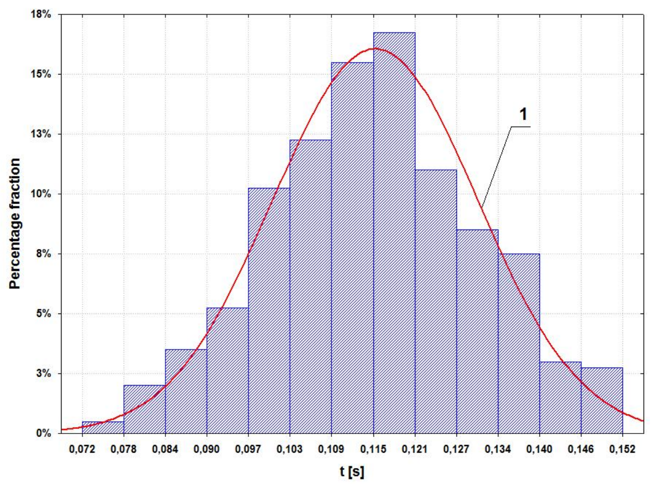

Fig. 2. Histogram reflecting the duration distribution of stage 1 of the 4CT90 diesel engine start-up; normal distribution fit; 1 – normal distribution density function fitted to empirical data [6].

Figure 2 indicates that stage 1 of diesel engine start-up lasts from 0.108 s to 0.121 s in 32.7% of the registered cases. Out of the observed cases, only 5.8% were longer than 0.14 s [6].

In stage 2 of the internal combustion engine start-up, its crankshaft is rotated only with an electric starter at "almost constant" angular speed. This speed depends solely on the state of charge of the batteries [5]. Stage 2 occurs until the first self-ignitions of the air-fuel mixture in the combustion chambers of the diesel engine. This is shown in Figure 1.

The author's own research showed that stage 2 is very short (more than 72% of cases were shorter than 0.2 sec.) or that it did not occur at all (4% of cases) [6]. This is reflected in the histogram shown in Figure 3.

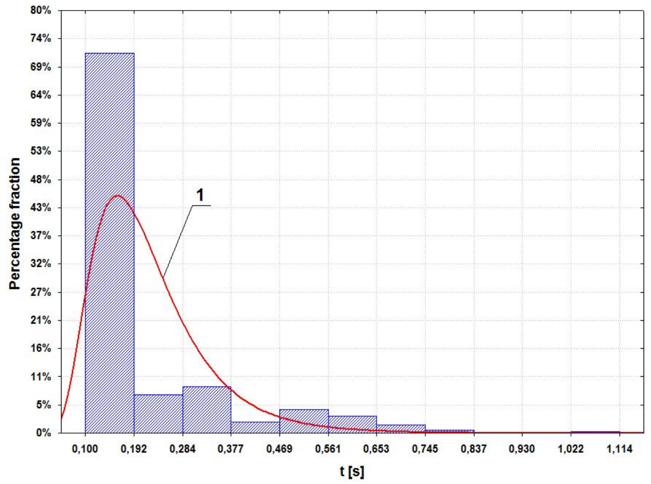

Fig. 3. Histogram reflecting the duration distribution of stage 2 the 4CT90 diesel engine start-up; 1 - log-normal distribution density function fitted to empirical data with threshold: 0.000, scale parameter: -1.6180, and shape parameter: 0.4601 [6].

Figure 3 shows that the average duration of the start-up stage 2 during which the crankshaft is driven by the starter only, amounted to 0.225 s. Stage 2 was shorter than 0.178 s in 67.3% of registered cases. In most cases (99.7%), stage 2 took up to 1 s [6].

Stage 3 of the diesel engine start-up is initiated with the first self-ignition of the combustible mixture in the combustion chamber of an engine. This stage is characterized by the intermittent starter operation as well as irregular combustion of the fuel-air mixture in the engine cylinders (see fig. 1).

It should be mentioned that in the course the actual vehicle internal combustion engine usage, in the vast majority of starts (almost 84%) there is no stage 3. However, there are also start-ups in which the engine crankshaft is driven again with the starter itself following the occurrence of stage 3, that is, there is a return to stage 2. In the tested engine, such starts accounted for about 1% [6].

In the research conducted by the author, the average duration of stage 3 amounted to 0.137 s, which is shown by the histogram of the statistical distribution of stage 3 duration (see Figure 4). It can be seen that the duration of stage 3 of the start-up was within the range of 0.095 s up to 0.13 s in 58.2% of registered cases [4].

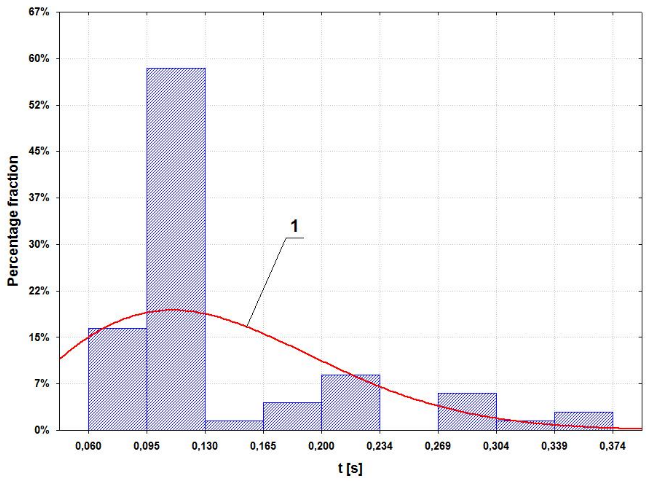

Fig. 4. Histogram reflecting the duration distribution of stage 3 of the 4CT90 diesel engine start-up; 1 – Rayleigh distribution density function fitted to empirical data with threshold parameter: 0.000, and scale parameter: 0.1097 [6].

Finally, in stage 4 (see fig. 1) there is only self-ignition of the fuel-air mixture and the start-up process is about to finish. Figure 5 shows a histogram of the statistical distribution of the stage 4 duration. Figure 5 shows that the stage 4 of the diesel engine start-up lasted from 0.683 s to 0.886 s in 29.3% of registered cases. The start-ups of the internal combustion engine in which the stage 4 lasted up to 1 s in 65.1% of cases. The mean duration of stage 4 of the start-up equaled 0.958 s [6].

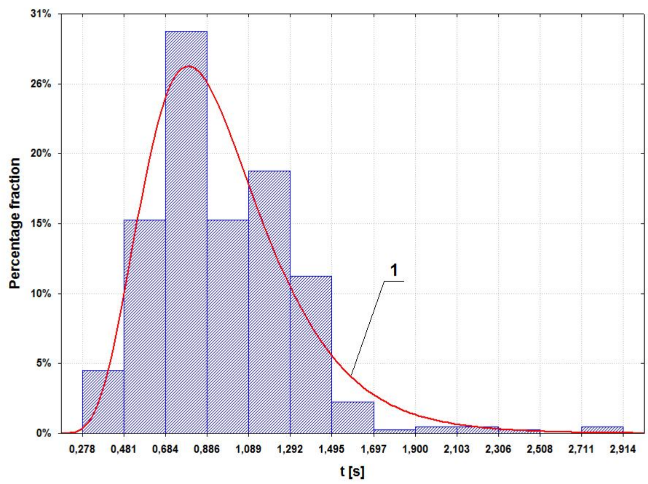

Fig. 5. Histogram reflecting the duration distribution of stage 4 of the 4CT90 diesel engine start-up; 1 – log-normal distribution density function fitted to empirical data with threshold parameter: 0.000, scale parameter: -0.1053, and shape parameter: 0.3574 [5].

It should be mentioned that the start-up time of a vehicle diesel engine is the total duration of each of its four stages combined. In the conducted tests, the average value of the combustion engine start-up time amounted to 1.139 s. Nearly 29% of the registered diesel engine start-up times did not exceed 1 s, and 73.8% lasted up to 1.5 s (see Figure 6) [6].

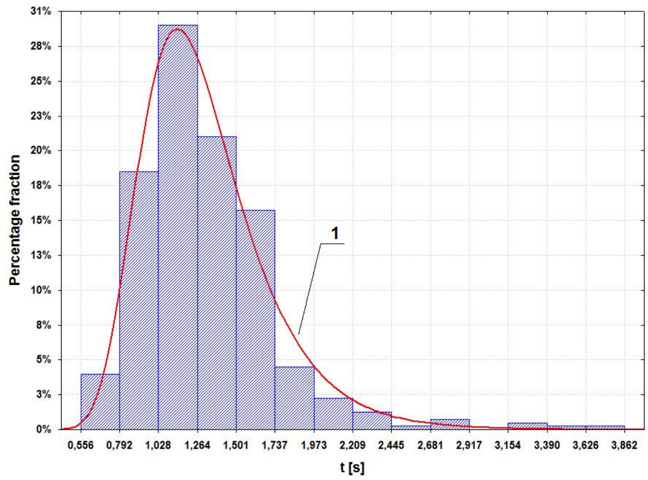

Fig. 6. Histogram reflecting the 4CT90 diesel engine start-up time; 1 – extreme value distribution density function adjusted to empirical data with position parameter: 1.1391 and scale parameter: 0.2971 [6].

When comparing the duration of individual stages of the diesel engine start-up, it can be stated that the main factor that determines the starting time is the stage 4 duration. This is shown in Figure 7, where the scatter plot between the duration of stage 4 and the internal combustion engine start-up time is presented, with the confidence intervals for the forecasted mean observation and prediction calculated with the assumption of compliance with the normal distribution at the confidence level of 95%.

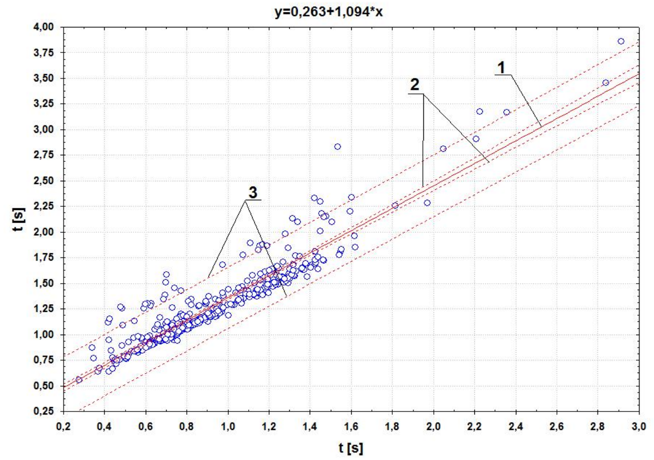

Fig. 7. The scatter plot for the duration of the stage 4 and the 4CT90 diesel engine start-up (y axis); 1 – regression line, 2 – confidence interval for the predicted mean observation, 3 – confidence interval for the predicted observation (prediction interval).

There is a very high correlation between the stage 4 duration and the start-up time of the internal combustion engine. The linear correlation coefficient between these variables is equal to r = 0.9313, proving a very strong relationship between the analyzed times.

IV. Conclusions

The paper, which summarizes the multiannual research conducted by the author under the actual operating conditions of a diesel vehicle engine describes four consecutive stages of its start-up. The presence of these stages results from the occurrence of complex phenomena and processes during the start-up. The analysis of the obtained and presented test results clearly indicates that the duration of the combustion engine start-up is determined by the duration of stage 4.

References

[1] K. F. Abramek, "Ocena wpływ paliwa w początkowej fazie rozruchu silnika na intensywność przedmuchów gazów do skrzyni korbowej," Zeszyty Naukowe WSOWL. Nr 4(174), 2014, pp. 98–103. [in Polish].

[2] P. Bera, "Development of Engine Efficiency Characteristic in Dynamic Working States. Energies, vol. 12(15), pp. 2906, 2019.

[3] J. Caban, "Wpływ parametrów wtrysku paliwa na przebieg procesu rozruchu silnika o zapłonie samoczynnym," Doctoral thesis, Politechnika Lubelska. Lublin, 2018. [in Polish].

[4] A.Datoo, M. F. Fox, "An initial investigation of the lubricant condition in the automotive ring zone under cold start conditions," Editors Dowson D. and others. Tribological research and design for engineering systems. Tribology series 41, Elsevier, 2003. pp. 517-523.

[5] P. Droździel, "Widmo rozruchu silnika o zapłonie samoczynnym jako kryterium oceny warunków użytkowania samochodu," PNTTE. Warszawa, 2009. [in Polish].

[6] P. Droździel, L. Krzywonos, Š. Liščák, "Selected aspects of diesel engines start-ups," Wydawnictwo-Drukarnia Liber Duo. Lublin, 2013.

[7] J. Gao, G.Tian, A. Sorniotti, A. E. Karci, R. Di Palo, "Review of Thermal Management of Catalytic Converters to Decrease Engine Emissions during Cold Start and Warm Up," Applied Thermal Engineering, vol. 147, 2019, pp. 177–187.

[8] B. Giechaskiel, A. Alessandro, A.A. Zardini, M. Clairotte, "Exhaust Gas Condensation during Engine Cold Start and Application of the Dry-Wet Correction Factor, " Applied Sciences. Vol. 9, no. 11, 2019, pp. 1-15.

[9] J. B. Heywood, "Internal combustion engine fundamentals 2E," McGraw-Hill Education, 2018.

[10] M. F. Jensen, J. Bottiger, H. H. Reitz, M. E. Benzon, "Simulation of wear characteristics of engine cylinder," WEAR. No. 253, 2002, pp. 1044-1056.

[11] J. Mysłowski, "Rozruch silników samochodowych z zapłonem samoczynnym," WNT. Warszawa, 1996. [in Polish].

[12] J. Pszczółkowski, "Analiza i modelowanie procesu rozruchu silników o zapłonie samoczynnym," Redakcja Wydawnictw WAT. Warszawa, 2009. [in Polish].

[13] J. Pszczółkowski, "Badanie charakterystyk rozrusznika elektrycznego," Autobusy, vol. 6/2019, pp. 240-247. [in Polish].

[14] A. S. Ramadhas, H. Xu, D. Liu, J. Tian, "Reducing Cold Start Emissions from Automotive Diesel Engine at Cold Ambient Temperatures," Aerosol and Air Quality Research. No. 16, 2016, pp. 3330–3337.

[15] R. Suarez-Bertoa, C. Astorga C, "Impact of Cold Temperature on Euro 6 Passenger Car Emissions," Environmental Pollutio, vol. 234, 2018, p. 318–329.

[16] T. A. Tran, "Some methods to prevent the wear of piston-cylinder when using low sulphur fuel oil (LSFO) for all ships sailing on emission control areas (ECAs),"Diesel and Gasoline Engines, 2020.

Cases of the Commercial Aircraft Forced Landing Caused by Procedural and Military Means as a Factor Affecting Air Transport Safety

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***Abstract*—Commercial aviation covers the entire world. Therefore, there are situations where it operates in regions threatened by armed or political conflicts and is drawn into the international game of influence and pressure between states and non-state entities. Commercial planes have been shot down, both as a result of mistakes and deliberate actions. In this article, however, the focus will be on the possibility of forcing a commercial aircraft to reroute or land by legal, political and physical means.**

Keywords—commercial aviation, transport security, FR 4978, SP-RSM, Belarus, air traffic

I. Introduction

International Civil Air Traffic Regulations published by International Civil Aviation Organization (ICAO) provide the possibility of interception of civil aircraft by military aircraft, provided that several conditions are met [8]. First of all, an interception may occur if a civilian aircraft does not maintain two-way radio communication on a frequency determined by ATC air traffic control services, does not respond to calls, and when a civilian aircraft enters the airspace without express or implied consent. This may be related to the unauthorized crossing of a state border, as well as the boundary of a restricted area (e.g. entry ban) within a given state. Interception of civil aircraft should only be used as a last resort. ICAO also states that practice interception of civil aircraft should not be performed (ICAO Appendix 2, p. ATT-A1). Practicing such exercises would cause difficulties in air traffic control (problems with ensuring separation between intercepting military ships and civilian traffic), and could also arouse fear among passengers who would unexpectedly see a military plane outside the window in the immediate vicinity. Such practices have occurred in the past. For example, Tornado ADV fighters belonging to the British RAF air force sometimes tried to intercept Concorde supersonic airliners over the ocean, which by the way turned out to be very difficult [9].

The ICAO regulations also detail differences in interception procedures taking place in visual and non-visibility, i.e., instrument flight rules (IFR) flight conditions.

II. Procedures for interception of civil aircraft by military aircraft in VMC (Visual Meteorological Conditions)

In a situation where two military aircraft are involved in the interception, the first of them (the leading one) approaches the intercepted civilian aircraft, and the second military aircraft takes an observation position at some distance.

In Phase I, one of the military ships approaches the intercepted object from behind for the distance needed to identify the current state of the intercepted machine. ICAO states: *The intercepting aircraft should approach the intercepted aircraft from astern. The element leader, or the single intercepting aircraft, should normally take up a position on the left (port) side, slightly above and ahead of the intercepted aircraft, within the field of view of the pilot of the intercepted aircraft, and initially not closer to the aircraft than 300 m* (ICAO Annex 2, ATT A-2, 3.3).

W It is assumed that if military machines do not have ICAO compliant transponders turned on, they may fly in such a way that they can be noticed by passengers. ICAO even recommends disabling transponders, namely transmitting barometric altitude information (in Mode C responses or in Mode S responses in the AC field) at a distance of at least 37 km (20 NM) from the intercepted aircraft. The operation of the transponder at shorter distances could activate the ACAS / TCAS on-board anti-collision system in the intercepted aircraft (ICAO Annex 2, APP 2-1).

Pilots in the cabin of a typical commercial aircraft have very little possibility of seeing such an external object visually. The interceptor should maneuver calmly in order not to panic the passengers. The military interceptor which is on front position should be positioned slightly ahead, higher and to the left of the intercepted commercial aircraft. ICAO also states: *It is indispensable that the pilot-in-command of the intercepting aircraft be satisfied that the pilot-in-command of the intercepted aircraft is aware of the interception and acknowledges the signals given. If repeated attempts to attract the attention of the pilot-in-command of the intercepted aircraft by use of the Series 1 signal in Appendix 1, Section 2, are unsuccessful,* ***other methods of signalling may be used for this purpose, including as a last resort the visual effect of the reheat/afterburner, provided that no hazard is created for the intercepted aircraft*** (bold - J.M.; ICAO Annex 2, APP 2-1, 3.4.2).

The use of a warning fire with a cannon is therefore not recommended, although the above provision does not explicitly prohibit it. It is worth noting that the above record was made several months before the Korean Boeing 747 (flight number KAL 007) was shot down over Sakhalin by the Soviet Su-15 fighter. In addition, a few years earlier - on April 20, 1978, another South Korean plane, Boeing 707 (flight number KAL 902) was shot down by a Soviet Su-15 near Murmansk - this time, however, Boeing managed to land in the field, because it was hit by the light R-60 (AA-8) missile. There were also other similar incidents around the world, which undoubtedly influenced the above-mentioned ICAO record.

In phase II *The element leader, or the single intercepting aircraft, should begin closing in gently on the intercepted aircraft, at the same level, until no closer than absolutely necessary to obtain the information needed. The element leader, or the single intercepting aircraft, should use caution to avoid startling the flight crew or the passengers of the intercepted aircraft, keeping constantly in mind the fact that manoeuvres considered normal to an intercepting aircraft may be considered hazardous to passengers and crews of civil aircraft. Any other participating aircraft should continue to stay well clear of the intercepted aircraft. Upon completion of identification, the intercepting aircraft should withdraw from the vicinity of the intercepted aircraft as outlined in Phase III* (ICAO Annex 2, APP 2-1, 3.3).

It then moves on to Phase III, which is described by ICAO as follows: *The element leader, or the single intercepting aircraft, should break gently away from the intercepted aircraft in a shallow dive. Any other participating aircraft should stay well clear of the intercepted aircraft and rejoin their leader* (ICAO Annex 2, APP 2-1, 3.3).

III. Intercept without visibility (IMC - IFR Meteorological Conditions)

In such a situation, it is assumed that the intercepting machine will be within the radar range behind the intercepted aircraft and will maintain safe separation (also vertical). In both cases, the crew of the intercepted aircraft should follow ICAO rules, read the signals sent by the intercepting aircraft and respond accordingly. The crew of a commercial aircraft should notify the appropriate ATC air traffic control unit and attempt to establish radio communication on the 243.0 MHz or 121.5 MHz danger frequency, specifying the code (callsign), registration marks, aircraft location and type of the flight.

The crew of the commercial aircraft should set the mod A Squawk 7700 emergency code on the transponder, unless otherwise instructed. If the aircraft is equipped with an ADS-B or ADS-C device, it shall select the appropriate distress function, if available, unless otherwise instructed by the air traffic services unit. If instructions received from air traffic services conflict with those received from the intercepting aircraft crews, they should try to explain this but still follow the instructions received from the intercepting military aircraft.

It is worth noting that the crew of an intercepted commercial aircraft should adjust the speed to the needs of the intercepting fighters. For example, turboprop airplanes, in the event of interception by jets, should maintain IAS speed above 200 kt, in order not to cause problems for jets in maintaining position in formation. Bringing military machines to an intercepted commercial aircraft also requires special actions from the Air Traffic Control (including separation from other air traffic) and special attention.

IV. Other methods of influencing the flight course of a commercial aircraft

By law, the commander of the commercial aircraft is its captain, who makes the final decisions. In some situations, however, the captain may be forced by external factors to change the planned course of the flight. This article focuses on factors related to national and international security issues. Such factors include various acts of unlawful interference (kidnappings or threats on a criminal or terrorist-political basis) and the dissemination of information that may disrupt the course of the flight (e.g. a phone call about a bomb on the plane or at the airport - it is worth noting that such telephone information about the alleged bomb at Gran Canaria airport made it necessary to divert many planes to Tenerife airport on March 27, 1977, where two Boeing 747s collided as a result of the disturbance caused by this, killing 583 people in total).

A commercial airplane is an attractive target for various types of activities that threaten security due to the high media coverage of such events and the possibility of intercepting certain people or property. In addition to the possibility of shooting, one of the options for interfering with the course of a commercial aircraft flight is forcing its crew to change the flight route and land in a place other than planned. It is quite a difficult and complex undertaking and often requires far-reaching actions of military and intelligence services, but such situations have already taken place several times.

V. Cases of forcing a commercial airplane to land by military aircraft in the 20th century

For example, on August 10, 1973, the Caravelle passenger plane used by Lebanese Middle East Airlines (MEA) shortly after taking off from Beirut was intercepted by Israeli Mirage III Shahak fighters and forced to land at Lod Airport in Israel. Israel suspected that there were terrorists on board responsible for the attack at the Athens airport on August 5, 1973. These suspicions did not materialize, so the plane was released. Lebanon filed a complaint with the United Nations condemning this Israeli action. There were suspicions in the press that Israeli fighters mistakenly intercepted the MEA 006A flight, instead of the MEA 006, which took off with some delay. Both flights were due to end in Baghdad. It was the MEA 006A flight with a Caravelle plane chartered to Iraqi airlines that was intercepted near Beirut and forced to land at an Israeli military airport [11].

A similar event occurred on February 4, 1986, when Israeli fighters intercepted a private Libyan Gulfstream II (LN777) near Cyprus and forced it to land in Israel. There were concerns that Palestinian terrorists were on board. No wanted person was found there, so after a few hours the plane was released and flew to Damascus [4].

The most spectacular incident took place a few months earlier, on the night of October 10-11, 1985, when American F-14 Tomcat fighters forced an Egyptian Boeing 7378 to land in Italy. We briefly present here the history of the events that led to the incident [7].

On September 25, 1985, Palestinian terrorists abducted and murdered three Israeli tourists traveling on a yacht near Cyprus. This was probably retaliation for the recent arrest by the Israeli services of one of the leaders of the Palestinian Liberation Organization (PLO). In turn, for the murder of the mentioned tourists, Israeli F-15s bombed the PLO headquarters in Tunisia. In retaliation for this act, PLO members pretending to be tourists boarded the Italian liner ship Achille Lauro on October 3, on which they planned to travel to Ashdod, Israel, to attack refineries or military facilities. However, the plot was uncovered, which forced the terrorists to change their plans. They decided to hijack a ship and order the release of 50 Palestinians from Israeli prisons. This was not fulfilled, so the hijackers did shot the American tourist. On October 9, the hijackers left the ship.

The spectacular murder of an American citizen caused American public outrage and a quick reaction from the US authorities. At that time, the American aircraft carrier USS Saratoga (CV 60) was in the Adriatic Sea and was heading towards Dubrovnik, where it was to pay a courtesy visit. As a result of the hijacking of an Italian ship, Saratoga changed course and began preparations for combat action. F-14 fighters equipped with TARP reconnaissance pods took off from its deck, whose task was to find and observe Achille Lauro. This material was to be used during the planned rehashing of the ship by commandos, but the action was canceled because the ship had anchored in Port Said, Egypt.

The next day, Israeli intelligence notified the US side that the four hijackers were at Al Maza Airport near Cairo and were likely to fly to Tunisia. It was agreed that they would fly over Mediterranean Sea, as Egypt did not have very good relations with Chad and Libya at that time. Then Admiral James Stark of the US Navy proposed that the fighters can intercept an Egyptian plane and force it to land in Sicily. This idea was accepted by President Reagan.

On the USS Saratoga, 9 F-14 were planned for this purpose and received signal tracer ammunition for the cannons, as you can see in this case, cannons were envisaged to intimidate Egyptian pilots. The cannon bullets were to be clearly visible from the Boeing cockpit. The operation was secured by E-2 early warning aircraft, two flying tankers and radio-electronic warfare aircraft. There were also next 3 F-14 and 2 E-2 kept in the reserve.

Fig. 1. Boeing 737 SU-AYK of the EgyptAir airlines [28]

In the meantime, Israeli services have established all the data on the Egyptian aircraft - type, condition and registration marks. It was Boeing 737-266 with registration SU-AYK of EgyptAir airlines.

E-2 crews searched by the radar all planes traveling from Egypt to Tunisia, but they could not identify precisely detected targets. It was difficult to say whether the Boeing was flying with the transponder turned off, or whether the state of the art at the time did not allow reading transponder signals from a long distance. In order to identify them, the F-14 fighters approached each of the detected objects and made a final visual verification. It must be admitted that such activities are not in line with the international regulations of general air traffic (GAT - General Air Traffic), which is strictly separated from operational traffic (OAT - Operational Air Traffic, which is mainly military). Undoubtedly, the permissible minima for vertical and horizontal separation, as described in the ICAO Doc. 444 Air Traffic Management manual were exceeded there. The F-14 fighters had their lighting turned off and possibly their transponders were turned off also (or possibly broadcasting only a signal on secret military IFF frequencies received only by US military systems). F-14s flew up to each plane and judged in the light of the stars whether a given silhouette resembled a Boeing 737. If so, they did fly closer to read the markings. In the meantime, the F-14s intercepted e.g. two large light-turned-off planes that turned out to be American C-141 from USAF carrying commandos from Cyprus to Sigonella base in Sicily, where they would take part in the seizure of the Egyptian Boeing. Around 11 p.m., the wanted Boeing 737 SU-AYK was found. After consultations with the air traffic services, ATC controllers at Tunis and Athens airports refused permission to land for that Egyptian airplane.

A radar controller on an American E-2 plane radioed to the crew of the Egyptian Boeing and ordered a landing at the Sigonella base in Sicily. When the Egyptians refused, the nearby F-14 fighters turned on the lights, which was noticed by the Egyptian crew. From then on, the Egyptians began to carry out the orders of the Americans and headed towards Sicily. However, Italian ATC services refused to allow entry, explaining this because of the lack of a filled flight plan. Filing a flight plan by radio takes only a few minutes, but the Americans decided to use an effective ruse. One of the F-14s reported an emergency and asked for an immediate landing in Sigonella, which the Italians had to agree to according to the regulations. Thus, the Egyptian Boeing approached at Sigonella Airport in the presence of an F-14, and landed there on October 11, 1985 at around 00.45. The American fighters returned to the carrier.

Shortly after the Egyptian Boeing, two American C-141 transport aircraft with around 80 commandos also landed at Sigonalla. American commandos surrounded the Egyptian plane, but in the meantime the Americans were surrounded by several hundred Italian soldiers. The commander of the American commandos then estimated that a possible fight with the Italian guard would not be without deaths, and that the removal of the Palestinian hijackers without cooperation with Italy was unlikely. No fight took place.

The Americans showed great determination to kidnap terrorists who killed US citizen, going so far as to violate ICAO's international aviation regulations and the inviolability of Italian airspace and territory. The government of the Italian Republic was, of course, furious and demanded that, since such an incident had already taken place, the Italian side should play the role of the superior, and terrorists should be brought to an Italian court. The case was very complicated, as it also involved the hijacking of an Italian-flagged ship in the territorial sea of Egypt and the murder of a US citizen by Palestinian citizens from Lebanon. In the end, international opinion agreed that Italy was right and the captured terrorists were imprisoned there. One of the people suspected of being involved in the attack on Italian ship Abu Abbas was released because he had a diplomatic passport and Egypt had confirmed its credibility. Ultimately, the Egyptian Boeing was allowed to fly to Rome with Abbas on board. Probably Rome was the only destination for which the Egyptians were allowed to depart. To prevent Boeing from flying back to Egypt, SU-AYK was accompanied by an American T-39 aircraft that took off from a parallel runway without ATC permission. The T-39 accompanied the Egyptians until their approach to landing at Rome's Ciampino airport. When the ATC service of this airport denied the American T-39 the clearance to land, the Americans once again used a trick to report the emergency and finally landed in Ciampino.

Abu Abbas then flew to Yugoslavia on board that country's JAT national airlines. The authorities in Belgrade have released Abbas free despite US protests. Later, the Italian sentenced him in absentia to life imprisonment for steering the hijack of a ship. The Americans captured him many years later in 2003 in Baghdad. The remaining hijackers were sentenced by the Italian court to many years in prison.

US actions in this incident sparked lively discussions around the world. In many cases, they were considered illegal but morally justified. The international opinion has generally acknowledged that the fight against organized terrorism requires special methods, even if in some cases they are meant to violate certain civilized laws. Interestingly, the Americans were given some support in this case by the USSR, whose authorities described their behavior as understandable and justifiable. The Soviets added, however, that the Americans were also hypocritical, since they themselves refused to hand over two Lithuanians to the Soviet authorities, who in 1970 hijacked an Aeroflot plane to the West, killing a flight attendant [7].

VI. Ryanair Flight on May 23, 2021

In May 2021, there was a precedent, politically motivated incident that met with great attention from the media and air safety specialists [1]. On May 23, the Boeing 737-8AS aircraft with Polish registration SP-RSM belonging to the Irish-Polish Ryanair Sun airlines made a scheduled flight FR 4987 from Athens (ICAO LGAV code) to Vilnius (EYVI). Polish company Ryanair Sun S.A. is part of the Irish group Ryanair Ltd. The headquarters of Ryanair Sun is in Warsaw at Cybernetyki 21 street. These lines are also known as Buzz [19]. Ryanair Sun S.A. lines (Buzz) have their IATA code RR for assigning flight numbers, but they often use the FR code assigned generally to the Irish group Ryanair Ltd. (hence the flight number FR 4987). Wikipedia says that the Polish airline Ryanair Sun S.A. (Buzz) owns 47 Boeing 737-800s, and a further 19 are on order [18]. Probably all of them (or most of them) are in the Polish Register of Civil Aircraft kept by the Civil Aviation Authority (CAA) in Warsaw, so they have registrations starting with the letters SP.

Fig. 2. Boeing 737 SP-RSM of the Ryanair Sun airlines [18]

Boeing 737-800 (8AS) number MSN 44791 and LN 6418 was entered into the Polish register in November 2019, where it received the marks SP-RSM. Earlier, from delivery to Ryanair Ltd. in May 2017, it wore the Irish EI-FZX registration [6, 24].

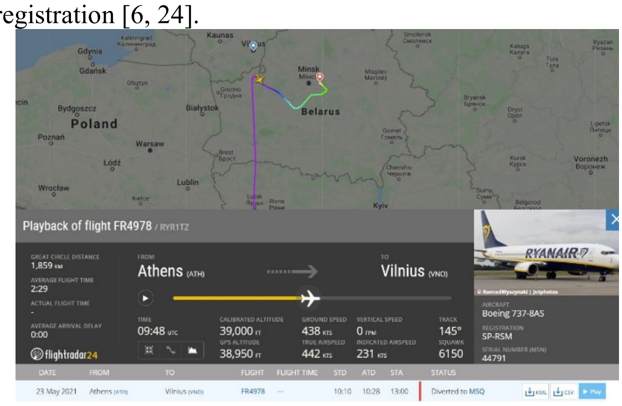

Fig. 3. Track of the FR 4987 flight on May 23, 2021 taken from Flightradar24 site [29]

There were 126 passengers and 6 flight and cabin crew members on board the Boeing during FR 4987 flight. One of the passengers was the Belarusian opposition activist Roman Protasiewicz and his partner Sofia Sapiega from Russia, who were returning from holidays in Greece. The take-off of the SP-RSM aircraft took place from the Athens-Eleftherios Venizelos airport (ICAO code LGAV) at 10:29 local time, with a delay of approximately 19 minutes. Landing in Vilnius was planned for 1:00 p.m. local time. Take-off, flight and scheduled landing times are based on UTC + 3 h (Eastern European Summer Time - EEST) in Greece, Ukraine and Lithuania. In May 2021, it was the same as the Moscow time in Belarus.

After about two hours of flight, crew of the Boeing was contacted by the Belarusian ATC area control service, informing that there was a bomb on the plane. At 12.45 LOC, while the Boeing was 45 nautical miles (83 km) from the Vilnius airport, the crew, following instructions from the Belarusian ATC, began a course change to approach Minsk airport (ICAO code UMMS). Boeing pilots set the emergency code 7700 on the transponder. According to some sources, the Boeing was supposed to be intercepted by the Belarusian MiG-29BM fighter from the 61st Fighter Air Base in Baranavichy, but this was not noticed on board the Boeing and there is no clear information on this. In the author's opinion, there are two possibilities in this regard: the fighter could not take off at all (although the MiGs in Baranavichy could be put in an emergency), or the MiG (or MiGs) took off, but was turned back so as not to exacerbate the situation. The Belarusian authorities could have realized that, in accordance with the ICAO regulations (cited earlier in this article), the interception of a commercial plane by a military aircraft can only legally occur if the crew of a civil aircraft does not maintain constant radio communication and does not respond to ATC commands. Meanwhile, the crew of the Ryanair plane was in constant contact with the Belarusian ATC and did not refuse to follow their instructions. Sending a fighter in such a situation could therefore be perceived as an infringement of powers and an act of air piracy on the part of Belarus. The more so because in this country there has already been an outrageous incident, when on September 12, 1995, the Belarusian military helicopter Mi-24 shot down a balloon of the US Virgin Islands representation near the Polish border, which took part in international competitions (XXXIX Gordon Bennett Cup). There is a possibility that the crew of the downed balloon did not contact the air traffic control of Belarus before and did not respond to their calls due to loss of consciousness by oxygen deficiency. In addition, the Belarusians forced to land also two other American balloons participating in the competition.

It cannot be ruled out that perhaps the Belarusian MiG-29 was in the vicinity of the Boeing, but it had the transponder turned off (or it did not emit an ICAO-compliant signal; it might also have no ICAO transponder at all) and did not take any final actions (or not that, which were noticed by anyone aboard the Boeing, which would be unlikely).

Data from the Flightradar24 website indicate that at the time of the alert, Boeing was about twice as close to Vilnius (about 80 km) than to Minsk. Even in Belarus it was closer to the airports in Grodno and Lida. However, the crew decided not to fly into Lithuanian airspace, because information was received that terrorists wanted to detonate a bomb over Vilnius. Belarusian President Lukashenka later announced that the alleged bomb could also threaten the Belarusian nuclear power plant, and only Minsk airport accepted the plane to land. He also added that airports in Warsaw, Lviv and Kiev refused to accept the plane. The authorities of Warsaw-Okęcie airport, however, claim that they did not receive any questions regarding the acceptance of flight FR 4978 [6]. The records of Flightrad24 also show that the crew did not start the approach to the airport in Vilnius at all, and when they were in the place where the procedure should begin and where the plane should descend, the level flight was continued at the same altitude - possibly an exchange of correspondence with the Belarusian area control service was taking place at that time [1]. Due to official Belarusian sources, the terrorists allegedly were members of the radical Palestinian group Hamas, and their attack was allegedly directed against participants of the Delphi Economic Forum in Greece who support Israel [6]. It is unlikely, however. Maciej Lasek, the former head of the Polish State Commission for Aircraft Accident Investigation, said that the pilots had no possibility of opposition, and theoretically there was also a possibility of shooting down a Boeing SP-RSM in case if pilots refused to carry out the orders of the Belarusian services, although it was unlikely [27].

The Boeing SP-RSM landed in Minsk at 13.21 LOC. They took off for the further flight to Vilnius at 20.47 LOC after an intensive exchange of correspondence on the part of the Lithuanian diplomatic services and the representative for foreign affairs of the European Union. The Boeing SP-RSM landed in Vilnius forty minutes later at 21:27 UTC. However, 6 passengers did not board the plane - Roman Protasiewicz, his partner Sofia Sapiega and 4 Russian citizens (according to some sources, 1 Belarusian and 3 Russians; there are also information that only 3 people remained in Minsk, including a Greek citizen who intended to get to Minsk by Vilnius [6]), who, according to official information, refused to continue the flight because they intended to get to Minsk via Vilnius anyway. However, it cannot be ruled out that they could have been officers of the special services of Russia and Belarus, the more so as direct flights from Athens to Minsk are offered by several airlines and they did not have to make this trip with a change in Vilnius. The Russian and Belarusian services somehow determined which plane Protasiewicz would travel with - they probably had to hack into Ryanair's online ticketing system and / or have Greek airports under surveillance from which he could take off. No bomb or any other hazardous material was found aboard the Boeing.

There is no doubt that the false information about the bomb was only a pretext for the capture of Protasiewicz, which was very important to the authorities of Russia and Belarus. Protasewicz himself is described in these countries in a completely different way than in European Union and USA. Western and opposition media describe him as a fighter for freedom and human rights, while in the official Russian and Belarusian media he is portrayed as a trickster and terrorist involved in alleged criminal activities in eastern Ukraine [6].

The incident related to the flight FR 4978, which took place on May 23, 2021, caused the international community to raise several important safety and legal questions [1]:

- Was there a potential threat to passengers and crew?
- Was there actually a bomb on board?
- Did the plane have to land in Minsk?
- Was fighter airplane sent to intercept Boeing, and if so, was that action justified?
- What are the legal consequences of this incident?

The answers to some of the above questions can be found in the earlier part of this article. It is also worth referring to the legal issues of this event. Belarus is a member of the International Civil Aviation Organization ICAO, which in turn operates on behalf of the United Nations. This means that the country declares that it complies with the standards laid down by ICAO and the United Nations, and feels responsible for any cases of non-compliance with them in its own territory.

In legal terms, the flight of the Boeing SP-RSM took place based on several collective international agreements called aviation freedoms, which regulate what rights an aircraft registered in another country has over the territory of a given state. A description of aviation freedoms can be found on the ICAO website [21]. Flight FR 4978 did use the first and seventh freedom during the flight over Belarus. The first freedom is the right to fly over the territory of a third country without landing, and the seventh freedom is the privilege of carrying passengers and cargo between the territories of two different countries by aircraft registered in a third country, without landing in a third country. Aviation freedoms for non-EU countries are granted through bilateral agreements between states. Boeing of the FR 4987 flight had Polish registration SP-RSM, so the parties to the bilateral agreement in this case were Poland and Belarus. It is the Agreement between the Government of the Republic of Poland and the Government of the Republic of Belarus on civil aviation, signed in Warsaw on June 8, 1993. This agreement was issued in 1993, entered into force in 1996, but surprisingly, it was announced very late, on 23 September 2020 [18].

Under the ICAO regulations, did the Belarusian authorities have the right to strain the provisions of this agreement? Pursuant to Article 1 of the Chicago Convention (ICAO), each state has complete and exclusive sovereignty in the airspace over its territory (this is established by the so-called sovereignty principle). The rule is that every state has the right to refuse to fly foreign aircraft if it is required for safety reasons. This is mentioned, among others, by article 4 of the said bilateral agreement between Poland and Belarus. Each state also has the right to make the passage of foreign aircraft over its territory subject to the specific rules it establishes. Each state also has the right to impose coercive measures against aircraft that do not comply with the instructions of the air traffic services (as long as they comply with ICAO regulations).

The fact is that flight FR 4987 posed no threat, considering that the alarm about the alleged bomb on board was just a lie created by the special services of Russia and Belarus in order to catch an oppositionist. If international services manage to prove such a thesis, it would also prove that Belarus broke the ICAO regulations and by spreading false information about the bomb, it created a dangerous situation in air traffic. It would also be a breach of the Convention for the Montreal Convention 1999. According to the media, violations of ICAO rules by Belarus should be considered very likely [25].

However, no complete information on a possible bomb on board FR 4987 is known. It has only been made known in general that extremist terrorist groups, possibly Hamas, are responsible. However, neither of them admits to this act. Initially, the crew received information from the Belarusian ATC that the bomb threat had been received from the Belarusian secret services, then it was announced that the source of the information were e-mails sent to several airports. There are also reports that such an e-mail was sent to the Minsk airport service mailbox several minutes after the Belarusian ATC informed the Boeing crew about the alleged bomb on board. In such a situation, the Belarusian authorities should immediately notify the Lithuanian authorities of the potential threat [1]. It is not known whether such correspondence has been established.

A separate issue is that from a formal point of view, the deck of an aircraft is an extra-territorial area of the state of registration of a given aircraft. Boeing flying FR 4978 has the Polish registration SP-RSM, so legally, its board belongs to the territory of Poland. If, therefore, officers of the Belarusian services (or any other) entered the plane, it would mean that they formally entered the territory of the Republic of Poland by force. However, according to reports that we have received, this did not happen, as all people on board left the plane voluntarily after receiving information about the bomb. Of course, an open question can be asked, whether forcing someone to leave the territory of a given state that protects them by a stratagem is not an abuse of authority and a crime? The matter is even more complicated as it was supposed to be an intra-EU flight, only a certain part of which was to go over an external countries, included Belarus.

The incident related to the flight of FR 4978 may set a dangerous precedent and tempt similar actions in the future around the world. At present, the matter is being dealt with by the legal bodies of the European Union and the case will undoubtedly have various consequences. So far, the main restriction introduced is the ban on the entry of Belarusian aircraft over the territory of the European Union, introduced on May 23, 2021. This ban was further detailed even later by adding a formal ban on the use of EU airports [2]. Authorities of the European Union, the USA and Canada have announced that entering Belarusian airspace is highly deprecated [3, 14]. As a result of the sanctions, the sky over Belarus almost emptied. Mainly lines from Russia (Aeroflot, Pabieda and S7) and China operate there. T. Hypki reports that only cargo carriers operate there from Western entities, including FedEx [6].

It is worth adding that a somewhat similar event took place on October 21, 2016, although it did not receive as much media publicity as the case of flight FR4978. On that day, Boeing 737-8ZM of Belarusian lines Belavia (Belavia) with registration EW-456PA, some time after taking off from Kiev airport, received an order from the Ukrainian ATC service to return to the take-off airport. T. Hypki reports that the Ukrainian ATC did not inform the crew of the Belarusian Boeing about the reasons for this decision, but threatened to intervene in the event of a refusal by military fighter planes. After landing, Armenian blogger Armen Martirosian was taken out of the plane. The Ukrainian side later denied that a threat of intervention by military aviation had been issued, and the Belarusian side upholds this version of the events [6, 16].

VII. Is it possible to legally shoot down a civil plane?

It turns out that it is, but not everywhere. After the attacks on the WTC in 2001, the "Concept of Operational Strengthening of Air Defense Against Terrorist Attacks MCM-062-02" was developed, where NATO for the first time defined the possibility of an attack using a civilian aircraft as a means of combat. A civil aircraft that could be used as a weapon was designated "Renegade". It can be classified as "suspected", "probable" and "confirmed". In the latter case, when there is an exceptional threat, it can even be shot down. An aircraft may be considered 'Renegade' if: a) violates an approved flight plan or changes flight parameters unexpectedly; b) refuses to comply or does not respond to orders of the state air traffic management unit, civil and military airport air traffic services units; c) cease all radio communication, especially in connection with a change in flight parameters; d) during radio communication, the crew uses unusual messages, deviating from standard aviation phraseology, or transmits messages not related to aviation procedures; (e) changes the codes emitted by the transponder, unduly uses the identification signal, emits loss of communication, emergency or hijacking codes or ceases to emit transponder signals without the approval of the state air traffic management unit; f) information from relevant services indicates the possibility of the aircraft being hijacked and used as a means of a terrorist attack from the air; (g) a terrorist organization or an unknown person has threatened to commit a terrorist attack using a civil aircraft [10, 12].
These principles were implemented by NATO countries, but in 2008 the Constitutional Tribunal in Poland found it inconsistent with the Polish Constitution, as it guarantees the inviolability of life and health protection for every citizen [15]. The Polish Constitutional Tribunal decided that in this case the principle of the "lesser evil" could not be applied, even if the destruction of the commercial plane with passengers would save the lives of even more people on the ground. This was taken as skeptical in the aviation community, arguing that the theoretical right to shoot down a hijacked plane was a good deterrent to potential terrorists. In the current situation, the Polish Air Force not only has no right to open fire to a civilian plane used as a weapon, but perhaps they are not even entitled to fire a warning series from a cannon, as it is a potential threat to the life and health of people on board the hijacked plane (and not only).

We should also remember about the possible risk of a collision between a civil and a military aircraft. The events of the past years indicate that this does not only apply to air incidents related to accidental violations of separation rules in the air. Since Russia's occupation of Crimea, its relations with the West have become increasingly tense. In the second half of 2014, there were even provocative flights by Russian military planes, which could pose a threat to civil air traffic. Russians often fly without ICAO transponders turned on and without submitting ICAO flight plans, which is clearly an act of provocation. For example, on March 3, 2014, the Russian Il-20 approached the SAS airliner A321 over international waters 50 km southwest of Malmö. The planes passed just 90 meters away. In October 2020, the Russian Sukhoi Su-27 fighter approached and flew past the Israir Airbus A320 from the Greek island of Rhodes to Tel Aviv [26]. There were more such cases in the world.

SUMMARY

The cited cases of forcing civil aircraft crews to change their flight route and landing place show that air transport safety is highly dependent on political issues and international events. In some cases, the intervention of fighter aviation was used, in other cases, the mere threat of using the armed forces was enough to force the execution of their own orders on the crew of a civil aircraft. The examples given here may create a formidable precedent that may be repeated in future. The most effective method of eliminating this type of threat from air transport would be its complete separation from regions where even the smallest international disputes take place. In practice, this is either unlikely or not possible. This means that special secret services (intelligence), whose task is to detect threats and counteract such situations, must play a huge role in ensuring transport safety.

REFERENCES

[1] Dudek P., “Lądowanie w Mińsku okiem prawnika”, in Skrzydlata Polska no 06/2021

[2] EASA Safety Directive Operations in FIR Minsk (UMMV) No.: 2021-02, effective 02 June 2021

[3] FAA Notam KICZ A0017/21

[4] Friedman T. L., “Israelis intercept a Libyan civil jet and then let it go”, in: The New York Times, February 5, 1986

[5] Harris S., “The Watchers: The Rise of America's Surveillance State”, publ. Penguin, New York, USA 2010

[6] Hypki T., “Twarde lądowanie w Mińsku”, in Raport WTO no 06/2021

[7] Hypś M., “Przechwycenie lotu Egypt Air 2843 - Władza państwa nad obcymi samolotami”, in: Lotnictwo no 6/2021

[8] ICAO Annex 2 Rules of the air

[9] Lee G., “Hold Fast To Your Dreams”, publ. Evangelista Media, UK 2014

[10] Olszewski R., “Reagowanie na zagrożenia z powietrza w czasie pokoju”, in Bezpieczne niebo ed. J. Gotowała, publ. AON, Warszawa, Poland 2002

[11] Onis H., “Airliner Returns to Beirut”, in: The New York Times, August 11, 1973

[12] Piątek Z., “Siły zbrojne w walce z terroryzmem lotniczym”, in: Reagowanie państwa na zagrożenia terroryzmem lotniczym, ed. A. Glen, publ. AON, Warszawa, Poland 2010

[13] Polek P., “Neutralizacja cywilnego statku powietrznego w sytuacji zagrożenia bezpieczeństwa państwa w prawie polskim”, in Przegląd Prawniczy Uniwersytetu Warszawskiego, no 1/2015

[14] Transport Canada AIC26/21-12 AUG 21

[15] Judgment of the Polish Constitutional Tribunal dated September 30, 2008, file ref. Act. K 44/07, Journal of Laws No. 177, item. 1095

[16] https://en.topwar.ru/102476-zachem-ukraina-grozila-belorusskomu-avialayneru-podnyatiem-v-vozduh-istrebiteley.html

[17] https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WMP20200000844

[18] https://pl.wikipedia.org/wiki/Buzz_(linie_lotnicze)

[19] https://www.buzzair.com/kontakt/

[20] https://www.consilium.europa.eu/en/press/press-releases/2021/06/04/eu-bans-belarusian-carriers-from-its-airspace-and-airports/

[21] https://www.icao.int/pages/freedomsair.aspx

[22] https://www.nytimes.com/1973/08/11/archives/israeli-jets-over-lebanon-force-down-arab-airliner-military-says-it.html

[23] https://www.nytimes.com/1986/02/05/world/israelis-intercept-a-libyan-civil-jet-and-then-let-it-go.html

[24] https://www.planespotters.net/airframe/boeing-737-800-sp-rsm-ryanair-sun/e2wd5d

[25] https://www.rp.pl/Polityka/210529780-ICAO-Bialorus-mogla-zlamac-Konwencje-Chicagowska.html

[26] https://www.timesofisrael.com/russian-warplane-said-to-come-dangerously-close-to-israir-flight/

[27] https://wyborcza.pl/7,75398,27121346,ekspert-od-lotnictwa-o-porwaniu-maszyny-ryanaira-zaloga-nie.html

[28] https://www.jetphotos.com/photo/9797157

[29] https://www.flightradar24.com/data/aircraft/sp-rsm#27cce9a2

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Forecasting Road Transport Demand with Use Machine Learning

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Abstract*—*This article deals with the topic of predicting the demand for road transport. Proposed is new term road transport demand basing on relation available freights and trucks on transport exchange. Data from Central Statistical Office in Poland and Transport Exchange are compared. Processing data for machine learning models are shown. 32 machine learning models are compared according to 3 success metrics. Implementation possibilities are presented. Models are shared in open access.

Keywords*—*forecasting, road transport demand, machine learning

I. INTRODUCTION

Knowing the dependencies that exist in the free road transport market helps to make better decisions in fleet management [1]. Knowledge what will be demand for road transport in future is beneficial. Demand forecast can be used as relevant data in forecasting prices for road transport services. Example [2] of road traffic forecasting was based on the correlation of the GDP coefficient and tonne-kilometres made by vehicles. In the publication [3], forecasting was based on the data of the Central Statistical Office in Poland, using an additive and multiplicative models. The paper [4] presents predictions the quantity of transported goods using 4 models: Holt-Winters double exponential smoothing, Holt-Winters double exponential smoothing assisted by artificial immune system, Bayesian networks and Bayesian networks with unemployment rate. The work [5] presents methods of forecasting the volume of road transport using the following methods: the seasonal Winter method, harmonic analysis and harmonic analysis supported by the artificial immune system. Scientists in [6] used Long-Short Term Memory Neural Networks (LSTM-NN) to predict the demand for transport during hurricanes "Irma" and "Matthew".

A. *Useful Software*

Python is very useful programming language for building machine learning models. It is attractive for exploratory data analysis and for the development of algorithms. A Jupyter Notebook [7] was used to write the code. It's a tool that allows you to write code and comments in your browser. It is convenient for project and document management. It also allows you to freely share the code like in this publication. There are many useful libraries for Python. Scikit-Learn [8] is a library that allows the implementation of many machine learning algorithms. The Pandas library [9] is useful for working with data sets. It enables data processing and creation of new features. The NumPy library [10] is useful for performing numerical calculations. Matplotlib [11] is a good library for data visualization. MapChart [12] allows you to create very precise data visualization in the form of maps. It is also possible to save the map configuration. This makes it easier to use in the future to achieve further goals. GitHub [13] is a platform that enables code sharing. It is beneficial for the advancement of science. Possible is easily create own version of a shared project or suggest changes. The code [14] for this publication is also available on the platform.

B. *Machine Learning Models*

32 machine learning models [15] were included in the study, divided into:

1) Linear Regression Models. The methods predict a value to be a linear combination of features.

a. Linear Classical Regression: LinearRegression, Ridge, RidgeCV. An example of an application is [16], where a model was used to predict the effort in a software development project.

b. Linear Regression with variable selection: Lasso, LassoCV, Lars, LarsCV, LassoLars, LassoLarsAI, ElasticNet, ElasticNetCV, OrthogonalMatchingPursuit, OrthogonalMatchingPursuitCV. Models have built-in variable selection fitting procedures.

c. Bayesian Linear Regression: BayesianRidge, ARDRegression. Bayesian regression techniques can be used to include regularization parameters in the estimation procedure.

d. Outlier-robust Linear Regression: TheilSenRegressor. A good model for corrupt data - either outliers or errors in the model.

e. Generalized Linear Models (GLM): TweedieRegressor. The models allow response variables to have a different error distribution than the normal distribution.

f. Miscellaneous Linear Regression: PassiveAggressiveRegressor. Models for large-scale learning.

2) Kernel Ridge Regression: KernelRidge. Models combines Ridge regression and classification.

3) Gaussian Processes: GaussianProcessRegressor. Method for generic supervised learning

4) Neural Network: MLPRegressor. Examples of the use of artificial neural networks in transport are automatic docking of ships [17], prediction of fuel consumption in ships [18] and price prediction for road transport [19].

5) Dummy Estimators: DummyRegressor. The model is based on a simple algorithm. It cannot be used for real problems. It is applicable as a model for comparison. If the model has a worse result than DummyRegressor then the prediction is useless.

6) Nearest Neighbors: KNeighborsRegressor. The model predicts value from the most similar example he has learned.

7) Support Vector Machines: SVR, LinearSVR, NuSVR. Models depends only on a subset of the training data.

8) Ensemble Methods: AdaBoostRegressor, BaggingRegressor, ExtraTreesRegressor, GradientBoostingRegressor, RandomForestRegressor, HistGradientBoostingRegressor. Models combined with multiple estimators.

C. Metrics

It was decided to evaluate the models according to 3 success metrics. Smaller error is better model.

- Equation (1) describes Mean Square Error (MSE)

$$MSE = \frac{1}{n}\sum_{t=1}^{n}(\hat{y}_t - y_t)^2 \quad (1)$$

where: $\hat{y}_t$ - predicted value of the dependent variable; y_t - actual value of the dependent variable.

- Equation (2) describes Root Mean Square Error (MSE). Smaller error is better model.

$$\mathrm{RMSE} = \sqrt{\mathrm{MSE}} \quad (2)$$

- Equation (3) describes Coefficient of determination R2. It ranges from 0 to 1. Closer 1 is better model.

$$R^2 = \frac{SS_M}{SS_T} = \frac{\sum_{t=1}^{n}(\hat{y}_t - \bar{y})^2}{\sum_{t=1}^{n}(y_t - \bar{y})^2} \quad (3)$$

II. Demand Prediction

It was decided to build demand prediction models based on data from one of the most important transport exchanges TimoCom [20]. Transport exchanges are one of the most promising solutions for transport logistics [21]. The data the barometer takes into account is not complicated. Equation (4) describes it as simply a percentage ratio reported cargos and vehicles. No scientific papers on predictions using data from freight exchanges were found.

$$D = QL/QT \quad (4)$$

where: D – demand; QL – quantity loads, QT – quantity trucks

A. Bilateral Relation Demand Transport Poland and other countries

The data is for 2019 and comes from the TimoCom barometer. It was decided to use a bilateral visualization defining the demand for exports from Poland in relation to imports. Data concern relations with 44 countries from Europe and Asia. The method of calculating the coefficient is presented in the pattern (5).

$$\mathrm{RY} = \frac{\sum \mathrm{DE}_n = (\mathrm{DE}_1 + \mathrm{DE}_2 + \cdots + \mathrm{DE}_{12})}{\sum \mathrm{DI}_n = (\mathrm{DI}_1 + \mathrm{DI}_2 + \cdots + \mathrm{DI}_{12})} \quad (5)$$

where: RY – ratio year; DE – demand export; DI – demand import; n – month number

Fig. 1 shows the export-import relationship. The color green shows the countries to which the demand for the transport service is greater in export than in import, and the red is greater demand for import. The greatest advantage of demand in exports is in relation to the Balkan countries: Croatia, Bosnia and Herzegovina, and especially to Montenegro. This may be due to the political situation in Montenegro. The biggest advantage of demand in import occurs in the countries of: Asia: Azerbaijan, Armenia and Georgia. A particularly high disproportion is in relation to Luxembourg. This may be due to the small area of the country and the fact that it is very economically developed.

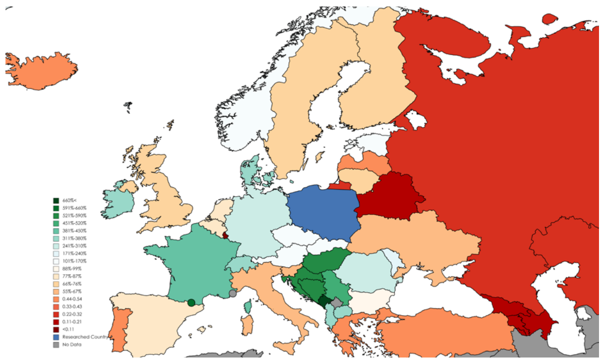

Fig. 1. Map of the relation of demand export to import Poland and other countries in 2019 based on barometer TimoCom.

Fig. 2 shows analogous data provided by the Central Statistical Office in Poland. The differences in the data presented may result from the fact that many goods are transported without the use of freight exchanges using permanent contracts.

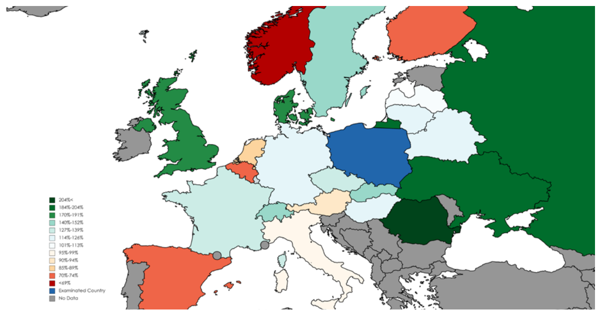

Fig. 2. Map of the relation of demand export to import Poland and other countries in 2019 based on data from Central Statistical Office in Poland

It is evident that in some relationships these data correlate more and in others less. The R-Person's correlation calculated from the pattern (6) is approximately 0.22.

$$r(x,y) = \frac{\mathrm{cov}(x,y)}{\sigma x * \sigma y} \quad (6)$$

where: r(x,y) – Pearson correlation coefficient; cov – coviarance; σ – standard deviation of the population

The correlation is positive which is expected. Figure 3 shows the breakdown of the demand based on the data from the barometer in relation to the actually transported goods in 2019. Perfectly even distribution is 1. In this case, it would mean that in 2019 the ratio of demand on the stock exchange coincides with the actually transported goods.

The most similar results were found in relation to Spain, Belgium, Finland, the Czech Republic, the Netherlands and Romania. The greatest disproportion in favor of the demand on the stock exchange occurred in relation to Hungary. This proves that much more is offered on the stock exchange than it is actually transported. The greatest disproportion in favor of the actual transported goods occurred in relation to Russia. This proves that more loads are transported without the exchange. This method of ordering may take place through standing contracts. The situation is similar in the case of Belarus and Ukraine. The reason for this may be the difficult access to the market due to the required permits.

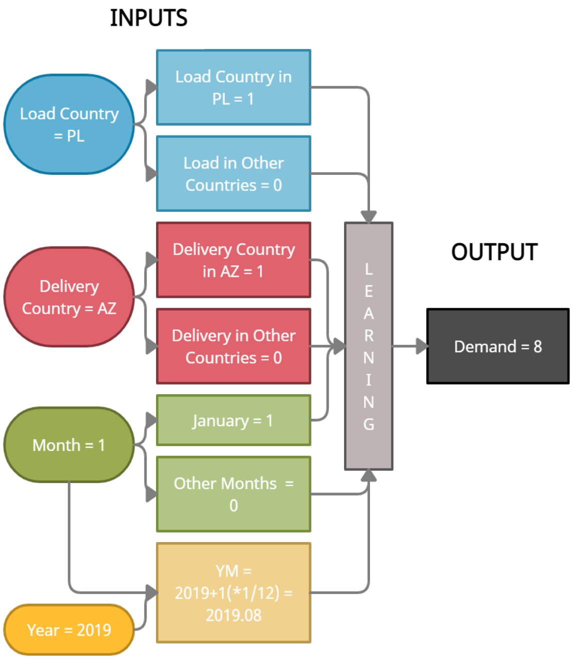

Fig. 3. Ratio demand on transport exchange and real transported goods in the 2019 year.

B. Data Preparing

Data was collected from publicly available data made available on the Internet by the Timo-Com barometer. Data concern 2019 and relations between Poland and 44 countries from Europe and Asia. Considering that a year has 12 months and each relation is bilateral, this equals 1056 rows with data. Calculations are made in Jupyter Notebook using the Scikit-Learn library. Fig. 4 shows a model diagram on the example of the demand for road transport services from Poland to Azerbaijan in January 2019. The diagram was prepared using the creately.com online wizard.

Fig. 4. Model scheme

C. Training and Testing

The collected data was divided into: 70% training data and 30% test data. Fig. 5 shows the results of testing according the RMSE metric. The chart on the MSE metric is not presented because it is a square RMSE metric. RMSE is better at showing errors than MSE.

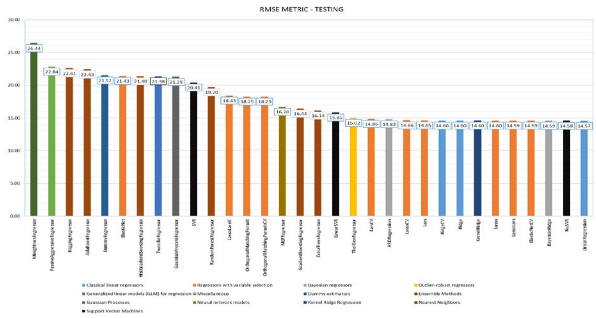

Fig. 5. Testing results according RMSE metric

Fig. 6 shows the results of testing according the R2 metric.

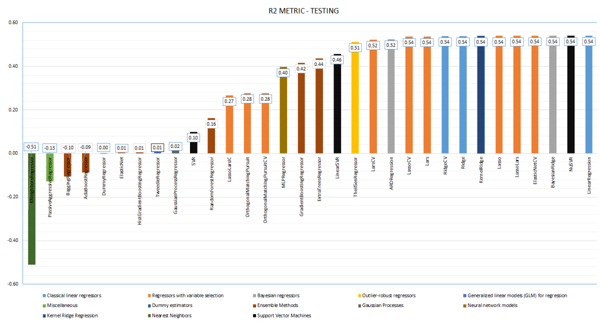

Fig. 6. Testing results according R2 metric

Fig. 7 shows the relationship between the forecast and real values using the TheilSenRegressor as an example.

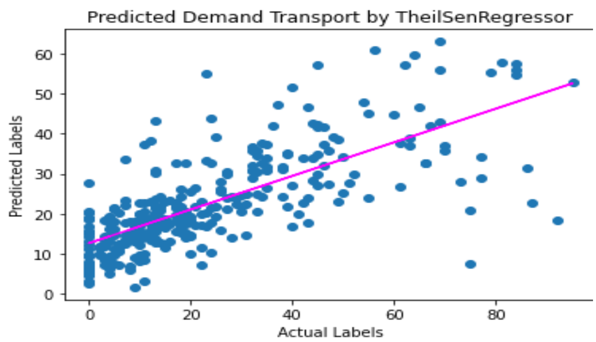

Fig. 7. Relationships between forecasted and real values on the example of TheilSenRegressor.

D. Validation

The form of validation data is the same as for training and testing. The difference is that the models are validated in the next year 2020. There were some changes in the market compared to the previous year. Fig. 8 shows these changes. The increase in exports in relation to imports with a given country is marked in green. The reduction is marked in red.

The more intense the color, the greater the change. This is described in detail in the legend

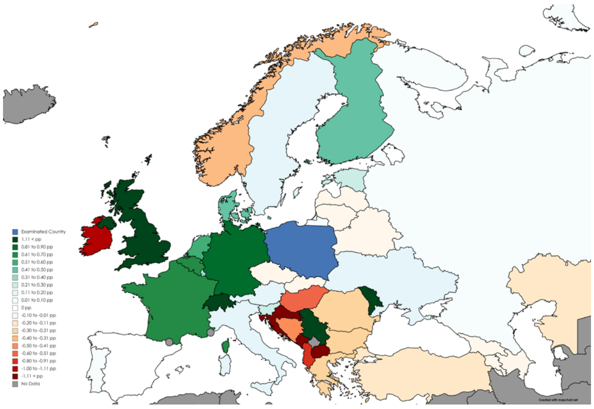

Fig. 8. Changes in the demand-supply relationship between 2019 and 2020 in percentage points

Fig. 9 shows the results of the validation according to the RMSE metric. The validation according to the MSE metric is not presented, because this is the square of the RMSE metric. RMSE metric better capture errors.

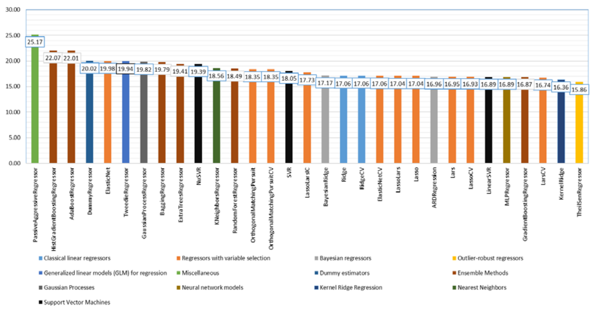

Fig. 9. Validation according RMSE metric

Fig. 10 shows the results of the validation according to the R2 metric. The model that performs best by all metrics is TheilsenRegressor. The LinearRegression model has been omitted from the graphs because it showed values with a very large error.

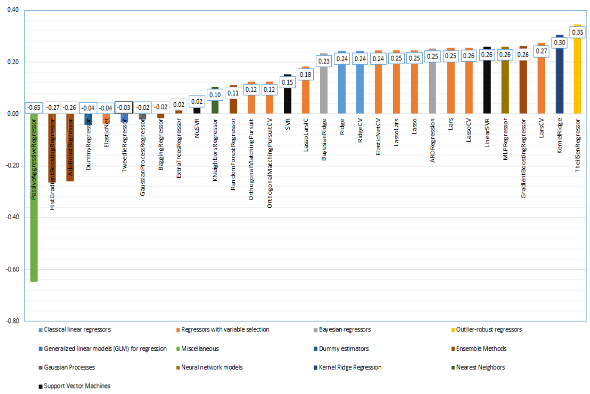

Fig. 10. Validation according R2 metric

III. IMPLEMENTATION

The model can be used to predict the demand. Fig. 11 shows an example of an application for demand prediction in relation to Poland to Azerbaijan.

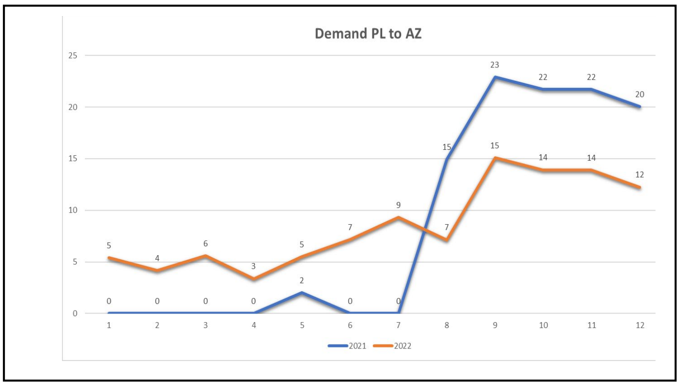

Fig. 11. Demand forecasting in relation from Poland to Azerbaijan

Fig. 12 shows a prediction in relation from Azerbaijan to Poland. Similarly, you can plot different relationships.

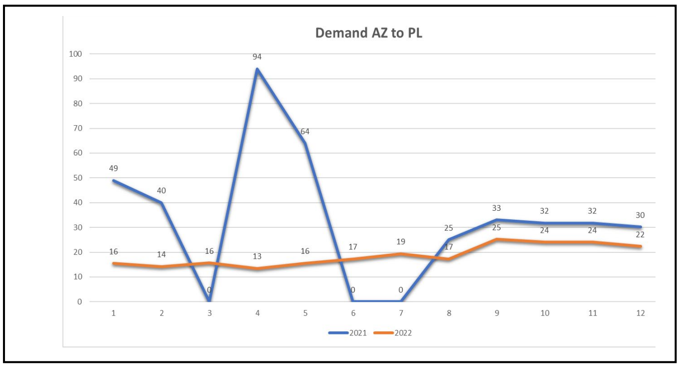

Fig. 12. Demand forecasting in relation from Azerbaijan to Poland

The introduction to this article covered the subject of the software language, tools, and software used. Creating the right environment to carry out such a project on your own is quite a complicated process. The solution to this problem is to use the ready-made Anaconda package. It should be downloaded from the manufacturer's website. The software is available for the most popular operating systems: Windows, Linux, and macOS. Once downloaded, the user gets access to Jupyter Notebook, which is a very convenient Python programming tool. All necessary libraries are also configured: Scikit-Learn, Pandas, and NumPy. The next step is to create your own "csv" file that will be used to train the models. Then download the ready code from the project's website and run it on your computer in Jupyter Notebook. In case of problems with implementation, you can use the "Step by Step" guide also on the project website. There, each of the steps above is presented with a detailed description of each click and a visualization of what it looks like in Windows. The tutorial is adapted to a person who had no contact with programming before.

IV. CONCLUSIONS

The transport barometer is an indicator that can be used to predict demand. Collecting and presenting data on the number of submitted offers is a favorable phenomenon for analyzes. Machine learning can be used to predict demand based on data from freight exchanges. The most effective model is TheilsenRegressor. The model presented in the text can be used by any company that uses road transport. Among them, the following can be distinguished: transport exchanges, transport, trade, production, and forwarding companies. The presented model can be used as a base or act independently. Demand prediction models presented in this text can be used in road transport price-prediction models. The implementation of forecasting into the transport barometer may make the exchange's offer more attractive to its clients. All data used to present the research results in this publication are available on the project website [14]. The project page contains raw data, data processing methodology, training, and testing, validation, charts, maps, map configuration. All this creates favorable conditions for repeating this experiment. The process of building models for similar problems in future research is also facilitated.

REFERENCES

[1] A. Budzyński, “Use dependencies between freight prices and economic factor as a solution in improve efficiency work in road transport,” in Proc. XII Int. Sci. Conf. & IX Int. Symposium of Young Researches „Transport Problems’2020”, 2020.

[2] A.C. McKinnon and A. Woodburn, “Logistical restructuring and road freight traffic growth,” Transportation 23, 1996, pp. 141–161.

[3] E. Macioszek and A. Kurek, „International road cargo transport in Poland and other EU countries,” Scientific Journal of Silesian University of Technology. Series Transport 111, 2021, pp. 99–108.

[4] B. Mrowczynska, M. Ciesla, A. Krol and A. Sladkowski, “Application of Artificial Intelligence in Prediction of Road Freight Transportation”, PROMET, vol. 29, no. 4, pp. 363-370, Aug. 2017.

[5] B. Mrowczyńska, K. Lachacz, T. Haniszewski and A. Sladkowski, “Acomparison of forecasting the results of road transportation needs.Transport,” 2012.

[6] K. C. Roy, S. Hasan and A. Culotta and N. Eluru, “Predicting traffic demand during hurricane evacuation using Real-time data from transportation systems and social media,” Transportation Research Part C: Emerging Technologies, Volume 131, 2021.

[7] T. Kluyver, B. Ragan-Kelley, F. Perez, B. Granger, M. Bussonnier, J. Frederic, K. Kelley, J. Hamrick, J. Grout, S. Corlay, P. Ivanov, D. Avila and S. Abdalla, “Jupyter notebooks – a publishing format for reproducible compu-tational workflows,” International Conference on Electronic Publishing, 2016.

[8] F. Pedregosa, G. Varoquaux, A. Gramfort, V. Michel, B. Thirion, O. Grisel, M. Blondel, P. Prettenhofer, R. Weiss, V. Dubourg, J. Vanderplas, A. Passos, D. Cournapeau, M. Brucher, M. Perrot, E. Duchesnay and G. Louppe, “Scikit-learn: Machine learning in Python,” Journal of Machine Learning Research, 2012.

[9] W. McKinney, “Data structures for statistical computing in python,” Prroceedings of the 9th Python in Science Conference, 2010, pp. 56–61.

[10] S. van der Walt, S. C. Colbert and G. Varoquaux, "The NumPy Array: A Structure for Efficient Numerical Computation," in Computing in Science & Engineering, vol. 13, no. 2, 2011, pp. 22-30.

[11] J. D. Hunter, “Matplotlib: A 2d graphics environment,” Computing in Science & Engineering, 9(3), 2007, pp. 90–95.

[12] R. E. Voorrips, “MapChart: Software for the Graphical Presentation of Linkage Maps and QTLs.,” Journal of Heredity, 93(1), 2002, pp. 77–78.

[13] L. Dabbish, H. Stuart, J. Tsay and J. Herbsleb, “Social coding in github: Transparencyand collaboration in an open software repository,” Proceedings of the ACM Conference on Computer Supported Cooperative Work, CSCW, 2012, pp. 1277–1286.

[14] A. Budzyński, “BudzynskiA/DRTPS: Demand Road Transport Predicting system,” GitHub. [Online]. Available: https://github.com/BudzynskiA/DRTPS. [Accessed: 27-Aug-2021].

[15] L. Buitinck, G. Louppe, M. Blondel, F. Pedregosa, A. Mueller, O. Grisel, V. Niculae, P. Prettenhofer, A. Gramfort, J Grobler, R. Layton, J. Vanderplas, A. Joly, B. Holt, G. Varoquaux, “API design for machine learning software: experiences from the scikit-learn project,” CoRR, 2013.

[16] M. Sadiq, A. Ali, S. U. Ullah, S. Khan and Q. Alam, “Prediction of softwareproject effort using linear regression model,” International Journal of Information and ElectronicsEngineering, 2013.

[17] Y. Shuai, G. Li, X. Cheng, R. Skulstad, J. Xu, H. Liu and H. Zhang, “An efficient neural-network based approach to automatic ship docking,” Ocean Engineering, Volume 191, 2019.

[18] E. Bal Beşikçi, O. Arslan, O. Turan and A.I. Ölçer, “An artificial neural network based decision support system for energy efficient ship operations,” Computers & Operations Research, Volume 66, 2016, pp. 393-401.

[19] A. Budzyński and A. Sładkowski, in Polish “Predicting freight price in road transport with using artificial neural networks,” in Proc. XIII Int. Sci. Conf. & X Int. Symposium of Young Researches „Transport Problems’2021, 2021, pp. 137-151.

[20] A Budzyński, in Polish: “Comparison the most important transport exchange in Europe,” B.S. Thesis, Silesian University of Technology, Katowice, 2018.

[21] A. Sładkowski and A. Budzyński, in Russian “Transport exchanges, as one of the promising solutions for the problems of transport logistics,” in Proc. of the IV Polish - Georgian Scientific-Technical Conference "Transport Bridge Europe - Asia", 2018.

Research and Analysis of the Functioning Quality of Hardware and Software Complexes Automotive Service Systems with Using Logistic Approach

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***Abstract*—The analysis of the advantages using the architectural concept logistics system for the construction highly efficient hardware and software systems automotive services, supporting a wide range information services. As a result of the research, a mathematical model of the quality of functioning systems automobile services using logistics system, as a queuing system (QS), is proposed. On the basis of the model, the characteristics multichannel queuing systems with waiting and limited queue length, as well as the total number hardware and software systems, were analyzed. For the criterion of the quality functioning systems automobile services using the logistic approach, complex indicators of the productivity and reliability of the functioning complex systems have been selected. Based on the study model, analytical expressions were obtained that make it possible to estimate the indicators peak throughput, stationary and limiting probabilities states, as well as the probability failure-free operation of the system when providing information services. The considered characteristics make it possible to assess the state of the system, indicators probability failure, and also allow to optimize their parameters. On the basis of the model, a numerical analysis was carried out and a graphical dependence of the maximum value peak throughput on the total number hardware and software systems was carried out at an admissible system load factor and at a given average speed. It has been established that an increase in the total number hardware and software systems leads to an increase in the maximum value of the peak throughput, which meets the requirements for the performance and reliability of the system.**

Keywords*—performance, logistic system, service, reliability, mathematical model, system automobile service, logistic process.

I. Introduction

Currently, the intensive development network infrastructures of the digital economy and the creation strategic plans "Roadmap for digitalization" requires the optimal organization and management limited information resources transport and technological complexes that ensure the high-quality functioning automotive service systems in the provision information services and in the processing various message flows.

However, the development and implementation information and computer technologies in the systems automobile services for processing information flows various traffic, make it possible to research the operation algorithms and analyze the architectures complex transport and technological complexes at a qualitatively new level, built in accordance with the concept logistics systems.

Logistics is the science planning, organizing, managing and controlling the movement and time material and information flows in a system from the primary source to the final recipient. The term "logistics" comes from the Greek word "logistike" - as the art of calculating, reasoning, as well as distributing and managing all available resources for the provision various information services, taking into account numerous parameters [1, 2, 3].

In this case, the essence of the logistic approach to managing information flows is to integrate individual sections telecommunication and logistics processes into a single system automotive services for service, technical and mass maintenance.

The management and distribution information resources is based on the efficiency processing information flows circulating in the logistics system. In this regard, one of the key characteristics logistics are indicators information flow. Here we assume that the information flow can exist in the form of paper and electronic documents, which are useful and service traffic [2, 4].

For the criterion of the quality of functioning indicators transport and technological complexes, using the concept logistics systems automobile services, the performance of the information flow processing system was selected, which is characterized by the following complex indicators [2 - 5]:

- performance automotive service systems when processing various information flows based on a logistic approach;
- single and complex reliability functioning of a complex transport and technological complex in the logistics system.

Considering the above, it can be said that the tasks research and analysis of the above-mentioned indicators quality of functioning systems automobile services using advanced computer technologies and new logistic approaches are the most urgent task.

Performance and reliability are characterized by numerous complex indicators such as throughput, probabilistic-temporal characteristics, system cost, as well as the efficiency use and distribution information and network resources.

It should be noted that a significant number works are devoted to the study of a mathematical model optimization of the planning solution of a gas station [3, 4] and theoretical studies transport and technological complexes with a probabilistic nature of the quality of functioning systems automobile services [5-7].

In this paper, we propose a solution to the problem formulated above - the development of a mathematical model for optimizing the quality of functioning automotive service systems based on the architectural concept logistics systems in the provision information services.

II. GENERAL PROBLEM STATEMENT

Note that the system for transmitting and processing information flows automobile services are sources electronic documents, paths hardware and software complexes and communication channels, as well as specialized units using logistics systems for resources management.

To calculate the indicators of the paths hardware and software complexes, it is necessary to create a scheme for the functioning of the mathematical model system automobile services using logistics systems, which will most accurately take into account the telecommunication processes and management resources flowing in the system under consideration when providing service maintenance. The mathematical model systems automobile services is as a network model of the quality of functioning hardware-software systems based on the logistic approach.

The analysis shows [1, 2, 8] that the systems automobile services in the provision information services is a large real-time information system, which is in accordance with the accepted logistic approaches and resources. This ensures the provision of the various services requested by the user, subject to the availability of the necessary resources.

Thus, the quality of functioning automobile services using the logistic approach can be considered as an open queuing system, as a network model of the system.

The development of a mathematical model quality of the functioning systems involves a quantitative assessment of the quality adopted technical solutions and can be formulated as a search for the vector optimal parameters hardware and software systems and elements of the logistics system [2]:

$$Q(\lambda) \to extr\,,\ \lambda \subseteq \lambda_{all.},\ G(\lambda) \subseteq G_{all.}(\lambda),$$
$$P_r(\lambda) \subseteq P_{r.\,all.}(\lambda) \qquad , \qquad (1)$$

where $\lambda -$ the vector of parameters of hardware and software systems system automobile services based on the concept of logistics systems in the provision information services and is equal to $\lambda = \sum_{i=1}^{n} \lambda_i$, $i = \overline{1,n}$; $\lambda_{all.} -$ the set valid values for these parameters; $Q(\lambda) -$ a criterion for the quality of functioning of the network model systems automobile services of the decisions made, the extremum which must be ensured by choosing the appropriate vector parameters of the network model λ; $G_{all.}(\lambda) -$ the set of acceptable values for these criteria; $P_r(\lambda) -$ the vector of reliability of a single and complex functioning complex hardware and software complexes that determine the quality of functioning of the network model systems automobile services in the logistics system; $P_{r.\,all.}(\lambda) -$ a set admissible values indicators reliability functioning complex hardware and software systems.

Expression (1) characterizes the essence of the considered logistic approach to the management of information services and defines a set of criteria for the mathematical model of the quality of functioning of the paths of hardware and software complexes of systems of automobile services with minimal economic costs.

In addition, (1) performs the optimization problem of the quality of functioning systems automobile services based on a logistic approach to the problems managing network and information resources, which allows obtaining analytical expressions for assessing their main characteristics.

III. CONSTRUCTION OF A STRUCTURAL DIAGRAM AND DESCRIPTION ALGORITHMS FOR THE OPERATION OF THE PATHS HARDWARE AND SOFTWARE COMPLEXES

To perform the objective function (1), fig. 1 shows a block diagram of the mathematical model paths hardware-software complexes of the systems automobile services. The structure under consideration is a scheme for the functioning of the model of a link automobile services and consists of the following functional, block-modular systems such as a source and a load consumer, controlling an element of a logistics system and a transmission system, as well as an information processing system and a server buffer storage .

The algorithm operation and the presented scheme of the model's functioning is described in detail in [2, 9], where it is noted that the data flows generated by various load sources are analyzed at the channel level, which make it possible to determine the characteristics of the network model paths hardware and software complexes automotive service systems.

The investigated diagram of the mathematical model of the paths of the hardware and software complexes of the systems automobile services demonstrates the essence of the logistic approach for the management information services. Mathematical models are based on the integration individual control elements logistics with the links performing the telecommunication and logistics process to create a unified system automotive services [2, 3, 10].

Taking into account expression (1), the algorithms of the presented scheme show [2, 3, 11] that the considered system automobile services is a queuing system (QS, Queueing Systems) with a servicing hardware and software complex (server, router) and a buffer storage (BS) final capacity N_{BS}.

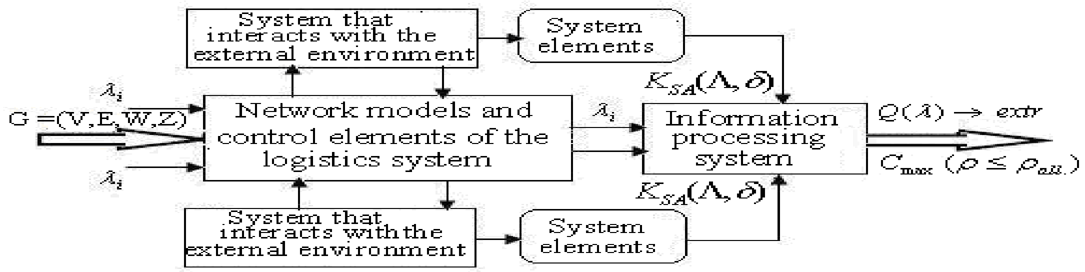

Figure 1. Block diagram of the model paths hardware and software complexes systems automobile services using the logistic approach

We represent the mathematical model automobile services based on a logistics system in the form of an undirected weighted connected graph:

$$G = (V, E, W, Z), \quad |V| = N, \quad |E| = M$$

where $V -$ set of peaks; $E -$ many edges (hardware and software systems or channels); $W -$ set of edge weights; $Z -$ a lot of traffic of information services (service data).

From the description of the weighted connected graph, it can be seen that the considered model of automotive services is a VANET (Vehicular Ad Hoc Networks) road transport network for the provision any type of service, technical and information services.

In the system, the incoming flows messages (requests) information services are random and have the properties of the simplest Poisson flow to obtain indicators characterizing the process functioning automobile services based on a logistics system. To implement and describe this problem, it is advisable to apply the mathematical apparatus Markov random processes [2, 3, 9-11].

To quantify the performance of the system paths based on the network model, it is necessary to pay special attention to the required transmission rate $V_{i.k}$, $i = \overline{1, n}$ at a given rate of arrival of the input stream λ_i, under critical system load $\rho_i = (\lambda_i \cdot b_i) \le 1$, $i = \overline{1, n}$, route matrix $\Lambda_i = [\lambda_i, \eta_i]$, displacement probability matrices $P = [p_{ij} \mid i, j = 0, 1, ..., n]$, where the number waiting places in the system is limited N_{BS}. Here, $b_i -$ duration service of the $i-$th traffic flow; $\eta_i -$ coefficients effective use information and network resources logistics systems.

III. RESEARCH AND EVALUATION OF THE CHARACTERISTICS PATHS SYSTEMS HARDWARE AND SOFTWARE COMPLEXES

Taking into account the peculiarities of the proposed mathematical model, a necessary and sufficient condition for the existence of a stationary mode of the system is the following condition:

$$\rho = \sum_{i=1}^{n} [(\lambda_i \cdot L_m)/(N \cdot V_{i.k})] < 1, \qquad (2)$$

where $L_m -$ average message length; $V_{i.k} -$ average router speed, $V_{i.k} \ge (2.048, ..., 32.0)$ Mpbs.

Thus, the system-technical analysis shows [9, 10] that the system under study is a multichannel QS with expectations and a queue length limitation.

In this case, the multichannel QS $N > 1$ with waiting will be when the message request does not leave the system unserved, when all hardware and software complexes (channels) are busy, the request enters the queue and waits for service. Let the maximum number places in the queue be $N_{BS} \ge 1$, then in the queue they can wait for their service no more than $m = N_{BS}$.

An information flow (requests) that has arrived at the entrance to QS at the moment when there are already requests in the queue is rejected and leaves the system. This filling of QS with applications from the input information flow occurs in two stages: service servers (channels) are loaded first i, then the queue is full r. In this case, $i + r < N$, where $i \ge r$, $i = 1, 2, ..., n$.

Now we will consider the analysis algorithms for the operation filling stations based on the proposed network model using the resources logistics systems that provide a significant increase in system performance and economic the efficiency of the object.

Suppose that at filling stations there are a certain number of similar groups of fuel dispensers with th filling positions , and the flow $i-$th rate of cars arriving for filling is λ.

Let us denote the maximum number of places in the queue for refueling through m. In this case, the total number of cars at the gas station and at the waiting area will be

$$i + m \le N_o, \qquad i = 1, 2, ..., n \quad , \qquad (3)$$

where $N_o -$ the total number cars (request) at which the next request (cars) leaves the system unserved. If at the moment there is a petrol station $i+r$ cars and at the same time $i \geq r$, where i refuel, and r are queuing up for a gas station, then $i+r<N_o$.

In this case, the numbering of the states of the system will be as follows [2, 3, 6, 10]:

- from state S_0 (there are no orders in QS and all hardware and software systems (channels) are free) to state S_N (there are applications in QS $i-$th and all channels N are busy) there is no queue
- from the state S_{N+1} (in QS $N+1$ applications, where all channels are busy and one request is in the queue) to the state S_{N+m} (all channels N are busy and all $m=N_{бн}$ places in the queue are occupied by applications) the queue is filled.

Considering the above states of the system, the probability of a multichannel QS downtime with waiting (for all servicing hardware and software systems) is calculated using the formula under the following conditions:

1.The coefficient of effective use of hardware and software complexes in the system, $\rho \neq 1$:

$$P_0 = 1/\sum_{i=0}^{N} \frac{N^i}{i!} \cdot \rho^i + \frac{N^N}{N!} \cdot \frac{\rho^{N+1} \cdot (1-\rho^{N_{BSн}})}{1-\rho}, \quad (4)$$

2. The coefficient of effective use of hardware and software complexes in the system, $\rho = 1$:

$$P_0 = 1/\sum_{i=0}^{N} \frac{N^i}{i!} + \frac{N^N}{N!} \cdot N_{бн}, \quad (5)$$

where $\rho -$ also, is an indicator of the incoming load on one channel and is expressed as follows:

$$\rho = [\lambda/(N \cdot \mu)] < 1,$$

where $\mu -$ service speed information flows, $\mu = 1/t_o$, $t_o -$ average time of service of a request in the system.

Expressions (4) and (5) determine the probabilistic characteristics of the system automobile services based on the logistic approach with expectation. In addition, expressions (4) and (5) characterize the stationary states QS.

Taking into account the numbering states of the system, on the basis model it is possible to determine the remaining limiting probabilities of the states QS, which are calculated by the formulas:

$$P_i = P_0 \cdot \frac{N^i}{i!} \cdot [\lambda/(N \cdot \mu)]^i, i = 1, 2, ..., n, \quad (6)$$

Suppose that the system from the state S_{N+1} enters the state S_{N+m}. More over, QS has $N+1$ applications where all N channels are busy and all N_{BS} places in the queue are also occupied by applications, i.e. the queue is filling up in the system. Then, the limiting probabilities states for $i = N+1,\ N+2, ..., N+N_{BS}$ expressed as follows:

$$P_i = P_0 \cdot \frac{N^N}{N!} \cdot [\lambda/(N \cdot \mu)]^i,$$

$$i = N+1,\ N+2, ..., N+N_{BS}, \quad (7)$$

Expressions (6) and (7) estimate the limiting probabilistic states of a system based on a logistic system with an expectation for various state enumerations.

On the basis of the model, the obtained analytical expressions for the probability P_i value make it possible to calculate the main characteristics of the quality of functioning systems automobile services such as QS.

IV. ANALYSIS AND EVALUATION OF SYSTEM PERFORMANCE CHARACTERISTICS

It is known [1, 2, 6, 11] that the system performance according to the I.350 recommendation is defined in terms parameters that are important for automotive services based on the concept logistics systems, which are widely used for the design, configuration, operation and maintenance of the system.

One of the key characteristics for assessing system performance is the maximum value the peak throughput (Peak-raite throughput), which characterizes the maximum number information streams that the system can transmit per unit time. The maximum value of the peak throughput under the conditions allowable loading hardware and software systems $\rho_{all.}$ is determined by the following expression:

$$C_{\max}(\rho \leq \rho_{all.}) = N \cdot \sum_{i=1}^{n} V_{i.k}, \quad i = \overline{1,n}, \quad (8)$$

Under critical system load $\rho \leq \rho_{all.} \leq 1$, that is, when everyone is busy N hardware and software systems and all places $m = N_{BS}$ in the queue, the probability of a denial of service is found as follows:

$$P_{отк.}(\rho_{доп.} \leq 1) = \frac{N^N}{N} \cdot P_0 \cdot \rho_{all.}^{N+N_{BS}}, \quad (9)$$

Taking into account the state of the system in (4) and (5), expression (9) characterizes the blocking of the system with probability P_B. In a system with a blockage with probability P_B, the pure intensity income can be interpreted as

$$\Lambda_{pi}(\lambda) = N \cdot [1 - P_{pof.}(\rho_{all.} \leq 1)] \cdot \rho \cdot \mu$$

$$\text{at} \quad P_B = P_{pof.}(\rho_{all.} \leq 1). \quad (10)$$

Expression (10) determines the maximum value of the throughput hardware and software systems with a heavy load system. In addition, blocking probability means the probability that messages cannot be received by the system because the buffer storage is full.

If the system $N >> 1$ и $\rho \le \rho_{all.} < 1$, then $\rho^{N+1} << 1$ и $P_B = (1 - \rho_{all.}) \cdot \rho_{all.}^N$. This means the probability that the system is in a state $i = N$.

Taking into account the last assumption and expression (10), the actual intensity of servicing information flows is defined as

$$\gamma_{ai}(\mu) = (1 - P_0) \cdot \mu \quad . \qquad (11)$$

Based on the network model and formulas (9), ..., (11), the absolute throughput automotive service systems will be expressed as follows:

$$C_{\max}^{an}(\rho \le \rho_{all.}) = \lambda \cdot [1 - P_B] = \Lambda_{pi}(\lambda), \quad (12)$$

As a result of the research, the obtained analytical expressions (8), ..., (12) determine the performance indicators of the system in the provision information services.

On the basis of a model systems automobile services using the concept logistics systems, analytical expressions were obtained, with the help which numerical calculations were carried out using MATLAB 7.5 and its Signal Processing Communications packages [12].

Taking into account the obtained numerical results, in figure 2, a family graphical dependence of the maximum value peak throughput on the total number hardware and software systems is built at an admissible systems load $\rho_{all.}$ factor and at a given value of the average speed V_{ik}.

Analysis of the family graphical dependencies shows that an increase in the total number of hardware and software systems leads to an increase in peak throughput $C_{\max}(\rho \le \rho_{all.})$, a system that meets the requirements for the reliability of the functioning information security. Its noticeable change begins with the meaning $N \ge (250,...,300)$ at $V_{ik} \ge 20.0$ Mbps. In this case, the gain in throughput is manifested along with the gain in system reliability.

V. ANALYSIS RELIABILITY INDICATORS COMPLEX HARDWARE AND SOFTWARE SYSTEMS

The reliability of the system operation is a characteristic that determines the ability hardware and software systems over the VANET network in the event technical failures and operational errors without a noticeable deterioration in the probabilistic-time characteristics of the quality of service information services messages.

Let us assume that the system has many states operability hardware and software systems Q_{pc}. On the basis figure 1, the set failure states of system elements is equal to:

$$Q_{oc} = 1 - Q_{pc} \quad , \qquad (13)$$

One of the main characteristics assessing the reliability complex hardware and software systems is the probability failure-free operation of the system:

$$P_{ВБР}(t) = K_{AS}(\Lambda, \delta) \cdot \exp(-t_{nb} / T_{cb}) \quad , \qquad (14)$$

where $K_{SA}(\Lambda, \delta) -$ system availability taking into account the failure rate Λ and restoration δ of the working state hardware and software systems; $t_{nb} -$ continuous mean time between failures system elements; $T_{cb} -$ mean time between failures systems elements.

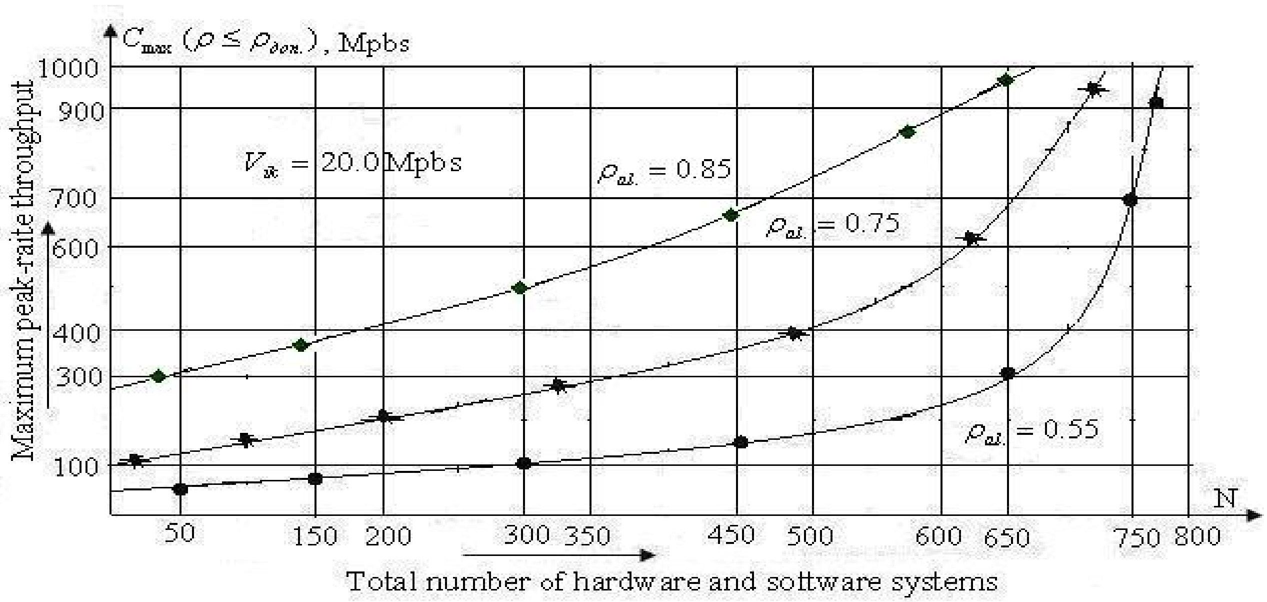

Fig. 1. Graphical dependence of the maximum value peak system throughput on the total number hardware and software systems

Based on the model, the non-stationary system availability factor is expressed as follows:

$$K_{SA}(\Lambda, \delta) = \frac{\rho}{1+\rho} \cdot \exp[-(\Lambda + \delta) \cdot t] + (1+\rho)^{-1}. \quad (15)$$

Expressions (13), (14) and (15) show that the reliability of the functioning hardware-software complexes is determined by the reliability of the system elements included in it. In addition, expressions (13), (14) and (15) are a single and complex indicator of the reliability functioning of a complex transport and technological complex in the logistics system.

Thus, on the basis of the proposed model, analytical expressions have been obtained that allow one to assess the quality indicators of the functioning of the automobile services system using the logistic approach.

CONCLUSIONS

As a result of the study, a network model was proposed for optimizing the quality of the functioning automobile services using the concept logistics systems, taking into account the performance indicators of the system, single and complex indicators reliability of the functioning hardware and software systems.

On the basis of the model, analytical expressions are obtained for assessing the indicators of the maximum value peak throughput, stationary and limiting probabilities states, as well as the probability failure-free operation and the availability factor of the system in the provision information services.

REFERENCES

[1] D.G.Evseev, M.Yu.Kulikov, A.S.Kuzyutin. Network model of service maintenance freight cars // Bulletin of the Bryansk State Technical University, No. 5 (66), 2018. – pp. 24 - 32.

[2] B.G.Ibrahimov, A.M.Talibov. Researches efficiency functioning systems processings information flows automobile services. *T-Comm*, vol. 13, No.5. 2019. - pp. 56-60.

[3] V.S.Lubentsova Mathematical models and methods in logistics. Samara State Technical University. Samara, 2008. – 157 p.

[4] D.G. Evseev, M.Yu. Kulikov, A.S. Kuzyutin Evseev. Methodological concept of technology for fright car Servicing // Fundamental and Applied Problems of Mechanical Engineering: Proceedings of the VI-th Inter. Conf. “Design-Technological Informatics”.M.: Spectrum, 2017. – pp. 90-97.

[5] M.A.Masuev. Designing of automobile transport enterprises: textbook. manual for university students. - M .: Publishing House "Academy", 2007. – 224 p.

[6] R. Yu. Levin, V. A. Maslennikov. Mathematical model optimization of the planning solution of a gas station // *Journal of automotive engineers*. No. 1 (96), 2016.-p. 34-35.

[7] A.V. Gasnikov, S.L. Klenov, E.A. Nurminsky. Introduction to mathematical modeling of traffic flows. Textbook. Moscow: MIPT, 2010. – 362 p.

[8] G.G. Levkin, Commercial logistics. Tutorial. St. Petersburg: SPbUEF, 2018. – 145s

[9] Aliev, T.I. Fundamentals of System Modeling / T.I. Aliev. – S-Pb.: U ITMO, 2015. – pp. 120.

10] V.G. Kartashevsky. Foundations of the theory of queuing. - M .: Hotline - Telecom. 2013. – 130 p.

[11] G.Bianchi. Performance Analysis of the IEEE 802.11 Distributed Coordination Function» // *IEEE Journal on Selected Areas in Communications*. Vol.18, No.3, 2000. – p.535-547.

12. O.I.Shelukhin. Information systems modeling. Textbook for universities.-M .: Hotline - Telecom, 2018. – 516 p.

Application of Microprocessor-Based Digital Signaling and Blocking Systems in Railway Transport Together with Neural Networks

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***Abstract*—There is a growing demand for speeding on railways and various programs are being implemented. In this case, the structural defects in the relay systems became a reality, and it was not possible to take the necessary measures to eliminate these shortcomings at the design stage of the control system. Modern experience shows that there are a number of shortcomings in relay, mechanical and relay processor systems. In this paper, the use of recommended methods is explained, stating the functional safety requirements used in railway signaling systems. In particular, the use of several methods in defining the software development process and software hardware architecture was discussed. The article presents the advantages of the microprocessor system over relays, relay-block and relay-processor systems and discusses its use in conjunction with a neural network. The frequency of occurrence of related scenarios was calculated in the reliability analysis using a general analytical model to compare the architectures of different blocking circuits in terms of security and usability. This document presents the results related to the safety of the machines and reflects the analysis method itself to support the selection of blocking architecture systems. It examines the analysis and selection of security methods for microprocessors and programmable logic controllers. The article considers the main indicators of the security functions of the system, makes suggestions on the technological processes of production in order to ensure safety.**

***Keywords*—microprocessor centralization, railway signaling and blocking system, microprocessor, security architecture, integrated security level, relay, digital system.**

I. Introduction

At present, it is impossible to imagine any field of railway transport without microprocessor systems. The main purpose of the railway automation and telemechanics system is to ensure the safety of trains, as failures and malfunctions (failures) in stations, road junctions, level crossings, bridges and tunnels, alarm systems installed in apartments can lead to numerous casualties.

The choice of hardware architecture in the design of interlocking circuits for signal exchange in machine protection systems in microprocessor centralization affects machine safety and availability. In an emergency, reliable stopping of the system elements (keeping the machine safe) is a special requirement. On the other hand, the limitations in terms of machine availability are different for different devices. To some extent, it is possible to allow incorrect parking, which reduces the accessibility of the machine, in places where it does not cause excessive wear of the equipment.

The analysis of the initial statistics allows to determine the general trend and regularities of change in the parameters of the devices of the centralization systems in operation. All calculations were carried out with a tolerance of ± 5, as allowed. Taking into account the operating conditions, traffic volume and climatic effects, the technical condition and reliability of the devices of railway automation and telemechanics systems are assessed by a complex change in these effects. Thus, the operation of field equipment, such as relay cabinets, centralized switches, traffic lights and relay equipment located in relay cabinets, is greatly affected. It should be noted that the failures in the devices against the flow of rejections under the influence of the unit are minimal, and the devices work stably. Stabilization and even reduction of failure rates during degradation can be achieved through properly organized maintenance aimed at restoring the characteristics and performance of system devices. The results of statistical analysis of the operation of electrical interlocking devices and systems provide information that allows to more accurately determine the causes of accidents, objectively justify the frequency of maintenance of devices, evaluate the maintenance tactics and methods of the operating system [1].

In this work, a model railway is vitally modeled with APN (automatic Petri net) and control and control theory is applied to signal lights, transmitters and route selection. This model can be converted to PLC code using Token Passing Logic (TPL) [2]. Prohibited situations cannot be enforced using this formal approach, and only safe situations can be reached where human error can be eliminated. For additional research, complex railway stations can be subdivided and easily modeled in this way. In addition, this work can be considered as the application of the official method to a real railway station, as the design will then be installed at the railway station without traffic lights used by the Turkish State Railways [3].

Despite scientific and technological progress in the application of computer technology and crystal-based multifunctional systems, relay control kits occupied a leading position in the field of railway signaling and blocking in the landscape of the former Soviet Union. A universal simulation environment for relay-contact circuits is proposed to test the above during both development and operation. This environment has a simple interface and is easy to use, ie you need to draw the tested circuits and set the parameters of the above elements. The use of an advanced modeling environment has shown that we can improve the performance of automation circuits on the High Speed Rail, and that some design flaws only manifest themselves in non-standard operating conditions. The simulation environment can be used not only to investigate the state of relay contact circuits, but also to solve problem-solving automation problems. At the same time, it is expedient to connect it with existing devices of permanent control systems of railway signaling and blocking devices [4].

The development of the blocking system is explained taking into account the functional safety requirements of CENELEC standards, in particular EN 61508 and EN 50128 related to rail. The voting system, which is part of an advanced interlocking system, consists of two non-crashing PLCs, the operation codes of which are determined using the Automatic Petri Network (APN) methods adopted by EN 50128 as a semi-formal method. The communication between the traffic control centers is achieved by a master supervisor, who connects the railway area with the PLCs, compares, reviews and implements all decisions. The resulting blocking program is tested and validated using both a blockchain Test Program (ITP) simulator and a small-scale hardware simulator for the railway garden set up at the Istanbul Technical University's Industrial Automation Laboratory [5].

The use of artificial intelligence (AI) will undoubtedly develop in the future. The planned S2R project will consider the use of SI for:

• Improving safety in self-driving vehicles (for example, by teaching the vehicle to detect obstacles related to the state of infrastructure associated with several variables);

• development of large data applications on railways (eg forecasting repair, Building Information Modeling (BIM) and optimization processes);

• detection of cybersecurity intrusions (for example, through exchanges with a large number of intelligent objects connected to the IP);

• flexible distribution of bandwidth (power) over the network;

• providing innovative real-time flexible services (for example: combining the full capacity of long block trains along freight routes - starting from railway freight corridors - flexible services - stopping and moving at automated terminals);

• Staff planning management to optimize the use of existing / appropriate rolling stock and existing staff within the network and within this service offer.

Another direction for the future development of digital railways is their joint development with space technology. In fact, for almost all optimization calculations of train movement, it is extremely important that the train has an accurate position on the ground, centimeter accuracy, and an accurate measurement time similar to an atomic clock in almost real time.

Since so much has already been said about the Internet for a digital railroad, it is worth focusing the reader's attention on general development trends that will determine many things. The figure shows the expected growth in the application of the five fastest growing digital technologies in the world. From the point of view of the development of a digital railway, it is quite possible to focus on this information [6].

Presents a method and results of a reliability analysis that touches on the characteristics of various blocking architectures related to machine safety and availability. It shows the advantages of 2oo3 architecture for systems with high requirements in terms of both security and availability. Subsequent studies are being conducted on the interface between intermediate locks (eg, circuit breaker) and protected machine subsystems (eg, magnetic amplifier circuits), including detectors. The Monte Carlo approach is further developed to validate different studies. In addition, the validation of the models, in particular the basis of the model, must be linked to the assumption of flawless voting [7].

Microprocessor system - designed to ensure the safety and control of train movement at stations and apartments of any size, configuration and purpose, as well as for coordination stations for trains with different types of traction. The system combines the functions of automatic and semi-automatic blocking, remote management of areas and parks of stations, as well as the ability to remotely control and integrate with higher-level systems (dispatch centralization and management).

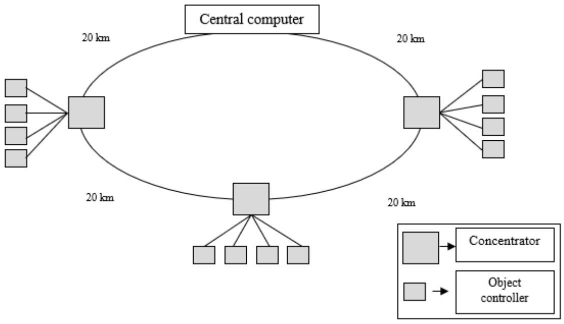
Until now, the advantages of centrifugal microprocessor systems for traffic lights and intersections compared to relay-type centralization were clear.

- A higher level of reliability (robustness) due to the duplication of the CPU, which is the heart of many nodes, including centralization, and the continuous exchange of information between this processor to ensure the safe movement of trains, control and management of facilities
- Possibility (probability) of managing many stations and road facilities from one place of work
- Integration of signaling, centralization and blockchain management with roadside devices and the possibility of ensuring security in a single-processor unit with devices
- Extensive set of technological functions, including the closure of the route without opening the traffic light, blocking the crossroads in the required condition, prohibiting the performance of traffic lights, isolated sections (sections) to exclude the issuance of the route
- High level of information for the operational and technical staff on the status of imb facilities at the

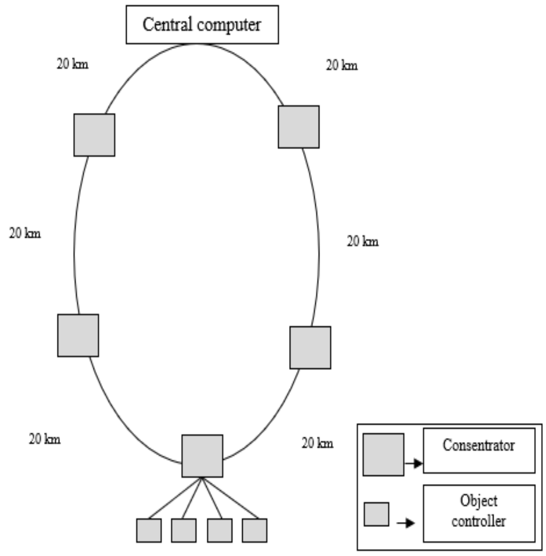
station, the possibility of transmitting this or that information to the regional control center

- Possibility of centralized and decentralized placement of control facilities for the management of station and road housing facilities. The decentralized placement of facility controllers allows for a significant reduction in the specific rate of cable consumption per centralized junction.
- Simple graft ratio with higher level control systems

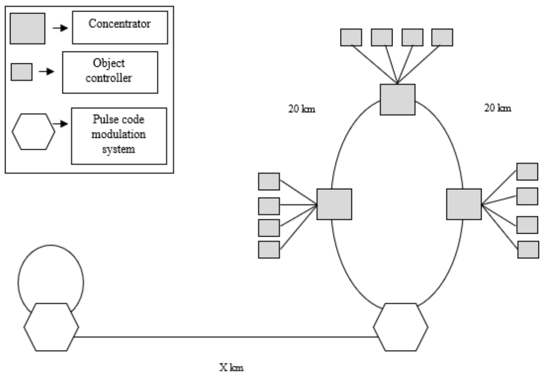
- Ability to archive the uninterrupted work of maintenance personnel in the management of all train situations and facilities at stations and road apartments
- Diagnostic control installed on the objects of control and management, the condition of centralized hardware
- Possibility to register refusal numbers of trains running at station and road apartments, as well as at control facilities
- The relatively small size of the equipment, the fact that the building is 3-4 times smaller for its placement, allows you to change the old type of centralization without building new electrical interlocking posts.
- The size of the construction and installation work is much smaller
- Convenient technology for checking the dependence of the model without assembly due to the use of specialized tuning tools
- Reduction of downtime of stations and road facilities in case of changes in the road development of stations and related dependencies between intersections and signals
- Use as a data transmission medium not only with copper wire cables, but also with optical fiber cables to controlled objects in control devices and vice versa
- Possibility of obtaining working parameters from the archive of IMB field devices without forecasting their future condition or planning of repair works without allowing complete failures in the operation of these devices.
- Reduction of operating consumption due to reduction of energy capacity, reduction of the number of electromagnetic relays, application of modern non-serviced power supplies, elimination of large mechanical controls and large control panels and manipulators with buttons
- contactless control of switches and traffic lights based on intelligent object controllers.
- Organization of communication according to the principle of communication, maintenance of communication channel.
- Advanced system diagnostics that allow you to detect equipment conditions before failure.
- Possibility of centralized or decentralized placement of equipment. High level of availability: the use of standard industrial modules, testing of software and hardware complex is carried out in the factory, the enterprise is provided with fully tested and selected equipment. Facility controllers monitor traffic lights, turnouts, crossings, road circuits, etc. Performs functions for the management of floor objects such as. Each object controller can manage one or more objects. The maximum distance between object controllers and the CPU is not limited. Decentralized placement of the control minimizes cable use and reduces the risk of induction currents interfering with signaling devices. When a fault is detected in advance, the built-in self-diagnostic system automatically places the damaged element in a separate print cycle. The system can be equipped with surge protection devices.



Typical configuration of communication loops



Configuration of communication loops in case of long distance



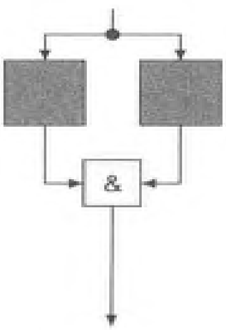
Configuration of communication loops using pulse code modulation equipment in case of long distance.

Compared to mechanical and relay centering, the application of microprocessor centering semiconductor element base reduces the security level of the system. Low voltage electronic components have a high sensitivity to external influences. It is difficult to know. Over time, the working characteristics of electronic components change. The complexity of the electronic components makes systematic errors in execution also difficult to control the process in the technical system and to change the situation. To some extent, the principles of sabotage and towing are used to overcome some of these shortcomings. In the redundancy system, one or the same function is performed on different hardware channels, and the result is compared with each other. Towing in microprocessor complexes primarily eliminates the possibility of accidental errors. Hardware backup is used in almost all microprocessor systems, the following options are used in the planning of this system.

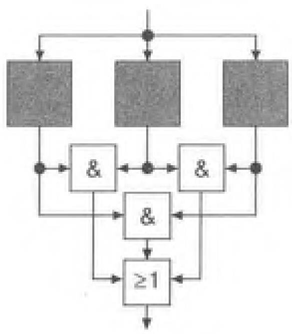
- 2oo2 system - In such systems, the responsible functions are processed on two independent computing channels and the security of the obtained results is compared. In case of compliance, the output of the system includes the agreed result, and in case of non-compliance, it makes the system safe.

- 2oo3 system - Functions are processed on 3 independent channels. If a channel is rejected, that channel is isolated. In this case, the centralization works as a 2oo2 scheme until the rejected channel is restored.

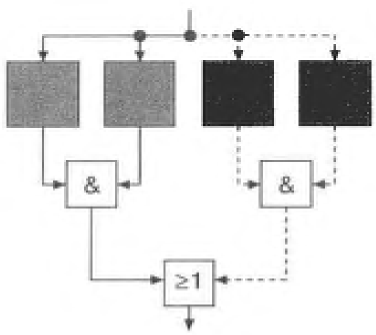
- 2x (2oo2) is a double system of two, in which case the 2oo2 subsystem is active and the other remains in reserve. If a failure occurs in the active subsystem, it is isolated, and the processing of the function takes place in another backup subsystem.



2oo2

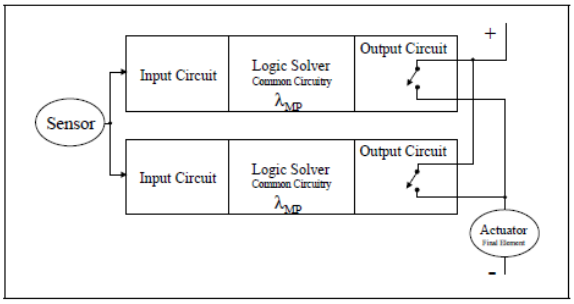


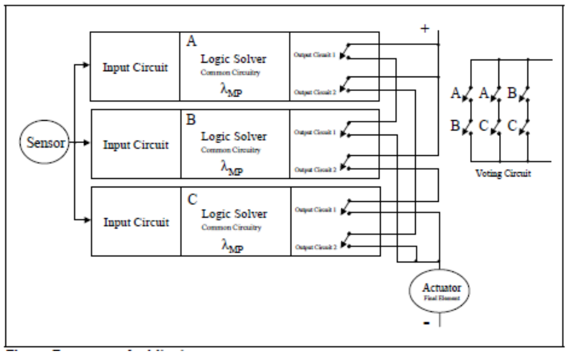
2oo3



2x(2oo2)

Microprocessor system backup





2oo2 and 2oo3 architectures

In a control system, the nonlinear mapping ability of neural networks can be used to accurately describe, act as a controller, optimize calculations, model nonlinear objects that are difficult to draw conclusions or misdiagnose, or both to match certain functions. Neural network-based intelligent control refers to the management of this network alone or to the integration of the neural network, as well as other intelligent control methods. The main types of control are the following forms.

1. Direct feedback control of the neural network. This is a way to directly implement intelligent control using only neural networks. In this method of control, the neural network is used as a direct controller, and algorithms are used as feedback to control self-learning.

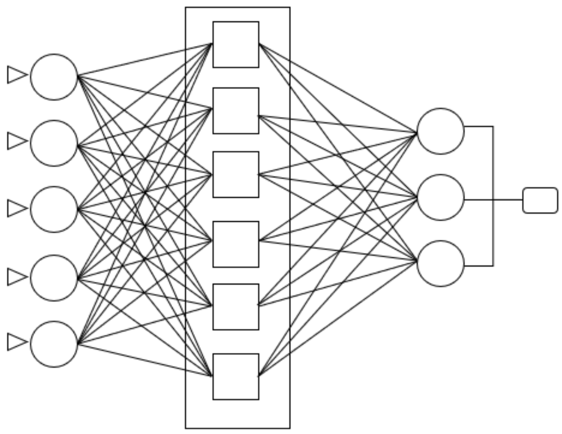
2. Nervous network specialist system control. Expert systems are good at expressing knowledge and logical thinking. Nerve networks are better than nonlinear mapping and intuitive reasoning. Combining the two to give the game the appropriate advantage will result in better control results.

3. Fuzzy logic control of the neural network. Fuzzy systems are good at expressing logic directly and are suitable for expressing knowledge directly. Neural networks are better at learning to express knowledge indirectly through information. The first is for top-down expression, and the second is for bottom-up learning. Therefore, their integration can complement each other and better develop the intelligence of the management system. There are three ways to connect fuzzy logic with a neural network. First, fuzzy control using a fuzzy neural network to control fuzzy thinking. This method uses a neural network to directly design multiple member functions and connects the neural network as a member function generator in a fuzzy control system. Second, use a neural network to

remember control of fuzzy rules. Third, the fuzzy controller settings are optimized using a neural network. In addition to the above-mentioned membership functions and fuzzy rules, factors affecting management performance in fuzzy control systems also have control parameters such as error variation quantization factor and output scale factor. These can be optimized using the neural network parameters optimization calculation function to improve the performance of the fuzzy control system.

4. Control of the sliding mode of the neural network. Variable structure control can be considered as a special fuzzy situation, and therefore belongs to the category of intelligent management. Nerve network slip mode control is the control of the slip mode of the neural network. This method classifies the control or state of the system, changes and selects according to changes in the system and the environment, uses the learning ability of the neural network, and improves the transition curve of the sliding mode by self-learning in an uncertain environment. to improve the control effect of the sliding mode.

The application of the idea of a neural network related to security is that the information for access is transmitted through intelligent sensors and a learning algorithm is released. The algorithm automatically analyzes the data structure and creates a relationship between input and output. Neural networking is a very powerful modeling method that allows you to build very complex dependencies.



Neural network (triple perceptron that transmits information directly).

Input solid source variables - rail circuit or axis meter, traffic light signals, condition of switches, condition of barriers and road blockers in the passage, signals from devices detecting hot buckets, signals of tracking devices or tracks on bridges and tunnels serves to enter the values of the data that are empty. It then sequentially develops neurons in the intermediate and output layers. In the intermediate layer, the values contained in the data from all inputs are collected in advance in a knowledge base (DB) with software. The knowledge base determines the output mechanism of the solution embedded in the system. These components determine the two main intellectual characteristics of the system: the ability to store knowledge about anything and the sequence of operations on this knowledge. Knowledge-based systems include systems that can learn, grasp new knowledge, expand BB, and adjust knowledge to changing conditions and events in the field of research.

At network nodes, the neuron calculates its activation value, taking the number of outputs from the previous layer. The activation value then uses another activation function, resulting in a neuron output. Once the entire network is complete, the output values are taken from the elements in the last layer, generally for the output of all networks.

CONCLUSION

A modern electronic locking system must be extremely flexible and measurable to ensure that it can be adapted to different sizes, different devices, different environments, different signal principles and even different applications. In addition to being suitable for critical operation in terms of safety, railway systems must also be highly reliable and accessible, and in most cases must meet strict requirements in real time.

The intelligent complex allows the transition to significantly new technologies for driving vehicles, minimizing the negative impact of the human factor, the efficiency and economy of management, operational reliability of traction personnel, safety of train operation, as well as solutions. In the near future, the use of artificial intelligence, neural network systems with the centralization of the microprocessor will help solve the problem of staff shortages of drivers and assistants. New technologies for driving trains can increase the carrying capacity of railways and save 5% to 15% of energy resources in the construction of trains, greatly facilitate the work of train drivers, increase traffic safety and pave the way for innovative transport development. industry. The importance of new technologies to operate trains is very high.

As a result, the advantages of neurocomputers based on the idea of a neural network are as follows:

Ensuring a high level of accuracy with the parallel operation of a large number of computing devices

The neural network has the ability to learn, and this is done by adjusting the parameters of the network

The neural network is highly resistant to rejections and external influences.

The simple structure of individual neurons allows the use of new physical principles of information processing for the hardware realization of the neural network.

REFERENCES

[1] Semikova TI, Analysis of the structure of the electrical centralization system. AUTOMATION, TELEMEKHANIKA, ZV'YAZOK, Zbirnik naukovikh prats DonIZT. 2006 №7, UDC 656.257, pp. 71-89.

[2] M. Uzam, A.H. Jones and I. Yucel, "A Rule-Based Methodology for Supervisory Control of Discrete Event Systems Modeled as Automation Petri Nets", Int. Journal of Intelligent Control and Systems, vol.3, pp. 297-325, 1999.

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Signalization and Interlocking Design for a Railway Yard: A Supervisory Control Approach by Enabling Arcs. The 7th International Symposium on Intelligent and Manufacturing Systems, IMS 2010, Sarajevo, Bosnia Herzegovina, 15-17 September, 2010.

[4] Dmitry Efanov, PhD, IEEE member, Associate Professor at "Automation and Remote Control on Railways" Department, Emperor Alexander I St. Petersburg State Transport University TrES-4b@yandex.ru, Andrey Lykov, PhD, Associate Professor at "Automation and Remote Control on Railways" Department, Emperor Alexander I St. Petersburg State Transport University bastdrew@mail.ru, German Osadchy, Technical Director at RSC "Monitoring of Bridges" osgerman@mail.ru, Testing of Relay-Contact Circuits of Railway Signalling and Interlocking, IEEE EWDTS, Novi Sad, Serbia, September 29 - October 2, 2017

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[6] O.N. Покусаев, А.А. Климов, В.П. Куприяновский, П.М. Morkhat, D.E. Namiot. Digital Railway of Europe - from ERTMS to Artificial Intelligence International Journal of Open Information Technologies ISSN: 2307-8162 vol. 7, no.7, 2019

[7] S. Wagner, A. Apollonio, R. Schmidt, M. Zerlauth, CERN, Geneva, A.Vergara-Fernandez, ITER Organization, St.Paul-lez-Durance Architecture for interlock systems: reliability analysis with regard to safety and availability, Proceedings of ICALEPCS2011, Grenoble, France.

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Applying the UN/CEFACT Multimodal Transport Reference Data Model (MMT RDM) Along the GUAM Corridor

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This article stems from the experience of projects of the United Nations Economic Commission for Europe (UNECE) to support digitalization of transport corridors and facilitate trade and transport in the region.

The UNECE is one of the five United Nations regional commissions, the main purpose of which is to promote economic integration in the broader European region. The UNECE brings together 56 member States and more than 70 international professional and non-governmental organizations. One of the tasks of the Commission is to set regulations, standards and conventions to promote international cooperation in UNECE region and beyond.

The UNECE has consistently made efforts during decades to support the development of digital transport corridors. This position was re-emphasized at the eleventh UNECE International Seminar on Trade and Transport Facilitation "Digital Transformation of Multimodal Transport Using the UN/CEFACT Reference Data Model", which took place in Odessa, Ukraine, from 26 to 28 May 2021.

The UNECE actively cooperates with regional organizations on these issues. In particular, an agreement was reached on cooperation with the Organization for Democracy and Economic Development GUAM (GUAMNet) on support a digital multimodal corridor.

Within the United Nations Economic and Social Council, the United Nations Economic Commission for Europe acts as the focal point for trade facilitation recommendations and e-business standards covering both commercial and government business processes that can foster the growth of international trade and related services. In this context, the United Nations Centre for Trade Facilitation and Electronic Business (UN/CEFACT) was established as a subsidiary intergovernmental body of the UNECE, with the task of developing a work programme of global relevance to improve coordination and cooperation worldwide on the development of semantic standards and other trade facilitation tools.

UN/CEFACT supports activities aimed at enhancing the ability of business, trade and administrative organizations from developed, developing countries and countries with economies in transition to effectively exchange products and related services. Its main focus is on facilitating national and international transactions through the simplification and harmonization of processes, procedures and information flows, which contributes to the growth of global trade.

UN/CEFACT's work in the areas of trade facilitation and e-business encompasses both commercial and government business transactions that can contribute to the growth of international trade and related services. The Centre encourages close collaboration between governments and private businesses to ensure interoperability for the exchange of information between the public and private sectors, as well as among regulatory agencies and within the business community. To achieve this goal, UN/CEFACT offers such tools as:

- The UN Layout Key for Trade Documents, which forms the basis, for example, of the EU Single Administrative Document (SAD) in the European Union;
- UN/EDIFACT, the only global standard for electronic data interchange (EDI);
- Over 40 Trade Facilitation Recommendations, covering best practices for streamlining processes, documentary exchange, codes for international trade and electronic business, etc.;
- The Core Component Library, containing syntax-neutral and technology-independent building blocks used for data modelling;
- XML Schemas that provide a set of coherent, consistent, and normalized syntactic solutions, which are aligned with a family of domain reference data models.

The UN/CEFACT data model structure is a hierarchy of Reference Data Models, notably the more general Buy-Ship-Pay Reference Data Model (BSP-RDM), which acts as a chapeau for the more specialized Multi-modal Transport Reference Data Model (MMT-RDM) and the Supply Chain Reference Data Model (SCRDM)

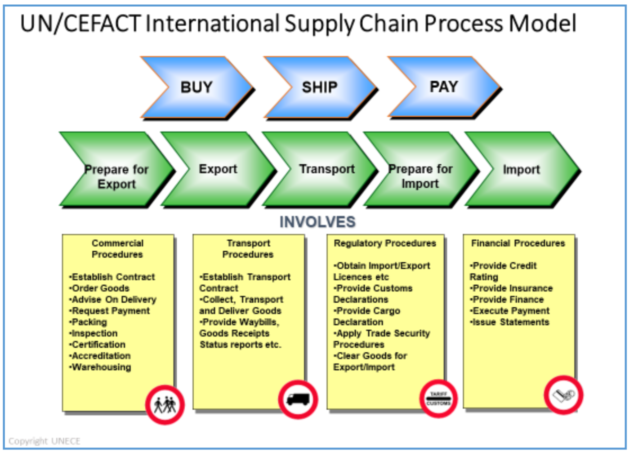

Fig. 1. The UN/CEFACT International Supply Chain Model (Buy-Ship-Pay, BSP) - Source: UN/CEFACT Recommendation No. eighteen

A broad spectrum of information is exchanged within the international procurement and supply chain. SCRDM and MMT-RDM provide a cross-domain framework for creating common data exchange structures for the exchange of information between customers, suppliers, resellers and authorities, regardless of which countries or modes of transport may be involved.

Both SCRDM and MMT-RDM are based on the UN Trade Data Elements Dictionary(UNTDED version 2005 [1]), maintained by UN/CEFACT, which is also the basis for the World Customs Organization (WCO) data model. Thus, the models use the same set of common terms and definitions for the parties involved and for the business information objects they contain. These models also use the UN/CEFACT Core Component Library.

The diagram in Fig.2 shows the top-level business information objects and relationships (BIEs) in BSP-RDM, which combines SCRDM and MMT-RDM.

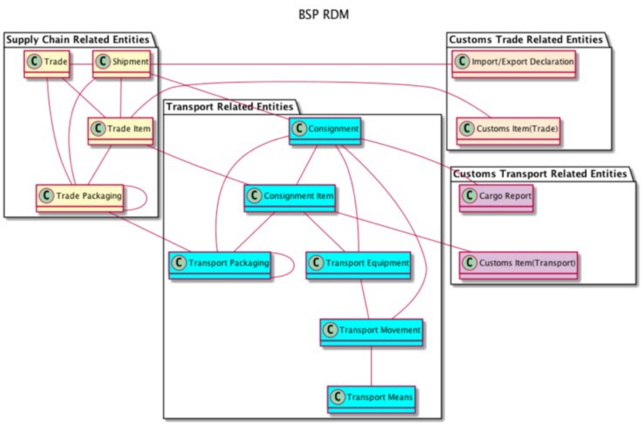

Fig. 2. Hierarchy of data models. Source - BUY - SHIP - PAY Reference Data Model BRS, UNECE-UN/CEFACT

A typical supply chain process can be represented by the diagram in Fig.3:

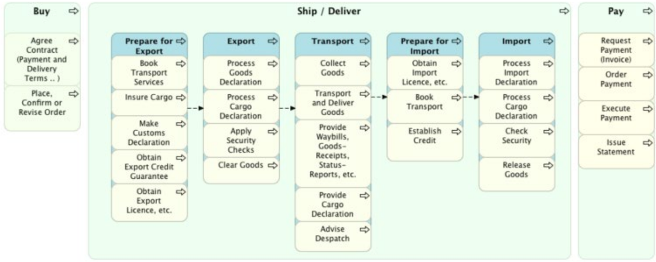

Fig. 3. Processes and operations in the BSP model. Source – The BUY - SHIP - PAY Reference Data Model BRS, UNECE-UN/CEFACT

The multidimensionality of the model is due to the multiplicity of roles of the actors, participating in the process. From the point of view of the purchase transaction, the actors can be the Client, the Buyer, the Seller, the Supplier, the Exporter, the Importer, etc. From the point of view of the delivery, the roles are the Transport Service Provider, Carrier, Sender, Recipient, Buyer of Transport Services, Forwarder, etc. Also, government agencies (Customs, border control agencies, sanitary inspections, port authorities, etc.) and auxiliary participants - warehouses, terminals, banks, brokers, insurance companies, etc., are involved in the process at its various stages.

The execution of such a process involves the movement of material, financial and information flows between the participants. Due to the methodological complexity of the model and the fact that each of the participants has a large number of documents and business requirements, as well as the direct interdependence of the regulatory process on the information flow, the process as a whole is often slowed down precisely because of delays in the information flow.

Thus, the focus the UN/CEFACT data modelling is to harmonize datasets and requirements within the information flow in the supply chain.

The information flow itself is also a complex concept that includes several levels (views):

- physical level - the level of organization of the information exchange between the sender (of information) and the recipient (of information);
- interface level - the level of negotiation of the interaction between the sender and the receiver;
- presentation level - the level of description of the information transmitted between the sender and the receiver;
- semantic level - the level of semantic content of the information transmitted between the sender and the recipient.

The UN/CEFACT Data Models and the tools on which they are based focus on enforcing the Semantic Layer, namely:

- defining the business information entities (BIEs) and the relationships between them;
- defining the aggregated information entities and the relationships between them (ABIE);

[1] untded-iso7372:2005 – UNECE – Trade Data Elements Directory (TDED) - https://unece.org/DAM/trade/untdid/UNTDED2005.pdf

- defining the specifications of the business requirements for datasets of the information entities.

A further development of these efforts is the concept of Data Pipelines proposed by UN/CEFACT[2]. The concept involves providing data directly at the source and only once, and reusing it throughout the supply chain, regardless of the mode of transport, party or regulatory body that needs access to the data.

Connectivity infrastructures for information exchange, such as Pipeline Data Exchange Structures, enable higher data quality, supply chain transparency, and information exchange. They open new possibilities for system-based audit and the development of smart software applications to offer value-added services to business, such as automated planning and scheduling, and for regulatory agencies, such as automated monitoring and targeting.

Basic principles of the concept of data pipelines:

- Capture the Data from the Right Person at the Right Place at the Right Time;
- Capture Once and Use Many Times in the Supply Chain;
- Data is transferred to the pipeline at the point of their origin;
- Data can be retrieved from the pipeline both on demand and sent to the recipient.

The main purpose of data pipelines is to improve the quality of data and ensure their seamless transfer within the information flow of the supply chain, in particular, by shifting the paradigm from "document-based" exchange of information to support international trade to the concept of "data and dataset"-exchanges. The key difference between these two concepts is that the document-exchange model is based on a rigid (paper) structure of the document - even in electronic form, whereas the dataset model assumes the presentation of information in the form of flexible structures - data sets (BIE and ABIE), which can be formed from generic data models on the fly by a simple request of information by the recipient in the form, which corresponds to specific business process requirements.

Another key shift of paradigm is the move to a possibility to "pull" (PULL) data from the pipeline instead of the usual practice of sending or submitting documents to recipient's information systems (PUSH). "Pulling" data, or receiving data on demand, opens up the possibility of optimizing information processes for receiving, processing and storing data and increases its efficiency.

Of course, such paradigm shift is not possible without appropriate support at other levels of the information sharing process. In particular, the usual mechanism for electronic document authentication by signing them with a digital electronic signature (DES) is not applicable to data sets generated on the fly. At the same time, the use of the DES as the only legally trusted means of authentication of information in electronic form has become in recent years a significant obstacle to international trade. This is because of the difference in cryptographic algorithms used in different countries, as well as the need for a single supranational (root) key certification authority to automate the recognition of such signatures. This approach is unacceptable for many States for a number of reasons, which, in turn, has led to the development of alternative approaches, for example, a Trusted Third-Party mechanism[3] (TTP). This mechanism has been implemented in practice in cross-border trade transaction in a number of countries. However, it has not been widely recognized, because of methodological limitations associated with the use of the documentary model, among others.

As an alternative, concepts focusing on the use of blockchain technology have been proposed[4] to simplify trade procedures, as well as Application Program Interface technologies - WEB APIs[5]. These approaches demonstrate the existence of technical solutions for implementing the principles of the data pipeline concept, provide mechanisms for working with datasets, access to them both on demand (PULL) and on supply (PUSH), strong identification and authentication of data with the ability to create flexibly modifiable and limited by time access tokens (JWT[6] and JWS[7] mechanisms).

Thus, providing a harmonized dataset that is a subset of a functionally complete model built on standardized and generally accepted definitions of information entities for business operations is key to optimizing the information flow of the supply chain.

In this regard, in response to the crisis caused by the COVID-19 pandemic, which had an exceptional impact on the global economy and supply chains, the United Stations (UN) initiated the UNTTC project [8] Transport and Trade Connectivity in the Age of Pandemics, implement all five UN regional economic commissions and UNCTAD. The UNECE leads several segments in it, including the one on developing a package of standards for the digitalization of multimodal transport data and document exchange and pilot projects on their implementation.

As part of this initiative, several assessments aimed at increasing the harmonization and standardization of data exchanged in international transport, trade and logistics took place. The objective is to stimulate the transition to paperless information exchange technologies in trade and transport, and reduce physical contacts between people and between people and objects, such as paper documents, during the COVID-19 pandemic, thus supporting economic recovery after the crisis using UN/CEFACT instruments.

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[2] White Paper Data Pipelines – UN/CEFACT - https://unece.org/fileadmin/DAM/cefact/GuidanceMaterials/WhitePaperDataPipeline_Eng.pdf

[3] White Paper on Trusted Transboundary Environment – UN/CEFACT - https://unece.org/fileadmin/DAM/cefact/cf_plenary/2018_plenary/ECE_TRADE_C_CEFACT_2018_7E.pdf

[4] https://unece.org/trade/uncefact/blockchaintf-april2018

[5] https://unece.org/uncefact/34thcfforum-conf-webapis

[6] JWT – JSON WEB Token, RFC 7523, https://datatracker.ietf.org/doc/html/rfc7523

[7] JWS – JSON WEB Signature, RFC 7515, https://datatracker.ietf.org/doc/html/rfc7515

[8] https://unttc.org

In particular, studies were carried out on the application of the UN/CEFACT Reference Data Model for Multimodal Transport (MMT RDM) along the Black Sea-Baltic Sea transport corridor, as well as on the Danube-Dnieper inland waterways. Transport and trade documents used in real business operations in the transportation of goods along transport corridors in the scope of the project were analysed and mapped with the data model. Prototypes of electronic documents were prepared based on the MMT RDM data model. Also, practical tests of data transformation took place between documents used in different modes of transport and jurisdictions.

The key objective of the projects is to test and advance the use of the MMT RDM data model as the semantic core of the information system to automate the task of transforming data between different trade and transport documents.

As a result, a number of recommendations were prepared, the implementation of which should facilitate and support the information exchange along these transport corridors and the expansion of the application of international standards in the electronic interaction of participants in the supply chain.

The reports are published on unttc.org:

- https://unttc.org/sites/unttc/files/2021-07/Belarus%20report%20on%20CIM_SMGS.pdf
- https://unttc.org/documents/report-standardized-digitalization-multimodal-transport-ua

This resource also provides information on standardized packages for documents by modes of transport, in particular:

- eCMR
- RASFF (Rapid Alert for Security of Food and Feed)
- Export Packing List
- Waybill
- Shipping instructions
- Booking
- CIM/SMGS and SMGS consignment notes, CIM/SMGS Wagon List
- Maritime bill of lading
- River bill of lading
- Preferential Certificate of Origin
- FIATA eFBL

The implementation of the GUAM digital corridor project is a further development of the East-West transport corridor projects. The scope of the current study includes shipment of cargo between Ukraine and Azerbaijan, both import and export, via Georgia using rail, road and maritime transport. For the purpose of the assessment, freight and transport documents, used in real business operations for the transportation of goods between countries, were analysed.

The need to transform information between different documents emerge both when changing jurisdiction (that is, crossing the border between territories with different jurisdictions), and when changing the mode of transport (modality). As an example of multimodal transportation, we can note the practice of using a railway consignment document as a maritime consignment note on the Poti (Georgia) – Chornomorsk (Ukraine) route. At the same time, certain sections of the transport operation are often carried out using their own documents. Thus, a port becomes a key point in the transformation of documents and data as a place of change of both national jurisdiction and mode of transport.

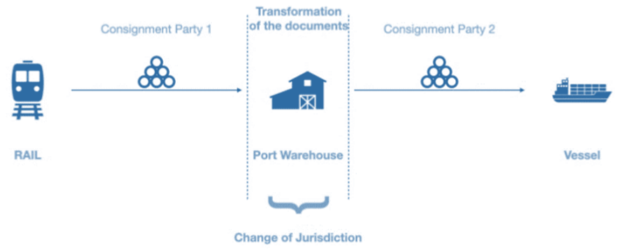

Fig. 4. Port as a transformation point. Source: Authors

As most participants in the transportation process already have their own information systems, which fully meet the requirements imposed on them by the business community, the main point for optimization is at the borderline of interaction of these systems with each other. In most cases, this problem is solved by building a system-to-system interface based on an appropriate bilateral agreement (between the railways of different countries, between railways and maritime carriers, etc.).

As a result, to solve the problem of information exchange between all participants in the supply chain, we need to reach in general terms a solution represented in the following equation:

$$Q_S = \frac{n!}{(2*(n-2)!)} \quad (1)$$

where Q s is the total quantity of interfaces between IT systems, and

n is the quantity of IT systems to be linked.

For each IT system, the quantity of interfaces to be implemented is:

$$Q_S^1 = n - 1 \quad (2)$$

where $Q_s{}^1$ is the number of interfaces for one IT system, and

n is the number of IT systems.

Considering the number of parties interested in this information exchange, such a task looks poorly implemented in practice.

The use of international standards and formats for electronic documents and messages looks like an attractive solution to the problem. However, the complexity is caused by the presence of a large number of complex and expensive information systems run by the different participants in the supply chain. For this purpose, it is proposed to use the UN / CEFACT electronic document formats based on the MMT-RDM data model as interface for solving the interaction problem. In this case, the complexity of the task of building information interaction decreases:

$$Q_S = n \quad (3)$$

where Q_s – is the total quantity of interfaces between IT systems, and

n is the quantity of systems.

The quantity of interfaces for each IT system in the case is minimal:

$$Q_S^1 = 1 \tag{4}$$

where $Q_s{}^1$ is the quantity of interfaces for one IT system.

The application of the UN/CEFACT data model and the formats of electronic documents (data sets) generated from it looks obvious in view of the above discussed properties of its functional completeness and semantic commonality for business information entities.

Consequently, the use of the MMT RDM data model offers as a direction for implementing the transformation of data sets in the interaction of IT systems solves the problem of not only reducing the fundamental complexity of implementing interaction interfaces between information systems of one mode of transport, but also between systems of different modes of transport operating with different types of data sets, using common information entities.

For the practical application of the data pipeline, in addition to the semantic issue, it is necessary to resolve the issues of technical interaction and legal recognition. These issues are supposed to be considered in the framework of further research in the following areas:

- The issue of technical interaction can be solved in a general way by using WEB APIs, using the possibility to describe then in terms of the UN/CEFACT MMT RDM and subsequent programmatical generation from such metadata.

- To resolve the issue of legal recognition, it is possible to consider the experience of the European Union, in particular the Regulation (EU) 2020/1056 on electronic freight transport information (eFTI[9]) and Regulation (EU) 910/2014 on electronic identification and trusted services for electronic transactions in the internal market (eIDAS Regulation[10]), as well as the concept of decentralized identity (Decentralized Identity/Self-Sovereign Identity (SSI[11])).

[9] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32020R1056&rid=1

[10] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2014.257.01.0073.01.ENG

[11] https://w3c.github.io/did-core/

Azerbaijan's Position in the East-West Transport Corridor, LPI Index and Container Transportation

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***Abstract*—As a result of large-scale investments in infrastructure to create the potential to increase the volume of transit cargo on various international transport corridors, there has been a recent increase in the volume of transit traffic through Azerbaijan. Such large-scale regional projects are the New Baku International Sea Trade Port Complex, the Baku-Tbilisi-Kars railway and the Astara-Astara railway. These infrastructure projects boosted volume of cargo(containers) transportation through East to West, North to South and especially China to Europe. In addition, these researches include Zangazur corridor perspectives, regional countries development indexes, import volume from China, automatization and Azerbaijan new "HUB" strategy. The article will also examine the Logistics Performance Index (LPI), its parameters and Azerbaijan's score for this index.**

Keywords—Middle Corridor, Automatization, HUB strategy, Container, LPI index

I. Introduction

In the framework of ongoing recession in the world economy, deep economic reforms in recent years, the development of the non-oil sector, the creation of an export-oriented economic model and establishing a productive business environment, as well as result of large-scale investments in infrastructure to create the potential to increase the volume of transit cargo transportation on various international transport corridors of the country, positive expectations are being formed in transit cargo transportation through Azerbaijan.

One of the recent regional projects implemented by Azerbaijan is the New Baku International Sea Trade Port complex. From the day of starting operations, project was successful within first 3 years and the potential of port's handling capacity is 15 million tons of cargo per year, including 100,000 containers, new Port of Baku have experienced growth in current periods. In recent periods, the largest increase was recorded in the volume of fertilizers, oil and oil products with origin of Turkmenistan, the number of containers and auto vehicles transport between Turkey and Central Asia. The fertilizer terminal, the construction of which began this year with a capacity of 2.5 million tons and a storage capacity of 120,000 tons, will play an important role in increasing the volume of cargo handling in the Port of Baku in the future. It should be noted that the total volume of cargo handling in Baku Port in 2020 was more than 4.8 million tons, and in the first 8 months of this year was about 3.9 million tons. In 2020, the number of containers in the TEU equivalent was 40,345 unit, the number of Auto vehicles was 43,218 and the number of railcars was 37,447. The improvement the potential of port attracts cargos from numerous locations and through the corridor, these transit cargo's creates adding value for owner of infrastructure and logistics companies. Ports are main connection line for all world.

II. Middle Corridor

Middle corridor which passes through Azerbaijan borders, integrates to the infrastructure projects and global logistics through right logistic solutions. So that, there have been marked improvement in transit containers in the middle corridor via the East-West corridor (both Turkmenistan and Kazakhstan directions).

The number of containers transported in Baku Port for 8 months of 2015-2021 was as follows:

Table 1

	2015	**2016**	**2017**	**2018**	**2019**	**2020**	**2021 (8 months)**
TEU container	13336	17108	15337	22887	35024	40345	26 585

Source: Author's Research

As can be seen from Table 1, there is an increase in the number of containers. To compared with 2015, the number of containers in the TEU equivalent increased more than 3 times in 2020.In general, Middle corridor man source of cargos are Black Sea, Europe-Central Asia and reverse direction, at the same time development of trade turnover in the China and corridor countries.

Thus, there have been serious improvement trade turnover Central Asia and Turkey and that growth continuing every year. For the information, in 2019 total TIR transport from Turkey to the Uzbekistan was 36606 and many of these auto vehicles didn't pass in Azerbaijan borders. The statistics of the TIR transportation through the Port of Baku seen in Table 2 and Table 2.1:

Table 2

Direction	2015	2016	2017	2018
On the Baku Port, total				
West to East	5 485	14 836	16 767	13 345
East to West	3 271	8 710	11 817	8 056
Total	**8 756**	**23 546**	**28 584**	**21 401**
On Turkey				
Turkey to Central Asia	5 407	10 084	9 404	5 979
Central Asia to Turkey	3 260	8 353	11 031	7 406
Total	**8 667**	**18 437**	**20 435**	**13 385**
Turkey to Uzbekistan	-	84	51	501
Uzbekistan to Turkey	-	39		1
Total	-	**123**	**51**	**502**

Table 2.1

Direction	2019	2020	2021 (first 8 month)
On the Baku Port, total			
West to East	22 954	24 626	14 653
East to West	10 717	18 592	10 607
Total	**33 671**	**43 218**	**25 260**
On Turkey			
Turkey to Central Asia	10 470	16 679	9 436
Central Asia to Turkey	6 203	11 931	6 667
Total	**16 673**	**28 610**	**16 103**
Turkey to Uzbekistan	259	4 620	1 263
Uzbekistan to Turkey	22	3 762	929
Total	**281**	**8 382**	**2 192**

Source: Author's Research

In General, if we examine the statistics, there have been growth in fertilizer products in open bulk forms. New fertilizer facilities build in Turkmenistan and at the same time Central Asia fertilizer potential on fertilizer products exports to the west is increasing. As a result, Port of Baku now building fertilizer terminal with total cargo capacity 2.5 million ton per year (in addition 120-thousand-ton storage capacity). Fertilizer products statistics shows high potential and return in that products. The figures below show total fertilizer handling in last years:

Table 3

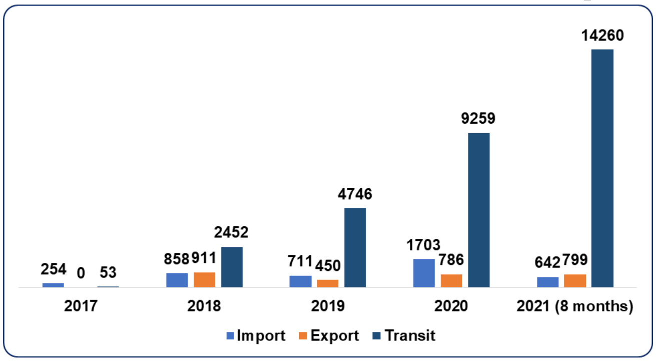
Indicator	2018	2019	2020	2021 (8 month)
Fertilizer products, ton	38 400	170 000	630 000	705 000

Source: Author's Research

Apart from Port of Baku, another Azerbaijan regional project was Baku-Tbilisi-Kars railway project. This project also succeeded, and it had positive progress recent years.

Information about Baku-Tbilisi-Kars railway container transportation is below:

Graph 1



Source: Author's Research

Azerbaijan transit potential were depending on Middle corridor countries welfare and economy. Middle corridor countries economy development statistics are below.

Table 4

Countries	2015		2016		2017	
	GDP, in billions of US dollars	GDP per capita in US dollars	GDP, in billions of US dollars	GDP per capita in US dollars	GDP, in billions of US dollars	GDP per capita in US dollars
Turkey	864.3	11,006	869.7	10,895	859.0	10,590
Ukraine	91.0	2,125	93.4	2,188	112.2	2,641
Georgia	15.0	4,014	15.1	4,062	16.2	4,357
Bulgaria	50.6	7,056	53.8	7,549	59.0	8,334
Romania	177.7	8,969	188.1	9,549	211.7	10,807
Moldova	7.7	2,732	8.1	2,880	9.7	3,510
Turkmenistan	35.8	6,433	36.2	6,388	37.9	6,587
Kazakhstan	184.4	10,511	137.3	7,715	166.8	9,248
Kyrgyzstan	6.7	1,121	6.8	1,121	7.7	1,243
Uzbekistan	81.8	2,615	81.8	2,568	59.2	1,827
Tajikistan	8.3	978	7.0	807	7.5	849

Source: World Bank

Table 4.1

Countries	2018		2019		2020	
	GDP, in billions of US dollars	GDP per capita in US dollars	GDP, in billions of US dollars	GDP per capita in US dollars	GDP, in billions of US dollars	GDP per capita in US dollars
Turkey	778.4	9,453	761.4	9,127	720.1	8,538
Ukraine	130.9	3,097	153.9	3,663	155.6	3,727
Georgia	17.6	4,723	17.5	4,698	15.9	4,279
Bulgaria	66.2	9,428	68.6	9,828	69.1	9,976
Romania	241.5	12,399	249.7	12,890	248.7	12,896
Moldova	11.5	4,230	12.0	4,494	11.9	4,551
Turkmenistan	40.8	6,967	45.2	7,612	47.4	7,851
Kazakhstan	179.3	9,813	181.7	9,813	169.8	9,056
Kyrgyzstan	8.3	1,308	8.9	1,374	7.7	1,174
Uzbekistan	50.4	1,529	57.7	1,719	57.7	1,686
Tajikistan	7.8	853	8.3	891	8.2	859

As table above, transit potential growth is still developing, and total GDP volume is proof for that. Turkey is largest economy apart from other countries. Romania, Kazakhstan and Ukraine also have significant economy.

Map1

China's influence on the East-West corridor transit on the long-term have positive contribution. Regional imports from China is shown as below:

Table 5

China export, in million US dollars	2015	2016	2017
Azerbaijan	439	346	387
Turkey	18,608	16,687	18,122
Ukraine	3,516	4,217	5,041
Georgia	769	745	913
Bulgaria	1,043	1,056	1,169
Romania	3,162	3,448	3,778
Moldova	100	77	98

Table 5.1

China export, in million US dollars	2018	2019	2020
Azerbaijan	516	617	618
Turkey	17,864	17,322	20,357
Ukraine	7,026	7,379	6,878
Georgia	1,103	1,400	1,276
Bulgaria	1,442	1,546	1,547
Romania	4,512	4,563	5,126
Moldova	109	120	146

Source: UN, Trade Statistics

From the Table 4 and Table 4.1, we could find out that biggest importer from China is Turkey and it followed by Romania and Ukraine. In Table 5, it shown the number of containers come from China to the Port of Baku:

Table 6

Indicator	2015	2016	2017	2018	2019	2020	2021 (8 month)
The number of containers comes from China (TEU)	83	107	248	2 321	5 941	5 660	7 736

Source: Author's Research

Those statistics shows emerging logistics services Chinese products to transport East to West and even in 2021 West to East transportation (Turkey exportation to China) started.

In pandemics, China economy main content containers were in shortage and that problem is still continuing. Container shortage on sea transportation rose shipping prices sharply (approximately 5 times) which it shifted their demand on land transport (railway transportation). From that reason, there are escalation of cargo transport in middle corridor. However, high prices on containers are also decreasing Corridor countries import from China. As a result, those high prices inflicts China's import and it includes Azerbaijan as well and it leads inflation on country economy. In long-term, China has opportunities to boost turnovers in corridor countries and even Europe transportation through Azerbaijan corridor which it considers their main goal

Azerbaijan Logistics Performance Index

In world, logistic sectors in developed countries not only satisfies in transition,as well as creating added value in order to make a contribution to the economy. If Azerbaijan achieves infrastructure goals to maximize our potential tranzit goods passes on country, it could bring limited income to the country(approximately 700-800 million US dollars). However, we could multiply that income by using value added services. Thus, the construction of a Free Trade Zone near the Alat settlement of Baku, which includes the transport and logistics industry, pharmaceutical cluster, facilities for the supply of oil for general use, as well as processing, packaging and labeling areas, has begun. It should be noted that the launch of this zone will make a positive contribution to the activities of the New Port of Baku. It also be noted that these projects are part of the central strategy ("hub" strategy) established by President Ilham Aliyev to strengthen the non-oil sector of Azerbaijan. The new Baku Port will become a leading trade and logistics hub in Eurasia, located at the crossroads of Europe and Asia, near major markets such as China, Turkey, Iran and Russia. The share of the transport sector in GDP, shown in the table below, once again proves the importance of the development of this sector.

The share of the transport sector in the gross domestic product of countries

Table 7

The share of transport in GDP	2019	
	Million US Dollars	Percentage
Azerbaijan	2,905.9	6.0%
Belgium	28,642.6	5.6%
Germany	164,866.8	4.4%
France	120,055.2	4.6%
Korea	429,079.0	23.8%
Turkey	42,276.8	9.5%
Georgia	718.8	4.1%
Kazakhstan	2,324.8	1.3%
Turkmenistan	40,496.4	4.7%

Source: Author's Research

If Azerbaijan's access to the world ocean was provided by Georgian ports as a bridge country, a new alternative emerges after this corridor and provides access to the Mediterranean Sea through Turkish ports (mainly Mersin), which creates additional logistics and transport opportunities. Relevant research will be conducted in the future to assess the development prospects of this area.

In order to achieve the identified goals, the following shortcomings in the development of the corridor need to be addressed:

Delay in digitization-- One of the modern challenges of the 21st century is the application of IT systems in any field and the production of devices based on new technologies. The application of modern information technologies in any field, including transport and logistics, is developing day by day. Currently, tracking of cargo transportation, automated transmission of documents in the system of delivery of goods from producer to consumer, and the introduction of new technologies have led to cost and time savings.If we look at the current state of the automation system along the middle corridor where Azerbaijan is located, we can see that there are some setbacks in this area. Although all transport and logistics entities along this corridor have internal systems, there are some problems in coordinating these systems on a common basis. It should be noted that the development of an automation system along the corridor will lead to attraction of additional cargo in this direction.

Lack of container vessels-- Although dry cargo vessels predominate in cargo transportation between ports in the Caspian Sea, the number of container vessels is insufficient. The low profitability of container transportation compared to dry cargo has reduced interest in this field.At present, the transported containers are mainly carried by dry cargo ships. Recent statistics on containers transported through the Baku Port show that the number of containers will increase in the future, which in turn will increase the demand for container vessels.

Azerbaijan's Logistics Performance Index

The Logistics Performance Index (LPI) is a comparative analysis tool developed by the World Bank to identify the challenges and opportunities that countries face in their trade and logistics activities. In addition, the World Bank provides guidelines for improving performance in the logistics sector based on the results of the LPI. The 2016 edition of the LPI presents a comparison of 160 countries. The data were collected on the basis of research conducted among logistics professionals, organizations and operators engaged in business activities in foreign countries.

The components analyzed in the International LPI were chosen based on recent theoretical and empirical research and on the practical experience of logistics professionals involved in international freight forwarding. They are:

• The efficiency of customs and border management clearance ("Customs").

• The quality of trade and transport infrastructure (Infrastructure").

• The ease of arranging competitively priced shipments (Ease of arranging shipments").

• The competence and quality of logistics services—trucking, forwarding, and customs brokerage ("Quality of logistics services").

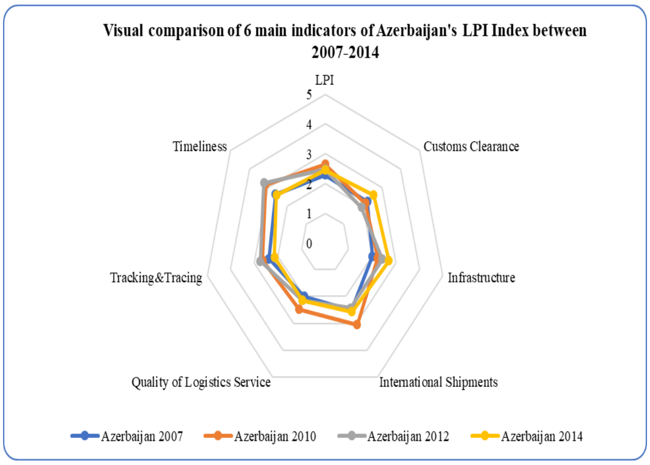
• The ability to track and trace consignments ("Tracking and tracing").

• The frequency with which shipments reach consignees within scheduled or expected delivery times ("Timeliness").

Based on this, a rating table is prepared for each country based on a general LPI based on a 5 score system.

The latest data on the logistics performance index of Azerbaijan is dated 2014. It shows that the country ranks 125th in the world with a score of 2.45 out of 5 points. Compared to global indicators, this indicator lags behind previous years. Thus, in 2012 it was 116th (LPI score: 2.48), in 2010 it was 89th (LPI score: 2.64), and in 2007 it was 111th (LPI score: 2.29). This process is described in the following graph:

Graph 2



Source: *World Bank* *http://www.worldbank.org/*

In 2014, Azerbaijan scored the highest score in the "Infrastructure" category (2.71 out of 5 points). He scored the lowest score in the "Logistics competence" and "Tracking & Tracing" categories and demonstrated a score of 2.14 points in both categories out of 5 possible points. Compared to previous years, there have been substantial improvements in the following categories:

• "Customs" - despite gaining 2.14 points in 2010 and 1.92 points in 2012, in 2014 it increased this figure to 2.57 points.

• "Infrastructure" - Increased from first three years scores of 2.42, 2.23 and 2 points to 2.71 in 2014.

In 2014, Azerbaijan scored low on the following indicators:

• "International shipments" - although in 2010 it scored 3.05 points, in 2014 this figure was 2.57.

• "Logistics competence" - 2.14 points in 2014 are the same as in 2012, but less than 2.48 points in 2010.

• "Tracking and Tracing" - the 2.14 score recorded in 2014 is the lowest since 2007 and is significantly lower than the 2.75 score in 2012.

• "Timeliness" - 2.57 points recorded in 2014 is the lowest since 2007. In 2012, Azerbaijan scored 3.23 points in this category.

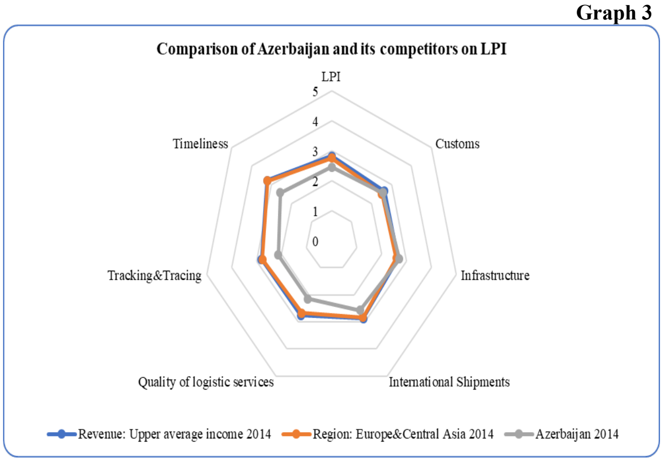
Azerbaijan's LPI score of 2.45 in 2014 led it to rank lower than its competitors in the following categories of countries.

1. Regional countries of Europe and Central Asia - LPI score: 2.76

2. Countries with the same income range (upper average income according to the World Bank classification) - LPI score: 2.82

The categories that show that Azerbaijan has a comparative advantage or is stronger than its competitors are "Infrastructure" and "Customs". The country performed poorly on 4 other indicators. This process is described below.

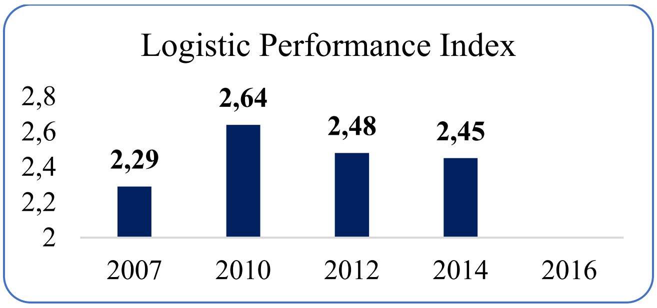
Graph 3



Source: *World Bank* *http://www.worldbank.org/*

The graphical description of the logistic performance index of Azerbaijan on years and 6 main factors is given below:

Graph 4



Source: *World Bank www.worldbank.org/*

Note: *Azerbaijan's Logistic Performance Index (by years). Data for 2016 are not available.*

The indicators of the Logistics Performance Index of Azerbaijan on 6 main factors are given in the following table:

Table 8

Years	Customs procedures	Infrastructure	International Shipments	Qualitative service	Tracking&Tracing	Timeliness
2007	2.23	2	2.50	2	2.38	2.63
2010	2.14	2.23	3.05	2.48	2.65	3.15
2012	1.92	2.42	2.43	2.14	2.75	3.23
2014	2.57	2.71	2.57	2.14	2.14	2.57
2016	-	-	-	-	-	-

Source: *World Bank www.worldbank.org/*

Note: *Azerbaijan's Logistic Performance Index (by factors and years). Data for 2016 are not available.*

CONCLUSION

Research shows that large-scale investment projects in which Azerbaijan has recently invested in transport and logistics infrastructure are exceeds their positive expectations. Azerbaijan's activities with the countries of the region aimed at the development of the middle corridor have also had positive impacts and recently there has been an increase in the number of containers from China. In addition, there are still some problems in the automation system along the corridor, such as non-harmonization of tariffs, non-coordination of railway and port potential, which has led to the transportation of large potential cargo by other routes via bypassing Azerbaijan. Expansion of the capacity of the Baku-Tbilisi-Kars railway (especially on the Georgian-Turkish border), construction of a container terminal and specific terminals in the port (fertilizer) as the main infrastructure and parallel development of super infrastructure (digitization) will increase the attractiveness of the transit corridor through Azerbaijan.

At the same time, Azerbaijan's alternative access to world ocean throught creation of Zangazur corridor will bring additional benefits to the current corridor while increasing the sustainability and reliability of the this corridor. Sustainability, reliability, time and price remain key factors for corridors.

REFERENCES

1) Luisa Martí, Juan Carlos Martín & Rosa Puertas (2017) A DeaLogistics Performance Index, Journal of Applied Economics, 20:1, 169-192, DOI: 10.1016/S1514-0326(17)30008-9
2) Raimbekov, Z.; Syzdykbaeva, B.; Mussina, K.; Moldashbaeva, L.; Zhumataeva, B. (2017), "The study of the logistics development effectiveness in the Eurasian Economic Union countries and measures to improve it", European Research Studies Journal, 4B: 251–276
3) Beysenbaev, R.; Dus, Y. (2020), "Proposals for improving the Logistics Performance Index", The Asian Journal of Shipping and Logistics, 36 (1): 28–42, doi:10.1016/j.ajsl.2019.10.001
4) Guner, S.; Coskun, E. (2012), "Comparison of impacts of economic and social factors on countries' logistics performances: a study with 26 OECD countries" (PDF), Research in Logistics and Production, 2 (4): 310–343
5) Jacoby, D., & Fugueiredo, B. (2008). The art of high-cost country sourcing. Supply Chain Management Review, 12(5), 32-38
6) Arvis, J. F., Saslavsky, D., Ojala, L., Shepherd, B., Busch, C., Raj, A., & Naula, T. (2016). Connecting to compete 2016: trade logistics in the global economy – the logistics performance index and its indicators. World Bank, Washington, DC.
7) Azərbaycan Respublikasında logistika və ticarətin inkişafına dair Strateji Yol Xəritəsi" 06 dekabr 2016-cı il, Azərbaycan Respublikası Prezidentinin Fərmanı

Research of Regional Environmental Conditions in the East-West Transport Corridor on the Basis of Space Images on the Territory of Azerbaijan

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***Abstract*—A calculation method is provided for the use of satellite imagery in connection with environmental research in the "east-west transport corridor". The results of the calculations are related to the territory of Azerbaijan.**

Keywords*—*space images, east-west transport corridor, regional atmospheric correction, atmospheric transparency, spectral coefficient of the earth

I. INTRODACTION

Spectrophotometric observations made by Earth's satellites are based on measuring the energy characteristics of solar radiation coming into the "atmosphere-Earth's surface" system. These characteristics are informative carriers of the environment. Continuously through space data: receives optical data from satellites, space database is created, atmospheric correction of satellite data is carried out [1, 2]. In our country, as well as in the "east-west transport corridor", the study of the environment on the basis of regional space images remains a topical issue [3].

Satellite imagery consists of two-dimensional images obtained as a result of remote recording of special reflection radiation by technical means designed to detect objects, identify events and processes. Spatial images - spatial resolution - with the minimum size of objects, spectral resolution - with the number of spectral zones, their width and location according to the electromagnetic spectrum, time separation - with the periodicity of a field, radiometric resolution - with the number of gradations in each spectral zone and caliber are characterized [2, 4].

The processing of space images in determining the optical characteristics of the Earth's surface and atmosphere is a complex, multi-stage and multi-purpose process. A number of special software is used for this purpose. These programs can be used in conjunction with GIS programs. Our main goal is to conduct physical modeling of spectral characteristics of radiation returning to the system "atmosphere - surface ambient layer - background - surface" for the purpose of studying the environment on the basis of satellite images in the "east-west transport corridor" in Azerbaijan.

II. CALCULATION METHOD

Sunlight returning to space from the Earth's surface is subjected to multiple scatterings of light in the "atmosphere - Earth's surface" system (figure 1). The main

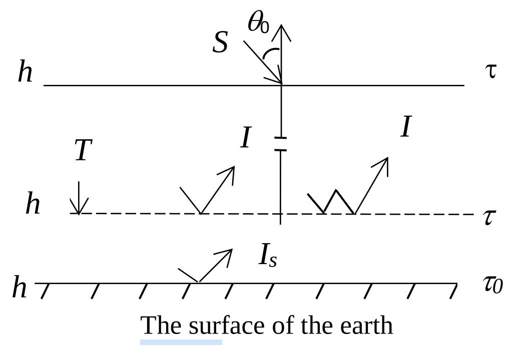

Figure 1. Reflection of light in the "Atmosphere - Earth's surface" system: S_0: Solar constant, I: "Sun radiation returning from the" atmosphere - earth's surface "system, I_{at}: from the atmosphere, I_s : from the Earth's surface, T - transparency of the atmosphere", h - height , τ: optical thickness of the atmosphere, θ_0 : angle of sunlight.

quantities that characterize this radiation are: the transparency and optical thickness of the atmosphere, the spectral brightness coefficient (SBC) of the earth's surface [2].

Since energy is an additive quantity, the intensity of the reflected radiation from the earth's surface h or the optical thickness of the atmosphere τ can be expressed as follows:

$$I(\tau_\lambda;\mu_0,\mu) = I_{at}(\tau_\lambda;\mu_0,\mu) + I_s(\tau_\lambda;\mu_0,\mu) \quad (1)$$

Where $\mu_0=\cos(\theta_0)$, $\mu=\cos(\theta)$; θ is the angle of scattering of light.

If we determine the radiation reflected from the earth's surface at any height h, then at this height $I(\tau_\lambda, \mu_0, \mu)$ returning from the atmosphere remains intact. This quantity is calculated as the solution of the atmospheric correction problem [2, 4].

Radiation returning from the "Atmosphere - Earth System" can be determined as follows, depending on the values of t - optical thickness [2]:

$$I(\tau;\mu_0,\mu) = F\rho(\tau;\mu_0,\mu)\mu_0 . \quad (2)$$

Here $\rho(\tau_\lambda, \mu_0, \mu)$ is the SBC of the "Atmosphere - Earth's surface" system. As can be seen from (2), the reflected radiation depends on the directions of sunlight and the observation point, in addition to the values of optical thickness. Will be set by us for the following values of atmospheric transparency:
for incident radiation:

$$T^{\downarrow}(\mu_0) = exp(-\tau / \mu_0) , \quad (3)$$

for returning radiation:

$$T^{\uparrow}(\mu) = exp(-\tau / \mu) . \quad (4)$$

The distribution of radiation characteristics of the "atmospheric-terrestrial" system on the basis of the processing of space images related to the "east-west transport corridor" in the territory of our country is determined below. In space images, the coordinates of the pixels of the cross section of the space images are determined in the form of a DNij matrix. DNij raster images are called primary (raw) data [1, 5]. For the processing of this data, we use the software package MATLAB (matrix laboratory), which is used to solve technical computational problems [6].

III. RESULTS OF CALCULATIONS

The distribution of radiation characteristics of the "atmospheric-terrestrial" system on the basis of the processing of space images related to the "east-west transport corridor" in the territory of our country is determined below. In space images, the coordinates of the pixels of the cross section of the space images are determined in the form of a *DNij* matrix. *DNij* raster images are called primary (raw) data [1, 5]. For the processing of this data, we use the software package MATLAB (matrix laboratory), which is used to solve technical computational problems [6].

To evaluate the transparency of atmospheric air was carried out using the following formula:

$$T_{ij} = \pi DN_{ij} / S_{i0}\mu_0 \quad (5)$$

In the visible region of the spectrum, based on the formula (5), the values of the Earth's surface area SBC at the approximation of the Lambert surface are determined as follows:

$$R_{ij} = 1-T_{ij} \quad (6)$$

In formulas (3) and (4), the optical thickness of the atmosphere is calculated according to the graph we constructed [2], given in figure 2.

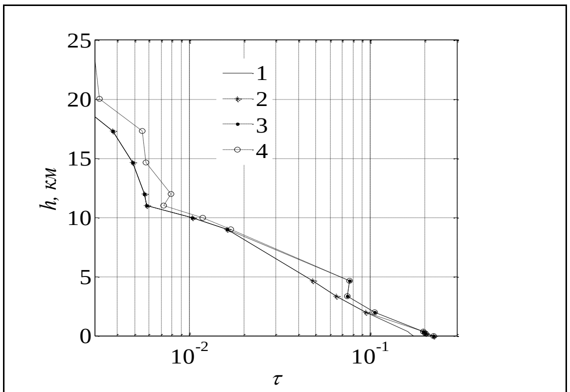

Figure 2. Vertical profiles of optical thickness of the atmosphere in the territory of Azerbaijan: 1 - average profile, 2, 3 and 4 -: daily (2), daily and seasonal (3), daily, seasonal and average annual (4) variations of optical thickness according to height.

Figure 3 shows a section of a spatial image of the “east-west transport corridor” in Azerbaijan.

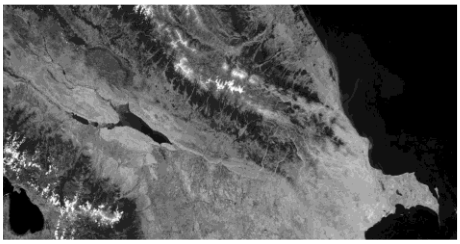

Figure 3. Section of space image to “east-west transport corridor” in the territory of Azerbaijan: A2005162.1010.250m _ Terra MODIS_ Bands 1-4-3 _true color [7].

Figure 4 calculates the brightness of the area given in figure 3. As can be seen from this picture, the territory of the Republic of Azerbaijan differs sharply in its diversity: the brightness of the mountainous areas is greater than that of the plains around the Absheron Peninsula and other Kura rivers.

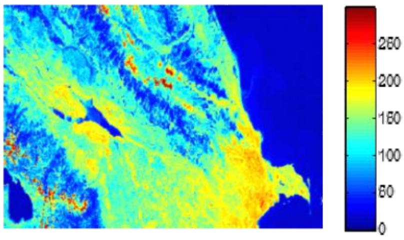

Figure 4. Brightness of the territory of the "east-west transport corridor" in Azerbaijan.

Figure 5 shows the transparency of the atmosphere and the distribution of the surface area SBC in the "east-west transport corridor" in the territory of our country. Figure 5a shows that the relief diversity of our country affects the background of the distribution of atmospheric transparency. This effect is more pronounced in the distribution of the Earth's surface area SBC. Thus, changes in the earth's surface can be accurately and quickly identified by satellite imagery in the "east-west transport corridor".

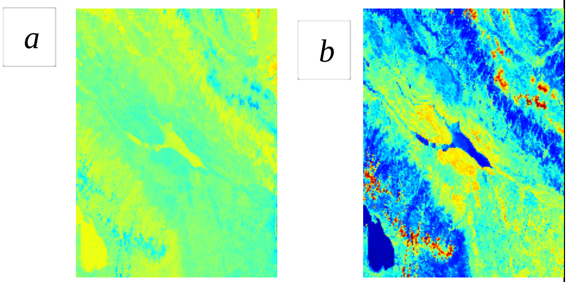

Figure 5. a - transparency of the atmosphere, b - surface area SBC.

IV. CONCLUSION

In Azerbaijan, on the basis of satellite imagery in the "east-west transport corridor", a calculation method has been provided for the study of the environment and the operative investigation of possible changes in this area. A regional optical model of the atmosphere was used to make the calculations. As a result of the calculations, the vertical profiles of atmospheric transparency and the SAA of the earth's surface cover are determined in the "east-west transport corridor".

REFERENCES

[1] GIS-Lab: Processing of data remote sensing (https://gis-lab.info/start.html) (in Russian).

[2] Ismailov F.I. Atmospheric aerosol. LAP LAMBERT Academic Publishing,, 2019. – 288 c. ISBN: 978-613-9-45431-0.

[3] East-West Transport Corridor - ADY Express. https://wvvw.adyexpress.az/en/transport-corridors/east-west (in Azerbaijani).

[4] A.M. Chandra, S.K. Gosh. Remote sensing and geographic information systems. Moscow, Technosphere, 2008, p. 82-84.

[5] Geographic information systems and remote sensing Electronic resource]. - Access mode: http: //gislab.info/qa/ndvi.html.

[6] Дьяконов В. Р. A guide to using the PC MATLAB system. - М .: «Физматлит», 1993. - 112 с. - ISBN 5-02-015101-7.

[7] NASA Visible Earth: Caspian Sea. MODIS Atmosphere: Images

(http://modis- atmos.gsfc.nasa.gov/IMAGES/index.html).

Development of Digital Economy: Current Situation and Future Prospects for Azerbaijan

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***Abstract*— This study examines the digital economy and its differences from the traditional economy, researches the strategic course that develops digitalization in world practice, and identifies the development and future prospects of the digital economy in Azerbaijan.**

Keywords*— *digital economy, big data, artificial intelligence, digital strategy

I. Introduction

In a rapidly developing world, digitalization is already at the forefront as a criterion measuring the pace of development and modernization. We can see how our lives and all spheres surrounding us are integrating with technological innovations, in other words, the partial or complete digitalization. Digitalization is also causing great changes in the economy. Thus, "digital economy", used as a contemporary term, is a new form of economy based on digital knowledge and technological innovation. This form of economy provides high-level information and communication technology (ICT) infrastructure and their mobilization for the benefit of users. Covering civil society, government, and business, this area is forming new digital knowledge and skills.

II. Technologies That Form the Digital Economy

A. *Selecting a Template (Heading 2)*

The following are the main technological trends that form the digital economy.

- **Big data** is a real-time e-technology that collects, processes, stores, presents, retrieves, transmits data and performs other data operations. Different procedures also have algorithmic and workflow information. In short, the inception of digitalization is the emergence of big data.

- **Artificial intelligence** is the second most widespread technological trend and the builder of many other technological innovations. It also acts as a base technology.

- **Neurotechnologies** are cyber-physical systems that affect or control the functions of the nervous system of a biological object, fully or partially, through artificial intelligence.

- **Blockchain technologies** (distributed registry technology) are algorithms and protocols consisting of blocks of information that are linked together in a chain and cannot be changed later.

- **Quantum technologies** are calculating systems working on quantum-effects-based new principles. These technologies allow changing the transmission and processing of data radically.

- **Additive technologies** builds 3-dimensional models of objects based on digital twins. It also includes highly complex geometric figures and profiles. 3D printers are the most vivid example of this technology.

- **Supercomputer technology** allows faster and precise calculations based on the processing of data on parallel and distributed principles.

- **New production technologies** mean digitalization of production processes. They enable the production of better quality products at a lower cost by ensuring more efficient use of resources, development of individual approaches, and design

- **Computer engineering** performs digital modeling of all objects and processes that surround people throughout their life.

- **Industrial Internet** is a network that provides internal circulation of information covering the manufacturing sector, as well as communication with external databases without the human interference.

- **Robotics components** provide the development of systems with 3 or more criteria of mobility (walking, talking, hearing, etc.) through sensors and artificial intelligence. These systems are able to perceive the environment, adapt to it and control their behavior.

- **Sensorics** are technologies that create devices collecting and transmitting information about the environment through data transmission networks. These technologies are applied in the production of all sensory items (phones and tablets, computers, home appliances, devices, etc.).

- **Wireless network technologies** provide transmission of through a standardized radio interface without the need for a cable connection. This includes the well-known Wi-Fi, Bluetooth, etc.

- **5G** is the 5th generation of wireless communication technology with speed much higher than others (provided that it is not less than 10Gbps). At the same time, the waiting time during data processing is also very short (provided it does not exceed 1 millisecond).

- **Virtual reality technology** is a technology that provides computer modeling of 3D images and environments. Application of these technologies let connect people to virtual reality through sensors. This type of technology is used in various games, psychological research, treatments, teaching methods, and simulators.

- **Augmented reality technology** makes the real world more interactive through visual effects. It is made possible by adding graphic design or sound effects to data or objects.

III. How does digital economy differ from traditional economy, and what are its advantages?

A) The digital economy increases efficiency

By introduction of new technological solutions, the digital economy is able to make all economic processes faster, more accurate, and efficient. Digitalization saves time, manpower and wages, which is considered one of its advantages. Thus, artificial intelligence and other opportunities created by technology allows perform more simultaneous work and attract less workforce. Consequently, increased productivity and reduced costs result in more productive activity.

Another indicator of the digital economy is the emergence of hyper-communication between different industries, sectors and individuals. These connections are made possible by the Internet, mobile technologies, and the Internet of Things (IoT).

The development of the economy, which is called a big organism, entails the development of its various sectors as interconnected ecosystems. In its turn, the strong communication created by the digital economy, strengthens the interaction between individuals in the ecosystem and ensures more efficient operation.

B) Ensures the access to new markets

Digitalization leads to the elimination of geographical barriers, access to new markets, and new partnerships. Unlike traditional economies, digitalization makes digital integration of markets possible. Various platforms are used for the exchange of information as well as transaction of documents and payments are transacted through various platforms. This makes a particularly positive contribution to international trade. Thus, import-export procedures are carried out more efficiently. In its turn, the expansion of markets and the increase in the range of products serve as a positive factor for both producers and consumers. Thus, by gaining access to new markets, producers can sell more products. Buyers can expand their options and take advantage of more affordable offers. In other words, a market with a productive and competitive environment is being formed. A competitive economy is known for its absolute tendency to development and improve. These interrelated procedures trigger economic development.

3.3. Digitalization causes economic development

We should also mention the positive effects of digitalization on economic development. The world practice demonstrates that the growth rate of the digital economy is twice as high as the traditional economy. At the same time, this pace is expected to continue with increasing dynamics. Digitalization has both direct and indirect effects on economic development. An example of a direct effect is the investment multiplier. According to international researches, investments are higher in countries with high digitalization. Savings in transaction costs also increase macro-level GDP. Certainly, the increase in education and work skills is also a factor in economic development. Coming to the indirect effects, we can mention such positive effects as increased productivity, increased coverage, elimination of geographical restrictions, etc.

New opportunities created by digitalization and new business models lead not only to the transformation of individual sectors, but also to the displacement of the entire economy as a single ecosystem. As more awareness, a higher level of accessibility, a more transparent, competitive and mobile market environment increases consumption, new technological solutions also create more modern and efficient production environment. For example, the Fero Labs' new platform, which predict the undesirable acidic environment in metallurgy (with 80-100% accuracy), allows to reduce this phenomenon to 15% and save millions of dollars every year by using technological devices. Following international experience, Russia also aims to increase the number of smart factories of the future based on machine learning and artificial intelligence to 40 by 2035.

Nowadays, development is considered an inevitable factor: all states enter a certain stage of development over a period of time. However, only agility makes it is possible to take advantage of this development for the sake of prosperity.

Agile adaptation to innovative solutions without lagging behind the global agenda helps countries to take their share of global value chains by entering a wave of development in a large ecosystem. In other words, it is important to be in the right place at the right time. The incredible pace of digitalization around the world makes prompt reaction and agility necessary for adaptation. In this regard, the term agile approach has already become a trend.

Considering the impact of digitalization on various sectors of the economy and its rapid spread, we can evaluate it as a key driver of economic development. According to Russian researchers, in 2030 more than half of the GDP (gross domestic product) growth will depend on digitalization (2.75% GDP growth with 1.47% of digitalization)

C) Social aspects of the digitalization

Along with a positive impact on the development of the overall economy and, indirectly, on the well-being of the population, the digital economy leads to positive changes in various aspects of people's lives. In other words, digitalization causes not only quantitative but also qualitative growth. Thus, by offering full or partial solutions to a wide range of problems that will arise in human life, digital solutions improve and facilitate people's living conditions. In parallel with the digitalization of the economy, there are formed a concept of a smart society. This society is more creative, quicker in adaptation to change, faster in development, and more prone to flexible solutions.

The mass character of digitalization does not cover only smart things, but also new concepts such as smart homes, smart cities, digital factories and jobs. Technology is involved in almost all areas of human life and is becoming an indispensable part of it.

Digitalization leads to changes in labor market, healthcare, education, and work of various service sectors.

IV. THE ROLE OF A STATE IN THE DEVELOPMENT OF DIGITAL ECONOMY

In all developed countries, the state and its reforms, as well as strategic measures play an initiative role in the development of digital technologies. Almost all countries set technological development as a priority in the national strategies. The approaches to ensuring technological development are the same but the implementation mechanisms are different. European Union countries are developing their strategies based on the Digital Agenda for Europe.

The first strategies in this field date back to the late 1990s and early 2000s. Thus, the e-Europe initiative came into force in 1999. At that period, the main goal was to build a digital infrastructure and ensure the integration of ICT into various sectors.

The next stage of the political and strategic course in the field of technological transformation began during the financial crisis of 2008-2009. The main goal of that period was to increase productivity by applying new technological solutions to various areas of production. That was the purpose of creation of 4th Industrial Initiative, launched in 2011.

Today, the strategy of the states in this area is focused on complex development. This approach covers such issues as ensuring the overall digital transformation, the development of new technologies-based information and communication infrastructure, strengthening information security, and the development of digital knowledge and skills. However, there are also strategies that include mainly separate areas of technological development. For example, among them we can mention the German National Strategy for the Development of Artificial Intelligence. Besides, the International Digital Strategy, approved by France in 2017, is mainly focused on cybersecurity.

The **Going Digital** project of the Organization for Economic Co-operation and Development's (OECD) aims to address the following issues:

• Define common political principles for the development of the digital economy, focusing on sustainable economic development and improving the welfare of the population, covering all sectors of the economy;

• Carry out an in-depth analysis of the current digital transformation policy, as well as the current level of development, future development prospects and risks;

• Investigate how different sectors will be affected as a result of digitalization.

One of the most important factors for the successful implementation of digitalization is the implementation of this process in a complex manner, as well as the involvement of all stakeholders (government officials, business entities, experts in science and education, etc.). In accordance with this model, during the preparation of Strategic Road Maps, which were approved in 2016, Azerbaijan also ensured the participation of all stakeholders – first, in discussions, and then, in providing of written proposals. Discussions also covered a broader format with visits to the regions. This type of approach is very effective for in-depth study of real gaps and needs.

Another important condition for the success of strategies is the definition of targets in accordance with performance indicators and timing, followed by monitoring. In the case of Germany, as a result of these inspections, the **Digital Economy Index** was calculated in 2013. Conducting inspections and delivering them to the public imposes additional responsibilities on executors and motivates them. In Azerbaijan, all strategies and state programs are also monitored upon the implementation and the results are disseminated via media portals.

We can see a wide difference between application mechanisms of technological innovations. During the implementation of innovations, there were created various pilot sites for the implementation of pilot projects (automatic driving in Germany, blockchain technology in the Republic of Korea on), 4th Industrial Testing Laboratories (Australia), Innovation Centers (Republic of Korea, as well as in Azerbaijan), production innovation institutes (USA) etc.

To solve the problem of the lack of legal and regulatory framework for new technologies and the inability to legally regulate their application, there was created a new concept called "Sand Box". According to this concept, innovations that have no legal basis are implemented in a test mode under state control and are monitored during their operation. Then, once they are successful, the legal framework is updated and amended as needed.

Another task of the state is to provide financial support to stimulate technological development. Thus, startups with a large share in innovation often do not have the financial resources and need financial support to implement their ideas. Although there are various Venture Funds, Seed and Angel investors in this area, state funds and various concessions and subsidies applied by the state also play a highly significant role. For example, Japan offers tax credits to companies specializing in technology. European Union countries have established subsidies for small and medium-sized businesses specializing in the given area. Australia sets softer tender conditions for local technology companies to take part in public procurement. A similar mechanism is applied in Azerbaijan. A special fund has been set up in France to finance innovations for the development of the digital economy. The United States has Technology Modernization Fund.

The creation of technological solutions and the development of infrastructure is not sufficient for the development of digitalization and the wider application of technological. The needs of users also play an important role in this area. Thus, an increase in demand without supply does not lead to development. The formation of the supply primarily depends on the increase of public awareness, as well as the increase of literacy in this area. In this regard, it is important to conduct various trainings, prepare informative social videos.

V. Development of Digital Economy in Azerbaijan and Future Prospects

Azerbaijan is distinguished by its propensity for innovation and development in many areas. The entrepreneurs and the people, especially the state has always been interested in introduction and application of new global trends in our country. Our country has always focused on the implementation of the latest digital trends and included it in various state strategies and programs as one of the important parts of Azerbaijan's state policy.

D) The level of economy digitalization in Azerbaijan

In 2020, the information and communication sector accounted for 2% of GDP. During 2005-2019, the added value in the ICT (information and communication technologies) sector increased from 320 million manat to 1,279 million manat. With a share of 41 percent mobile communication ranks first in the structure of the ICT sector. The biggest increase over the last 10 years has been in the use of websites (web portals) and *software* development. After the launch of the first satellite Azerspace 1, there were launched satellite communication services. Between 2013 and 2019, there has been 8-time increase in the provision of services for this kind of activity.

The world experience demonstrates that the development of the ICT sector is directly proportional to the share of the private sector in this area. In other words, the development of the general ICT market is characterized by greater involvement of the private sector. There are 4,115 micro, small and medium enterprises operating in the information and communication sector in Azerbaijan. 96% of these enterprises are representatives of the private sector. In the telecommunications sector, mobile operators are private companies, while the largest fixed broadband network providers are state-owned.

Today, people in Azerbaijan can use 450 e-public services through a One-Stop-Shop system. In total, more than 1,000 e-services are offered by public and private organizations. Mobile network covers 100% of the country. Over the past 7 years, there have been made more than 100 million mobile e-signature transactions, saving hundreds of millions of working hours.

Coming to the digitalization of education in Azerbaijan, we can mention that ADA University is the most digitalized university. The university has an internal e-mail system, an online library with a cloud system, online forums for students, online conduction of tests and exams, and electronic homework assignments. In addition, the application of interactive methods, the use of "smart" boards, demonstration of audio and video materials were added to the traditional teaching process. Another university with a high level of digitalization is UNEC (Azerbaijan State University of Economics). The university's advanced electronic systems allow for a high level of online education. In addition, UNEC has implemented structural reforms on the road to digitalization. As a result, there were created the Faculty of Digital Economics, the Distance Education Research Institute, and the Digital Volunteers Organization. The technical base (unibook - electronic information system of education and "AZII e book house" electronic library), which is also available at the Azerbaijan State University of Oil and Industry, helps to continue the educational process online and conduct online exams. There are also several other educational institutions which are characterized by rapid digitalization.

E) Reforms in the field of digital development of Azerbaijan's economy

Measures to strengthen digitalization in Azerbaijan started with the "National Strategy for Information and Communication Technologies for the Development of the Republic of Azerbaijan" signed by national leader Heydar Aliyev in 2003. The work carried out in the field of application of "e-government" was continued with the adoption of the "State Program for the Development of Communications and Information Technologies in the Republic of Azerbaijan for 2005-2008" (E-Azerbaijan). Next was the the second E-Azerbaijan State Program for 2010-2012 and "Action Program for the formation of e-government in the Republic of Azerbaijan". Such initiatives as "smart city", "smart village" and "green zone" in Karabakh should also be considered as part of the digital transformation.

The strategy of electronic and digitalization in Azerbaijan has been implemented in a comprehensive manner. There were created such digitalized sites as State Control Information System, Azerbaijan Digital Trade Hub, Electronic Agricultural Information System, e-procurement platform for public procurement, e-document circulation system for obtaining state statistics, e-judicial system, e-health service, e-education, e-social services, electronic cadastre of property and lands, etc.

The digitalization of public administration has also led to a number of important government projects. Thus, the Center for Analysis of Economic Reforms and Communication established **monitoring.az** portal to monitor and evaluate state programs, strategic road maps, action plans, economic incentive projects, as well as activities in industrial parks, neighborhoods, and agro-parks. At the same time, the process of e-government is underway to improve local governance in local executive bodies in accordance with the principles of e-government and open government. Since May 2021, Government Development Center (EGD) of the State Agency for Citizen Services and Social Innovations under the President of the Republic of Azerbaijan operates Digital Executive Power portal, the creation of which has started **with e-municipality** system.

The process, which began with the e-municipality system, has been continued since May initial version of the by the e- with the. In addition, the Decree of the President of the Republic of Azerbaijan dated April 27, 2021 "On improving governance in the field of digital transformation" states that the digital transformation of the economy and society has become one of the priorities of the Republic of Azerbaijan in recent years. Moreover, the Decree of the President of the Republic of Azerbaijan "On improving governance in the field of digital transformation" dated April 27, 2021 states that the digital transformation of the economy and society has become one of the priorities of the Republic of Azerbaijan in recent years.

F) The position of a country in international digital assessment rankings

The implemented reforms have a positive impact on the country's position in international rankings. Thus, for two years now, World Bank has evaluated Azerbaijan and put in the list of the top 10 most reformist countries in the world. According to the **Global Cyber Security Index 2020** (GCI) of the International Telecommunication Union - one of the leading reports at the international level, this year, Azerbaijan has moved up 15 positions and reached 40th place. With a total of 89.31 points, our country ranks third among the CIS countries after Russia and Kazakhstan. It is no coincidence that this year, Estonia - our closest partner in the field of digital solutions, ranks third in the index.

Digitalization also contributes to the country's global development, integration with other countries, as well as increase of international trade and cross-border transactions. According to **the UN Global Survey on Trade Facilitation**, Azerbaijan has shown 5% growth compared to 2019 and ranked first among both neighboring countries and the CIS with a total of 86.02%.

The establishment of the **Digital Trade Hub** as a result of the reforms implemented in this sphere by President Ilham Aliyev and implementation of tasks set in the Decree of the President of the Republic of Azerbaijan on additional measures for strengthening the position of the Republic of Azerbaijan as a Digital Trade Hub and expansion of foreign trade operations has led to the simplification of cross-border trade procedures and stimulated the development of e-commerce and paperless trade, particularly, cross-border paperless trade. It is no coincidence that in 2 years, Azerbaijan has achieved a 33% increase for cross-border paperless trade sub-indicator of the rating and gained a leading position at the global level in terms of the pace of development in this area.

Reforms in the field of customs - creation of "Green Corridor", "Automated Customs System" and One-Stop-Shop electronic systems, e-filling of customs declarations and e-submission of certificates, as well as e-payment of customs duties and taxes served to simplification of trade procedures in Azerbaijan.

At the same time, the fact that Azerbaijan was one of the first countries to sign the Framework Agreement on Facilitation of Cross-border Paperless Trade in Asia and the Pacific, which came into force on February 20, 2021, has made a positive contribution to improving the country's position in this area.

G) Development prospects for the digital economy

Azerbaijan has favorable opportunities for the development of the digital economy. The geographical position of our country, its participation in the global digital agenda, and international cooperation are among the factors accelerating this process in a positive way. Digitalization is one of the main drivers of economic development, having a two-way interaction in the field of international integration. Thus, as international integration provides an opportunity to be closer to global trends, to adapt to them, and to apply them more flexibly, the increase in the level of digitalization also facilitates international integration.

Given the important role of digitalization in the development of the country, this area is considered a priority in all future strategies. It is no coincidence that the development strategy of Karabakh includes the task of building cities and villages with high-tech infrastructure such as "smart city" and "smart village" in the liberated territories. This factor can be considered a very important step for economic development. High digitalization will attract more investment as a factor that increases the investment multiplier and will stimulate the economic development of the whole country, not just the region. The existing e-government-private partnership platform - Digital Trade Hub - also allows investors to make these investments in digital format, i.e. through this platform without coming to Azerbaijan. Non-residents can become electronic or mobile residents of Azerbaijan online, set up their own company in Azerbaijan, open a bank account and carry out various operations online.

According to the Decree of the President "On measures to create a" government cloud "(G-cloud) and provide" cloud "services", all state bodies, state-owned legal entities and legal entities the controlling stake of which belongs to the state, as well as budget organizations and public legal entities has started shifting to cloud technologies. It is planned to completed this transition by 2024. Such transformation in itself will be a very important step towards the digitalization of public administration, as well as a positive contribution to the introduction of other technological innovations in the future.

CONCLUSION

The of the political and economic course of the country's leadership, as well as the people's own propensity for innovation and the ability to adapt to innovations, allows predicting that the transition to digitalization will be easier and faster in Azerbaijan. It means that Azerbaijan has high prospects for development in this area.

REFERENCES

[1] Cisco - Where to Begin Your Journey to Digital Value in the Private Sector Economic Analysis - https://www.cisco.com/c/dam/en/us/ solutions/collateral/service-provider/value-at-stake.pdf

[2] Deloitte - What is Digital Economy? - https://www2.deloitte.com/mt/en/ pages/technology/articles/mt-what-is-digital-economy.html

[3] DigitalGov -An Overview of the Technology Modernization Fund (TMF) - https://digital.gov/event/2018/05/22/an-overview-technology- modernization-fund-tmf/

[4] Dövlət Xidmətləri Portalı - https://www.dxr.az

[5] OECD Digital Economy Outlook 2020- https://www.oecd-ilibrary.org/science-and-technology/oecd-digital-economy-outlook-2020_bb167041-en

[6] Rəqəmsal Ticarət Qovşağı- İslahat İcmalı xüsusi buraxılış 2018 - http://ereforms.gov.az/files/review/pdf/az/5724444b86575a22f4086dca84eed192.pdf

[7] V.Qasımlı –İqtisadi Artım Post-Konflik və post-pandemiya dövrü: çağırışlar və həllər (2021)

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Technology of Adaptive Vibration Control of the Beginning of the Latent Period of Railroad Accidents

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***Abstract*—At present, control and diagnostics systems are widely used in rail transport. In this case, vibration parameters, pressure, efforts, current, voltage, resistance, impulses, time intervals are used as informative attributes. The control results are displayed on the driver's monitor. Among these parameters, vibration signals are of particular importance when solving diagnostic problems. They are obtained from vibration sensors installed on rolling stock, on bridges, on tunnels and have an immense information potential. As a rule, they have a complex cyclic stepwise abruptly changing shape and are accompanied by significant noise $\varepsilon(i\Delta t)$. Control systems currently use spectral methods and algorithms to analyze these signals. However, for a number of reasons, there are cases in practice when the adequacy of the results of the solution of the control and diagnostics problem is not ensured. This is due to the fact that the analysis and identification of stepwise and abruptly changing vibration signals with the use of spectral technologies in many cases requires determining a large number of spectral estimates with the corresponding amplitudes and frequencies. In addition, the vibration signal received from these vibration sensors is characterized by a change in the spectrum depending on the speed of the train. For instance, the spectra of vibration signals at a speed of 100 km/h will differ significantly from that of the same vibration signals at a speed of 200 km/h. Therefore, the sampling interval in the first case will be unacceptable for the second case. For these reasons, solving the problems of control of both rolling stock and railroad tracks becomes significantly more complicated. In view of the above, the authors propose an adaptive technology for the forming informative attributes from the estimates of position-binary vibration signals, which makes it possible to improve the adequacy of the control results.**

Keywords— vibration control of the beginning of accidents, rolling stock, information attributes, intelligent systems, sensors, vibration, vibration and Noise technologies

I. Introduction

It is known that spectral methods are used in most cases of control and diagnostics of the technical condition of cyclic (periodic) processes [1-4]. For instance, objects with equipment of reciprocating motion, objects with rotating nodes, etc. are cyclic. The importance of this problem is due to the fact that the vibration signals received from vibration sensors on rolling stock, on railway tracks, on bridges and tunnels have the main properties of cyclic objects, which have a great information potential. The signals $g(i\Delta t)$ received from the sensors installed on all these objects, as a rule, have a complex stepwise abruptly changing form and are accompanied by significant noises $\varepsilon(i\Delta t)$. Spectral methods and algorithms are currently used in control systems to analyze these signals [1, 4-6]. However, for a number of reasons, the adequacy of the results of the solution of the control and diagnostics problem is not ensured in practice [1]. This is due to the fact that the analysis and identification of stepwise and abruptly changing vibration signals with the use of spectral technologies in many cases requires determining a large number of spectral estimates with corresponding amplitudes and frequencies. This significantly complicates the solution of problems [1, 4-6] of controlling the beginning of the latent period of malfunctions of both rolling stock and railroad tracks. Therefore, to ensure the adequacy of the results of control and diagnostics, more effective methods and algorithms are needed, which would allow not only reducing the number of terms of the "spectrum", but also improving the reliability of the obtained results in comparison with the spectral method.

II. Problem Statement

It is known that when spectral method algorithms are used for the analysis of the vibration signals $X(t)$ with bounded spectrum, they are resolved into harmonic components, using the expression

$$X(t) = \frac{a_n}{2} + \sum_{n=1}^{\infty}(a_n \cos n\omega t + b_n \sin n\omega t) \quad (1)$$

In expression (1), a_n and b_n are the amplitudes of the cosine curve and the sine curve with the frequency $n\omega$, which are taken as informative attributes in controlling the beginning of accident initiation. It is known that the following inequality should hold true to provide accuracy of reconstruction of signal $X(t)$.

$$\sum_{i=1}^{n} \lambda_i^2 \leq S, \quad (2)$$

where λ_i^2 is the squared deviations between the sum of the right-hand side of equality (1) and the samples of the signal $X(t)$ at the sampling moments $t_0, t_1, \ldots, t_i, \ldots, t_n$ with the interval Δt; S is the allowable value of the mean square deviation.

For intermittent and abruptly changing vibration signals, ensuring inequality (2) leads to increase of the number of harmonic components, which therefore complicates the analysis and identification of experimental data. In addition, for the case where the measurement information is the mixture of the useful signal $X(t)$ and the noise $\varepsilon(t)$, condition (2) holding true depends to a certain extent on the value of the spectrum of the noise $\varepsilon(t)$. In the existing methods of spectral analysis in equality (1) the influence of noise is neglected and the error of the noise $\varepsilon(t)$ is equated to zero. However, for many objects of rail transport, the influence of the noise on the accuracy of reconstruction of the source signal $X(t)$ turns out to be significant and should be taken into.

If we take into account that in the latent period of the initiation and development of a malfunction, the spectrum of the noise $\varepsilon(t)$ changes continuously, then the difficulty of solving problems of identifying cyclic noisy signals with the use of traditional spectral analysis becomes obvious. Therefore, it is necessary to create new technologies for analyzing vibration signals, taking into account the peculiarities and specifics of the operation of rail transport.

In addition, to ensure the adequacy of the solution of control problems, it is necessary to use the entire information potential of noisy vibration signals $g(i\Delta t) = X(i\Delta t) + \varepsilon(i\Delta t)$. This, first of all, requires determining the sampling interval of these signals in real time. This is due to the fact that the spectrum of vibration signals $g(i\Delta t)$ received from the vibration sensors of these objects changes depending on the speed of the rolling stock. Therefore, to ensure the required accuracy of the results, the sampling interval has to be determined based on the signal spectrum at the current time instant. In other words, to ensure the adequacy of the results of control and diagnostics, an adaptive technology for sampling vibration signals is needed.

III. Possibility of Control of the Beginning of the Latent Period of Malfunctions Using the Position-Binary Technology

Studies [1, 7-9] have shown that for the analysis of vibration signals, it is advisable to use the position-binary technology (PBT) analysis of vibration noisy signals in control and diagnostics systems of rail transport [1].

It is known that in practice, in measuring of the signals $g(t)$, there is a minimum value of increment that depends on the resolving capacity of the device in use. Denote that minimum value of increment by Δx. Therefore, during measuring of the signal, the number of its discrete values will be equal to

$$m = \frac{x}{\Delta x} + 1.$$

In the process of analog-to-digital conversion of the vibration signal $X(t)$, its amplitude sampling occurs at each sampling interval Δt, i.e., the range of its possible variations is divided into m_{max} of quantization steps, and the value of the signal that gets into the m-th interval, with

$$m\Delta X - \frac{\Delta X}{2} \leq X(t) \leq m\Delta x + \frac{\Delta x}{2} \quad (3)$$

belongs to the center of the interval $m\Delta X$. In this case, values of binary codes of corresponding bits q_k of the samples of the sampled signal $X(i\Delta t)$ with the sampling interval Δt are calculated based on the following algorithm [1, 7-9]:

$$q_k(i\Delta t) = \begin{cases} 1 & \text{when } x_{rem(k)}(i\Delta t) \geq \Delta x 2^k; \\ 0 & \text{when } x_{rem(k)}(i\Delta t) < \Delta x 2^k; \end{cases} \quad (4)$$

$$x_{rem(k)}(i\Delta t) = x_k(i\Delta t) - [q_{k+1}(i\Delta t) + q_{k+2}(i\Delta t) + \cdots + q_{(n-1)}(i\Delta t)],$$

where

$$X(i\Delta t) > 2^n;\ x_{rem(n-1)}(i\Delta t) = X(i\Delta t), n \geq \log\frac{x_{max}}{\Delta x},$$

$$k = n-1, n-2, \ldots, 1, 0.$$

In accordance with this algorithm, the equality $x_{rem(n-1)}(i\Delta t) = X(i\Delta t)$ is assumed at each sampling interval Δt, and according to condition (4), the signals $q_k(i\Delta t)$ form in the form of code 1 or 0 iteratively. At the first step, $X(i\Delta t)$ is compared with the value $2^{n-1}\Delta x$. According to (4), if $X(i\Delta t) \geq 2^{n-1}\Delta x$, then the bit $q_{n-1}(i\Delta t)$ is equated to unit and the value of the remainder $x_{rem(n-2)}$ is calculated from the difference

$$X(i\Delta t) - 2^{n-1}\Delta x = x_{rem(n-2)}$$

In the case when $X(i\Delta t) < 2^{n-1}\Delta x$, the bit $q_{n-1}(i\Delta t)$ is equated to zero, and the difference remains unchanged. The same thing occurs in the next iteration. As a result, in every conversion cycle with the sampling interval Δt, the signal $X(i\Delta t)$ is as if decomposed into the signals $q_k(i\Delta t)$,, which assume values 1 or 0 and have weights corresponding to their positions. The codes remain unchanged as long as the value of the source signal $X(i\Delta t)$ does not change in the sampling process. Let us from now onwards call these signals position-binary signals (PBS). Therefore, position-binary technology (PBT) of analysis of the vibration signal is the aggregate of successive processing procedures based on decomposition of the vibration signal into PBS.

According to algorithm (4), in the process of analog-to-digital conversion, the width of PBS will be proportional to the number of Δt, when $q_k(i\Delta t)$ remains unchanged. Depending on the shape of $X(i\Delta t)$, the same signal $q_k(i\Delta t)$ can change its value several times at corresponding time spans. Note that $T_{k1_1}, T_{k1_2}, \ldots$ here correspond to the time spans when the condition $q_k(i\Delta t) = 2^k(\Delta x = 1)$ is fulfilled; $T_{k0_1}, T_{k0_2}, \ldots$ correspond to the time spans when the condition $q_k(i\Delta t) = 2^k(\Delta x = 0)$ is fulfilled. Naturally, if object's technical condition operating in the cyclic mode remains unchanged, then combinations of the time spans $T_{k1_1}, T_{k0_1}, T_{k1_2}, T_{k0_2}, \ldots$ of PBPS in each cycle will be constant values and reiterate. Otherwise, they change as well. According to expression (4), the sum of all PBS in each cycle will be equal to the source signal, i.e.,

$$X(i\Delta t) \approx q_{n-1}(i\Delta t) + q_{n-2}(i\Delta t) + \cdots + q_1(i\Delta t) + q_0(i\Delta t) = g^*(i\Delta t).$$

Each $q_k(i\Delta t)$ can be regarded as a separate signal, and the combinations of sequences of the time spans when $q_k(i\Delta t)$ are in the state of unit or zero, can be regarded as informative attributes. Due to this, for vibration signals, those PBS $q_k(i\Delta t)$ will be periodic rectangular pulses with the corresponding unit T_1 and zero T_0 half-periods. Here, at the moments t_i, the difference between the true value of the source signal $X(i\Delta t)$ and the sum of PBS will be equal to

$$X(i\Delta t) - X^*(i\Delta t) = \lambda(i\Delta t).$$

Taking into account expression (3), the following inequality can be written:

$$\lambda(i\Delta t) \le \pm\frac{\Delta x}{2}.$$

Due to this, the beginning of changes in object's technical condition leads to a change in the corresponding samples of the vibration signal $X(i\Delta t)$ by a value exceeding Δx, and it will reflect on its corresponding bits $q_k(i\Delta t)$. Therefore, already at the initial stage of the malfunction in the process of PBS formation in the form of the combination of the corresponding time spans $q_{n-1}(i\Delta t)$, $q_{n-2}(i\Delta t)$, …, $q_0(i\Delta t)$ of the current time instant, the difference from their analogous parameters in previous time instants will be revealed, which will allow one to form and present the information on the beginning of the latent period of changes in control object's technical condition. This only requires calculating the mean frequency $\langle f_k\rangle$ and the period $\langle T_k\rangle$ of position-binary signals. The algorithms for their calculation are easily implemented in practice, since each position-vibration signal assumes only two values. It is intuitively clear that for random and periodic noisy signals $g(i\Delta t)$ the estimate of the mean value of zero and unit half-periods of the position signals $q_k(i\Delta t)$, given the sufficient observation time T, can be calculated from the formula

$$\langle T_{q_k}\rangle = \langle T_{1q_k}\rangle + \langle T_{0q_k}\rangle, \quad (5)$$

where

$$\langle T_{1q_k}\rangle = \frac{1}{\gamma}\sum_{j=1}^{\gamma} T_{1q_{kj}}, \qquad \langle T_{0q_k}\rangle = \frac{1}{\gamma}\sum_{j=1}^{\gamma} T_{0q_{kj}}. \quad (6)$$

Here γ is the number of unit and zero half-periods of PBS in the observation time T, j is the is ordinal number of the q_k-the position of PBS.

It is demonstrated in [1] that for the sufficient observation time, if the condition of stationarity is satisfied, the estimate of the mean duration of the periods $\langle T_k\rangle$ and the mean frequency f_{q_k} of PBS will be nonrandom values. Therefore, they can be used as informative attributes to control the beginning of changes in object's technical condition. And due to the simplicity of their calculation, they can significantly simplify solving of control problems, which are traditionally solved by means of estimates of correlation or spectral characteristics of random processes. In the general case, in cyclic object's normal stable technical condition, sets of combinations of mean frequencies of PBS $q_k(i\Delta t)$ can be formed from the signal $g(i\Delta t)$. Obviously, a change in object's technical condition will lead to changes in the combinations of the estimates of their mean frequencies $\bar f_{q_0}, \bar f_{q_1}, \dots, \bar f_{q_m}$, which are calculated from the expressions

$$\bar f_{q_0} = \frac{1}{\langle T_{q_0}\rangle}, \bar f_{q_1} = \frac{1}{\langle T_{q_1}\rangle}, \bar f_{q_2} = \frac{1}{\langle T_{q_2}\rangle}, \dots, \bar f_{q_m} = \frac{1}{\langle T_{q_m}\rangle}.$$

and are nonrandom values.

Let us now consider the possibility of using the relationship between the beginning of the latent period of accidents and the estimates of the characteristics of positional-binary signals [1, 7, 8]. As mentioned above, for many cyclic objects, sharply changing high-frequency spectra appear in the signal at the beginning of the initiation of defects. For instance, on roller bearings of axleboxes of rolling stock, on reinforced concrete structures of railroad bridges, etc. a malfunction often manifests itself in the form of high-frequency spectra. As indicated above, when coding these continuous signals $g(i\Delta t)$, signals $q_k(i\Delta t)$ are iteratively generated in the form of code 1 or 0 from their samples at each sampling interval Δt. For this purpose, in the first step, samples of $g(i\Delta t)$ are compared with $2^{n-1}\Delta g$. For $g(i\Delta t) \ge 2^{n-1}\Delta g$, the value of $q_{n-1}(i\Delta t)$ is equal to one, and the sequence of the signals $\mathrm{q_k(i\Delta t)}$ is determined from the difference

$$g(i\Delta t) - 2^{n-1}\Delta g = g_{rem(n-2)}(i\Delta t).$$

Then combinations T_{1q_k}, T_{0q_k} are determined for all bits from expressions (5), (6). Then from expressions

$$\bar f_{q_0} = \frac{1}{\langle T_{q_0}\rangle}, \bar f_{q_1} = \frac{1}{\langle T_{q_1}\rangle}, \bar f_{q_2} = \frac{1}{\langle T_{q_2}\rangle}, \dots, \bar f_{q_m} = \frac{1}{\langle T_{q_m}\rangle}$$

$$k_{fq_0} = \frac{f_{q_1}}{f_{q_0}}, k_{fq_1} = \frac{f_{q_2}}{f_{q_1}}, k_{fq_2} = \frac{f_{q_3}}{f_{q_2}}, \dots, k_{fq_m} = \frac{f_{q_m}}{f_{q_{m-1}}}$$

$$k_{q_0} = \frac{\langle T_{q_1}\rangle}{\langle T_{q_2}\rangle}, k_{q_1} = \frac{\langle T_{q_2}\rangle}{\langle T_{q_3}\rangle}, k_{q_2} = \frac{\langle T_{q_3}\rangle}{\langle T_{q_4}\rangle}, \dots, k_{q_m} = \frac{\langle T_{q_m}\rangle}{\langle T_{q_{m-1}}\rangle},$$

the combinations of frequencies of PBS $\bar f_{q_0}, \bar f_{q_1}, \bar f_{q_2}, \dots, \bar f_{q_m}$ and the combinations of the relations $k_{fq_0}, k_{fq_1}, k_{fq_2}, \dots, k_{fm}$ and $k_{q_0}, k_{q_1}, k_{q_2}, \dots, k_{q_m}$ are detemined. It is easy to see that by forming a set of informative attributes from them, it is possible to create intelligent technologies for the control of the beginning of the latent period of malfunctions in the above objects.

IV. Adaptive Technology for Determining the Sampling Interval of Vibration Signals

As mentioned above, the vibration signal $X(t)$ can take any value within the range of $X_{min} \dots X_{max}$. At the same time, in measuring of the signals in practice, there is a minimum value of increment that can also be determined by of the device in use and depends on its resolving capacity. Therefore, during measuring of the signal, the number of its discrete values is finite:

$$n = X/\Delta X + 1,$$

and in the process of measuring the vibration signal, its amplitude quantization occurs, i.e., the range of its possible changes (X_{max}, X_{min}) is divided into n quantization intervals and the value of the signal falling into the S-th interval, at

$$S\Delta X - \frac{\Delta X}{2} \le X(t) \le S\Delta X + \frac{\Delta X}{2}$$

belongs to the center of the interval $S\Delta X$.

Due to the properties of analog-to-digital conversion, the signal $x(t)$ is represented here in the form

$$x(t) = q_0(t) + q_1(t) + q_2(t) + q_3(t) + \cdots = \sum_{k=1}^{n} q_k(t).$$

where the values of the signals $q_k(t)$ at each time instant represent the values of the corresponding bits of the digital equivalent of the signal $X(t)$.

Thus, the amplitude-quantized vibration signal in the process of analog-to-digital conversion is represented as the sum of the vibration signals $q_k(t)$. In this case, an approximate analysis of the frequency properties of position-vibration signals $q_k(t)$, which take only two values, is much simpler than that of the vibration signals themselves. In view of this, let us consider the possibility of using this specific feature of the analog-to-digital conversion process for adaptive determination of the sampling interval of the vibration signal. This formulation of the problem is of great practical interest for rail transport, where the frequency of the spectra of vibration signals changes depending on the speed of the rolling stock. This makes the time sampling interval somewhat difficult to determine by traditional methods. At the same time, in the process of analog-to-digital conversion, the original signal $X(t)$ is naturally decomposed into position-vibration signals $q_k(t)$, which take only the values "1" and "0". Due to this, the hardware determination of the frequency of change in these signals is quite simple. For instance, the mathematical expectations of the duration $T_{1_{q_0}}$, $T_{0_{q_0}}$ of rectangular pulses of the lowest-order position-vibration signal $q_0(t)$ can be determined from the expressions

$$T_{1_{q_0}} \approx \frac{1}{n_0}\sum_{i=2}^{n_0} T_{1_{q_{0i}}},$$

$$T_{0_{q_0}} \approx \frac{1}{n_0}\sum_{i=1}^{n_0} T_{0_{q_{0i}}},$$

where $T_{1_{q_{0i}}}$, $T_{0_{q_{0i}}}$ are time intervals when the following conditions are met:

$$q_0(t) = 1, q_0(t) = 0.$$

In this case, the mean period of pulses of the lowest-order position-vibration signal $T_{m\,q_0}$ and the mean frequency of their repetition are determined from the expressions

$$T_{m\,q_0} = T_{1_{q_0}} + T_{0_{q_0}},$$

$$f_{q_0} = \frac{1}{T_{m\,q_0}}.$$

$$f_{q_0} = \frac{1}{\langle T_{q_0}\rangle}. \quad (7)$$

We can assume that the result obtained by formula (7) is practically an estimate of the frequency of the period of the lowest-order position-vibration signal, which can be taken as an appropriate sampling frequency of the vibration signal.

Obviously, for noisy vibration signals, the values of the binary codes of neighboring samples of $g(i\Delta t)$ will be repeated at an excessive traditional sampling frequency f_T. Therefore, the following inequality will take place between the frequency f_T found by the traditional method and the current frequency f_t:

$$f_t \gg f_T. \quad (8)$$

It is intuitively clear that the estimate of the mean value of $\overline{f}_{q_0}$ for all implementations of the same vibration signal in the period of a stable technical condition of the object will be a stable value. Therefore, selecting the value of f_t so that conditions (8) are met, it is possible to calculate the estimate of the mean value of $\overline{f}_{q_0}$. Here, in the process of analog-to-digital conversion, the condition for determining sought-for frequency (8) can be represented as follows

$$f_t \geq f_{q_0}.$$

Following from this condition, the sampling interval Δt for the noisy signal $g(i\Delta t)$ can be selected in accordance with the inequality

$$\Delta t \leq \frac{1}{f_{q_0}}.$$

In that case, to calculate f_{q_0}, it is necessary to calculate the mean period of pulses of the lowest-order PBS $\langle T_{q_0}\rangle$ and their mean repetition frequency, using samples of the analyzed signal, from the expressions

$$\langle T_{q_0}\rangle = \langle T_{1q_0}\rangle + \langle T_{0q_0}\rangle,$$

$$f_{q_0} = \frac{1}{\langle T_{q_0}\rangle}, \quad (9)$$

where $\langle T_{1q_0}\rangle$ and $\langle T_{0q_0}\rangle$ are calculated from the expressions

$$\langle T_{1q_0}\rangle = \frac{1}{\gamma}\sum_{j=1}^{\gamma} T_{1q_{0j}} \quad \text{and} \quad \langle T_{0q_0}\rangle = \frac{1}{\gamma}\sum_{j=1}^{\gamma} T_{0q_0}. \quad (10)$$

Our experimental studies show the estimates of the mean frequency of low-order bits of PBS are correlated with the high-frequency spectra of the noisy vibration signal. Therefore, the sampling interval Δt of the useful signal $X(t)$ should be calculated from the frequency characteristics of high-order PBS. In the normal technical condition of object's operation, we can assume that he following approximate equality takes place between the mean values of durations of periods of PBS $q_0(i\Delta t), q_1(i\Delta t), q_2(i\Delta t), q_3(i\Delta t)$:

$$\langle T_{q_0}\rangle \approx \frac{1}{2}\langle T_{q_1}\rangle, \langle T_{q_1}\rangle = \frac{1}{2}\langle T_{q_2}\rangle, \langle T_{q_2}\rangle = \frac{1}{2}\langle T_{q_3}\rangle, \ldots \quad (11)$$

Therefore, the sampling interval Δt_X of the useful vibration signals can be calculated using the mean period of pulses of high-order bits of PBS. For instance, the formulas for calculating the sampling interval Δt_t of the useful signal by means of the q_3-th PBS can be written as follows:

$$\Delta t_t \leq \frac{1}{2^3 f_3}. \quad (12)$$

Thus, the formula for adaptive determination of the sampling interval of the noisy signal $g(i\Delta t)$ and the useful signal $X(i\Delta t)$ can be written as follows:

$$\Delta t_g \leq \frac{1}{q_0}$$

$$\Delta t_X \leq \frac{1}{2^k f_k}$$

where $k = 1, 2, 3$.

It is obvious that the sampling interval of the noisy vibration signal $g(i\Delta t)$ can be calculated from formulas (9)-(12) adaptively in real time in the process of analog-to-digital conversion, which will improve the adequacy of the results of analysis of noisy vibration signals g(iΔt).

V. Conclusion

In the control and diagnostics systems of rail transport, vibration, pressure, current, voltage, etc. are used as the main sources of measurement information. Among these parameters, the most informative are vibration signals, which are obtained at the outputs of vibration sensors installed in the most informative structures of rolling stock, bridges and tunnels. These are usually very noisy and stepwise, abruptly changing signals. At the same time, the noise in these signals also contain diagnostic information and their spectrum changes depending on the speed of the train. These specific features of vibration signals are currently neglected in the employed technologies of spectral analysis, which sometimes leads to the lack of adequacy of control results. To eliminate this shortcoming of control and diagnostics systems, the authors propose a technology for adaptive sampling of vibration signals and a positional-binary technology for controlling the beginning of the latent period of malfunctions.

References

[1] T. Aliev, Noise control of the Beginning and Development Dynamics of Accidents, Springer, 2019, 201 p.

[2] Машины и Оборудование для Диагностики Пути, Региональный Центр Инновационных Технологий. Путевые Машины, Применяемые ОАО "РЖД" Конструкция, Теория и Расчет, Глава 11. [In Russian: Machines and Equipment for Track Diagnostics. Regional Center for Innovative Technologies. Track machines used by Russian Railways. Design, Theory and Calculation. Chapter 11]

[3] Е. Ашпиз, Методы и Средства Диагностики Земляного Полотна, 2013, Zheleznodorozhniy put. [In Russian: Ashpiz, Y.S. “Methods and tools of roadbed diagnostics”]

[4] И. Михалкин, О. Симаков, Ю. Седелкин, и В. Атапин, “Новые Подходы к Мониторингу Железнодорожного Пути”, NPTS INFOTRANS. [In Russian: Mikhalkin, I.K. & Simakov, O.B. & Sedelkin, Y.A. & Atapin, V.V. “New approaches to monitoring the railroad track”]

[5] “Какие бывают вагоны-лаборатории и для чего они применяются?”, https://dvizhenie24.ru/railway/kakie-byvayut-laboratorii/ [In Russian: “What kinds of track test cars are there and what are they used for?”]

[6] Г. Осадчий, и А. Лыков, Система Диагностики и Удаленного Мониторинга Состояния Железнодорожного Пути, 2011, Otkrytoe Obrazovaniye. Federal State Budgetary Educational Institution of Higher Education “G.V. Plekhanov Russian University of Economics”, pp. 221-224. [In Russian: Osadchiy, G.V. & Lykov, A.A. System for Diagnostics and Remote Monitoring of the State of Railroad Tracks]

[7] T. Aliev, T. Babayev, T. Alizada, and N. Rzayeva, “Control of the beginning of accidents in railroad operation safety systems in seismically active regions using the noise technology”, Transport Problems, 2019, 14.

[8] T. Aliev, Babayev, T. Alizada, and N. Rzayeva, “Noise Control of the Beginning and Development Dynamics of Faults in the Running Gear of the Rolling Stock”, Transport Problems, 2020, 15.

[9] T. Aliev, Babayev, T. Alizada, N. Rzayeva, E. Alibayli, and H. Ahmedov, “Intelligent system of noise control of the technical condition of railroad tracks” Transport Problems: An International Scientific Journal, 2021, 16 (1).

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On Two Problems of Combinatorial Optimization in the Analysis of Road Networks

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***Abstract*— Two combinatorial optimization problems for the road networks analysis are considered in the paper. The shortest path problem is a traditional graph theory problem. Extensions of this problem have many real applications, for example, for modeling road or telecommunication networks. Thus, the shortest path problem in a non-stationary metric network allows to model road situations in the traffic congestion appearance conditions. The shortest path finding in the resource-limited network allows to display situations related to limited fuel or time reserve. Another problem is to find all the maximum induced bicliques in the network. This problem provides information about the structure of the network. The paper presents an analysis of real road networks based on the results of computational experiments. The real road networks analysis based on computational experiments results is presented in the paper.**

Keywords—road networks, routing algorithms, maximal bicliques, network analysis

I. Introduction

With the development of urban infrastructure a need for the road networks analysis, design and restructuring appears. The use of graph and hypergraph models in the road networks analysis is one of the topical areas of modern scientific research. At the same time, for modeling and analyzing the functioning of such networks, it is necessary to solve the combinatorial optimization problems of finding and enumerating various configurations. Of particular interest are configurations such as shortest paths and maximum bicliques, since they allows to determine the network bottlenecks, the main highways, and perform preprocessing to divide the original network into subnets.

Currently, the solution of logistics problems is relevant both for a separate district, city, region and for the whole country. There are many algorithms for solving the routing problem without additional restrictions on the network. However, in case of additional restrictions imposed on the network, the classical algorithms do not applicable for the shortest paths constructing. In addition, an increase of the analyzed road networks dimensionality significantly affects the performance of the using algorithms. This is due to the fact that classical algorithms are either unable to find an exact solution to the problems posed, or find it in an unacceptable time. To analyze the road network structure, one can use the problem of enumerating all the maximum induced bicliques. Let's note that this problem is an intractable task, since the number of bicliques can exponentially depend on the size of the original network. Thus, not only new algorithms are in demand for solving problems of the road networks analysis, routing and design, but also the approaches increase the existing algorithms performance.

The aim of the work is the road networks analyze of Krasnoyarsk, Tomsk, Novosibirsk and Baku cities. The analysis is given in detail on the example of the city Krasnoyarsk. The analysis is carried out using three algorithms developed by the authors to solve the problems of finding the shortest path with constraints and enumerating all the maximum induced bicliques [1]–[3].

II. Statements of Problems

In the article, the analysis of road networks is carried out on the basis of solving the following problems: determining the shortest path with additional restrictions on the network and finding all the maximum induced bicliques.

The Table I shows the notation and definitions of the graph and hypergraph theory used in the article according to the works [1]–[5].

The finding shortest path classical problem assumes finding the least weight route in a weighted graph. Wherein the graph can be either undirected or directed.

Shortest Path problem (SP). A weighted directed graph $G = (V, E)$ with weight function w_e, where $e \in E$ is arc and shortest path (s, d)-query are given. It is required to find for the (s, d)-query the path P of the least weight $\sum_P w_e$ and the sequence of vertices that form it.

This problem has been well studied and a large number of algorithms have been developed for it [4]–[6]. One of the classical algorithms is Dijkstra's algorithm [5]. In such statement SP problem is polynomial solvable [4]. However, in most cases, when additional constraints or requirements are imposed on the shortest path or input graph, the problem becomes much more complicated and belongs to the *NP* class.

We consider two extensions of SP problem: Time-Dependent Shortest Path problem for the metric network that satisfies FIFO condition and Resource Constrained Shortest Path problem.

A. Time-Dependent Shortest Path problem

A time-dependent network is a graph whose edge weights can change over time. So, weight of any edge is defined as function of time (Table I, line 6). This approach allows to simulate traffic congestion at different times of the day.

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TABLE I. DEFINITIONS AND DESIGNATIONS

1	$G = (V, E)$	Directed graph without loops and dual edges, where V is a set of vertices and E is a set of edges while $\|V\| = n$ and $\|E\| = m$
2	$t \in T$	A value t is measured in conventional units of time and takes values from a finite set T
3	w_e	Weight function for an edge $e \in E$
4	$r_i(e)$	Resource functions for an edge $e \in E$ where $i = \overline{1,k}$
5	R_i	Positive values reflecting the resource capabilities of the network where $i = \overline{1,k}$
6	$w_e(t)$	weight function depending on time t for an edge $e \in E$
7	$F_e(t) = t + w_e(t)$	Function of arrival at the vertex y when moving along an edge $(x, y) = e$
8	$F_e(t_1) \le F_e(t_2)$	FIFO condition (monotonicity condition) for any moments of time $0 < t_1 \le t_2$
9	P	Path P from vertex s to vertex d
10	$w(P) = \sum_{e \in P} w_e$	Weight of the path P
11	$w(P, t_s) = t_s + \sum_{e \in P} w_e(t_i)$	Weight of the path (P, t_s) where $t_0 = t_s$, $t_i+1 = F_e(t_i)$
12	$dist(s, d, t_s) = \min_P \left\{ w(P, t_s) : s \xrightarrow[P]{} d \right\}$	Weight of shortest (s, d, t_s)-path
13	Feasible (s, d)-path P	Path P which satisfies $\sum_{e \in P} r_i(e) \le R_i$ where $i = \overline{1,k}$
14	Optimal (s, d)-route	Feasible (s, d)-path P with minimal weight $w(P)$
15	Bipartite graph	Graph G with parts S_0 and S_1 which satisfies that $x \in S_0$ and $y \in S_1$ for any edge $e = (x, y) \in E$
16	Complete bipartite graph (a biclique)	Bipartite graph that contains all possible edges
17	Maximal biclique	biclique that cannot extended with additional adjacent vertices

Time-Dependent Shortest Path problem (TDSP). A time-dependent network $G = (V, E)$ and (s, d, t_s)-query are given. It is required to find value $dist(s, d, t_s)$ for the (s, d, t_s) shortest path and the sequence of vertices that form it.

The problem in such statement belongs to the class of *NP*-hard problems. However, if network is metric and satisfies FIFO condition (Table I, line 8) then TDSP problem is polynomial solvable. The example of the weight function $w_e(t)$ for the edge e of the time-dependent metric network satisfying FIFO condition is shown at fig. 1. Such TDSP problem formulation is considered in this work.

Many algorithms are known for finding the shortest paths in a graph [5]–[6], some of them are adapted for time-dependent networks [7]–[10]. The classical Dijkstra's algorithm is able to solve the problem of finding the shortest path in a time-dependent metric network with FIFO condition in $O(n^2)$ time. In developing modern routing systems, one has to deal with the network dimensionality problem. Thus, a network can contain several hundreds of thousands of nodes, and it is required to find the optimal route between the nodes of this network in a few seconds. Under such conditions, classical algorithms for finding the shortest paths, including Dijkstra's algorithm, work for an unacceptably long time. To cope with this problem, various methods of speeding up classical algorithms are used [5]. Most of these techniques are based on speeding up Dijkstra's algorithm by applying a two-phase approach to solving the TDSP problem. Various implementations of the two-phase approach of Dijkstra's algorithm are known [10]. They are usually divided into the following main groups: hierarchical algorithms (algorithms based on a multilevel representation of the original graph) [7], labeling algorithms [9], landmark routing algorithms [11]–[12]. Note that most of these modifications do not exceed Dijkstra's algorithm for time-dependent metric networks in theoretical complexity.

B. Resource Constrained Shortest Path problem

A resource-constrained network assumes that each edge in the graph has multiple weights. One is considered the main weight, over which the minimization is carried out, in the process of determining the shortest path. Other weights define different resources. Thus, the network or request contains the resource possibilities for searching the shortest path. This problem allows to simulate various traffic situations associated with toll highways, limited fuel or road capacity. Another extension of the shortest path problem assumes that each edge in the graph has multiple weights, and is formulated as follows.

Resource Constrained Shortest Path problem (RCSP). A directed graph $G = (V, E)$ on the edges of which positive real-valued functions are defined w_e, $r_i(e)$ and values R_i, $i = \overline{1,k}$ are given. It is required to find (s, d)-route and the sequence of vertices that form it.

It is known that even with one additional resource the RCSP problem is *NP*-hard [4], [13]. The resource is represented by an additional weighting function and a value that is a resource constraint (Table I, line 4-5). Example of such network is shown at fig. 2. The RCSP problem statement is admissible in terms of linear integer programming. Thus, at present, there are three classes of methods and corresponding

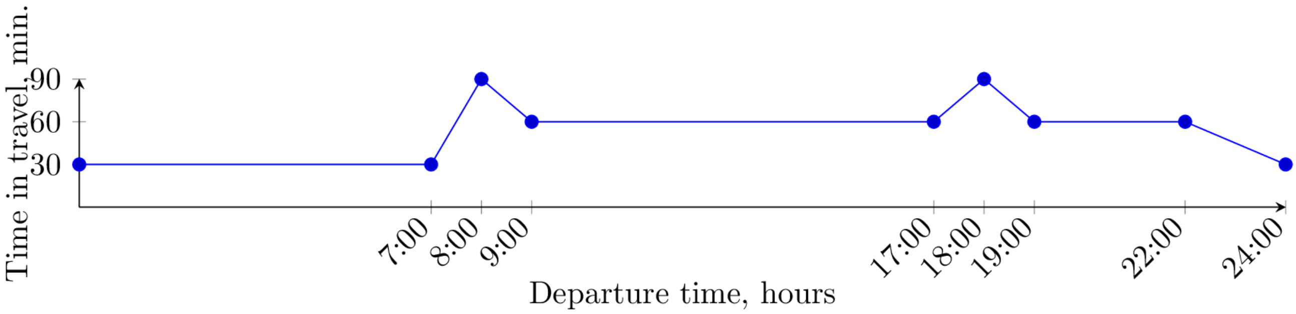

Fig. 1. Weight function of an edge that satisfies FIFO condition

algorithms capable of finding an exact or approximate solution to the RCSP problem: path ranking methods [14], vertex marking methods [15]–[18], Lagrangian relaxation methods [19]–[21]. The first two classes of methods are based on the graph-theoretical formulation of the problem, while the methods of the third class are based on the formulation of the RCSP problem in an integer linear programming language. Most of the algorithms based on the graph- theoretical formulation of the problem are extensions of Dijkstra's algorithm or similar ones. [15]–[16], [20].

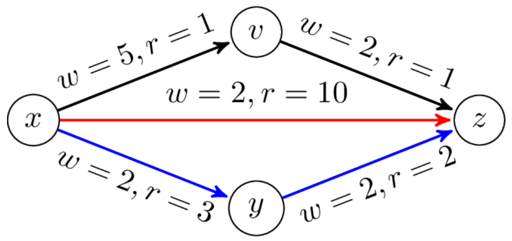

Fig. 2. Network with resource constrain R = 5 where red path does not feasible, black is a feasible and blue is the optimal route

Path ranking methods involve solving the k-shortest path problem in a graph. In this problem, it is required to find not only the shortest path, but also the next k–1 shortest paths, which may differ from the shortest and be heavier in the sense of the weight function. Since the optimal path for the RCSP problem may differ from the shortest path, in the sense of the resource function, the parameter k cannot be initially determined. Thus, the approach of finding k-shortest paths becomes more complicated by going through all the shortest paths until a feasible one is found. A prominent representative of this direction is Jen's algorithm, which finds a solution to the k-shortest paths problem in time $O(k \cdot n \cdot (m + n \cdot \log n))$, where k can exponentially depend on the size of the original network [14].

Vertex labeling methods involve the use of additional labels for correct routing in a resource-constrained network. This class of methods contains both exact algorithms for solving and approximate ones. Approximate algorithms are divided into two types: approximate in weight function, approximate in resource functions. The exact solution algorithm has complexity $O(N^5 \cdot b \cdot \log (n \cdot b))$ where b is the greatest weight of an edge in the graph [15]. The execution time of this algorithm is high. Therefore, studies of approximate algorithms for solving the problem are in demand. The most efficient algorithm for an approximate solution was proposed in [22] and has computational complexity $O(m \cdot n \cdot (1/\varepsilon + \log \log n))$. The algorithm finds a feasible path different from the optimal one at most $(1 + \varepsilon)$ times. Algorithms that are approximate in terms of resource functions are widely used in telecommunication networks. The most efficient algorithm is presented in [23] and has the following complexity $O(n \cdot m \cdot \log \log \log n + m \cdot (n/\varepsilon)^{k-1})$ where k is the number of resource constraints. It finds the shortest path that exceeds the resource constraints by no more than $(1 + \varepsilon)$ times.

Lagrangian relaxation techniques mainly consist of three phases. In the first phase, the lower and upper bounds of the optimal values for the problem are calculated. In the second phase, these boundaries are used to simplify the original graph. In the third phase, the gap between the boundaries is closed by finding the optimal route. For this purposes various algorithms for finding the shortest paths are used. Algorithms in this direction are presented in the works [19]–[21], [24].

C. *Maximal Induced Bicliques Generation problem*

The problem of finding all the maximal induced bicliques is formulated as follows.

Maximal Induced Bicliques Generation problem (MIBG). Let the hypergraph $G = (V, E)$ without double edges is given. It is necessary to find a set of all maximal induced bicliques.

It is known that complexity of the MIBG problem does not be easier than the *NP*-hard problem, since the problem of finding one maximal induced biclique is *NP*-hard [25]–[26]. A number of graph-theoretic problems that belong to the class of #*P*-complete or *NP*-complete problems are reduced to the

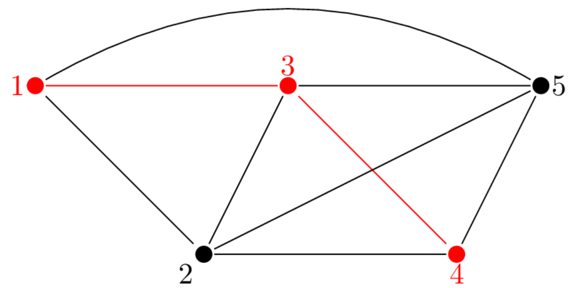

Fig. 3. Maximal induced biclique with parts $S_0 = \{1, 4\}$ and $S_1 = \{3\}$

search for bicliques [4]. Note that in the general case the number of maximal bicliques exponentially depends on the size of the graph [27].

The problem of finding all maximal bicliques is being actively studied for networks represented by a graph. There are two areas of research, the search for all maximal non-induced bicliques and maximal induced bicliques. Bicliques $X' = S_0 \cup S_1$ are called induced then each one of the sets S_0 and S_1 are independent, i.e. vertices in a set are not adjacent. If property of independency does not have place then bicliques are called non-induced. Example of the maximal induced biclique is shown at fig. 3. Algorithm for finding all maximal non-induced bicliques with the complexity $O(a^3 \cdot 2^{2a} \cdot n)$ where a is the arboricity of the input graph [28]. A number of researchers note that in practice, only maximal non-iduced bicliques of large dimensionality are in demand [29]–[30]. In the paper [29] the algorithm for the maximal non-induced bicliques search with parameter p for biclique size threshold has been proposed. The complexity of this algorithm is $O(n \cdot m \cdot N)$ where N is the set of all non-induced bicliques with size greater or equal to p. For finding all maximal induced bicliques of graph in the paper [28] algorithm is proposed. It has complexity $O(n \cdot k \cdot (\Delta + k) \cdot 3^{(\Delta + k)/3})$, where Δ is maximum degree of a vertex and k is degeneracy of graph.

Table II presents three algorithms and estimations of their complexity on time to solve the considered problems. Theoretical studies and assessment complexity of the algorithms presented in the works [1]–[3].

For the problem of the shortest path in a time-dependent metric network with the FIFO condition, the modified ALT algorithm is used [1]. The algorithm is based on a specific representation of the edges of the original network. For such a representation, a sufficient condition for the continuity and admissibility of potential functions is shown in paper [1], which are necessary for the correct operation of the ALT algorithm.

TABLE II. THE PROBLEMS CONSIDERED AND THE ALGORITHMS FOR THEIR SOLUTION

Problem		Algorithm	
Name	***Complexity class***	***Name***	***Complexity***
TDSP	*P*	ALT	$O(n^2)$
RCSP	*NP*-hard	RevTree	$O(n^2)$
MIBG	At least *NP*-hard	HFindMIB	$O(2^{2\Delta} \cdot \Delta \cdot (\lvert MBC \rvert + \Delta^3 \cdot \log(2^{2\Delta})) + n^2)$

To find the shortest path in a resource constrained network with one resource, the RevTree algorithm was developed earlier [2]. A distinctive feature of the proposed algorithm is that the accuracy of the solution can be estimated based on the weight and resource functions of the original network.

The search for all maximum induced bicliques is implemented by the HFindMIB algorithm [3]. The algorithm differs from previously existing algorithms in that it uses a hypergraph approach in bicliques generation process. The algorithm finds and lists in lexicographic order all maximal induced bicliques in graph and hypergraph networks.

III. COMPUTATIONAL EXPERIMENTS AND NETWORK ANALYSIS

Computational experiments were carried out for the modified ALT algorithm, RevTree and HFindMIB algorithms. Based on the results obtained, the analysis of the road networks under consideration is carried out. The experiments were carried out on real road networks from the DIMACS database [31], as well as on road networks obtained from the OpenStreetMap web-mapping project using the OSMnx package for Python [32]. Computational experiments were performed on a PC with an AMD Ryzen 5 3600 6-Core Processor 3.60 GHz and 16 GB of RAM. For the modified ALT algorithm and RevTree algorithm, 1000 queries were generated for each network. The HFindMIB algorithm was applied to undirected versions of the presented networks.

The first series of computational experiments was carried out for the modified ALT algorithm. The algorithm periodically sets up landmarks that it uses in its work. According to the results of work [33], the number of landmarks was assumed to be equal to 12, and the update period was equal to 30. The results are presented in Table III.

TABLE III. RESULTS FOR THE MODIFIED ALT ALGORITHM

Graph	*n*	*m*	Time, sec.
TOF	3840	9639	8.151
KJA	4362	10536	9.030
NSK	7357	19106	27.838
GYD	12458	28936	69.052

Heat map for KJA network is presented at fig. 4. A road section is red then it is most required in shortest paths and blue otherwise. Edges that have not met in any of the shortest paths are marked in black.

The second series of experiments was carried out for the RevTree algorithm. The RCSP problem do not always have a solution, since a feasible path may not exist for the request. The request is considered to have been complete if a solution has been found for it. The results are shown in Table IV.

TABLE IV. RESULTS FOR THE REVTREE ALGORITHM

Graph	*n*	*m*	Time, sec.	Percentage of completed requests
TOF	3840	9639	1.708	0.483
KJA	4362	10536	7.286	0.849
NSK	7357	19106	12.212	0.680
GYD	12458	28936	15.998	0.539

A similar heat map is presented based on the results of solving the RCSP problem for the KJA network in fig. 5.

It can be seen that the heat maps in fig. 4 and 5 have common road sections. This suggests that these roads are equally in demand in both time-dependent and resource constrained networks. Thus, these roads are main for considered network.

The last series of experiments was carried out for the HFindMIB algorithm. The results of the algorithm are presented in Table V.

The important indicators for network analysis are the bicliques sizes and their number. These data for each network are presented in Table VI.

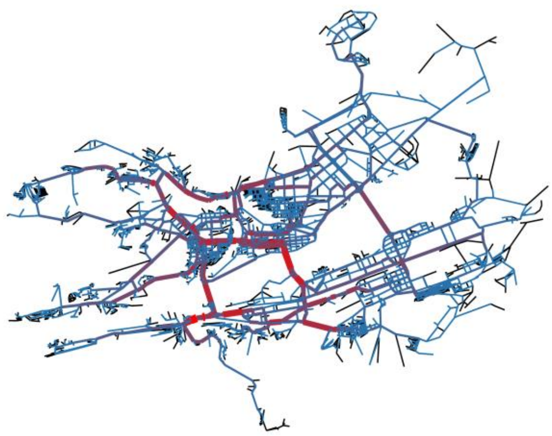

Fig. 4. Heat map of KJA network based on results of TDSP problem solution

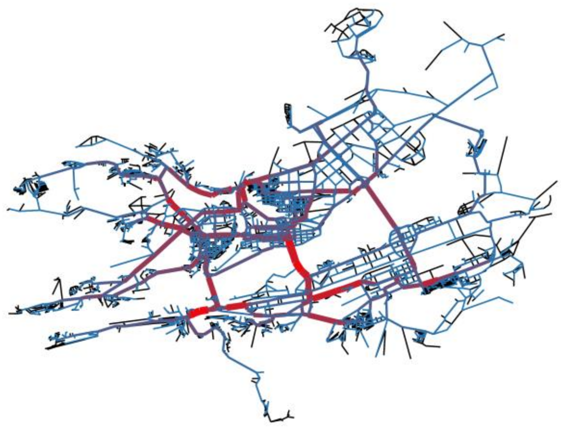

Fig. 5. Heat map of KJA network based on results of RCSP problem solution

TABLE V. RESULTS FOR THE HFINDMIB ALGORITHM

Graph	*n*	*m*	Δ	MBC	Time, sec.
TOF	3840	5227	5	4084	26.527
KJA	4362	6005	5	4823	36.898
NSK	7357	10218	6	7927	103.115
GYD	12458	16417	6	11844	252.244

TABLE VI. NUMBER OF BICLIQUES OF EACH DIMENSION

($\|S_0\|$, $\|S_1\|$)	TOF	KJA	NSK	GYD
(1, 1)	1	3	5	2
(2, 1)	955	1454	1612	2247
(2, 2)	589	535	1204	1154
(3, 1)	1981	2315	3886	7217
(3, 2)	2	–	1	–
(4, 1)	553	514	1215	1215
(5, 1)	3	2	4	9

Using the KJA network as an example, we will present the interpretation of the network elements according to the size of the bicliques. Maximal bicliques with size (2, 1) can be considered as a long road or bypass road. Such bicliques are shown at fig. 6. Different bicliques are marked with different colors.

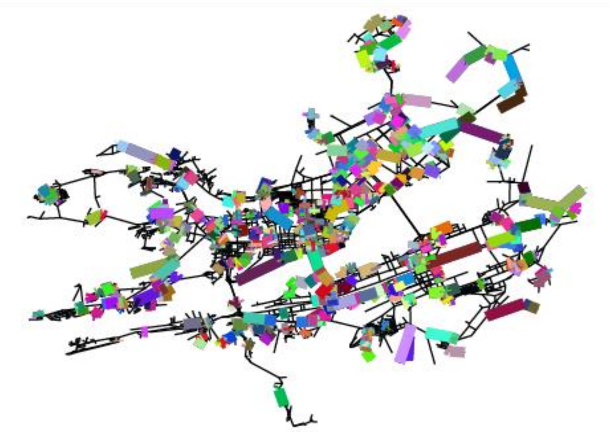

Fig. 6. Map of KJA network with (2, 1) bicliques

Maximal bicliques with size (2, 2) most often correspond to city blocks, which is easy to see in fig. 7. Similar to the previous figure, different bicliques are represented by different colors.

Crossroads and roundabouts are represented with maximal bicliques where the cardinality of one part is equal one and the other part is at least three.

Based on the solutions to the problems indicated in Table 2, an analysis of road networks can be carried out. The results of this analysis can be used to simulate network congestion. Based on information about the most requested edges in the network, one can reorganize and model new bypass roads.

We are present visualization of results of the GYD network without detail analysis. Heat maps for the GYD network are represented at fig. 8 and 9.

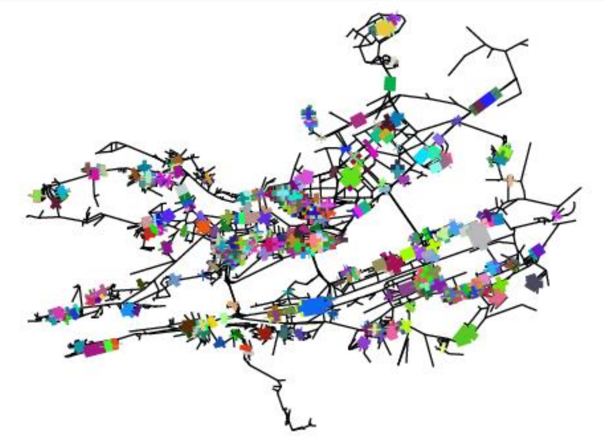

Fig. 7. Map of KJA network with (2, 2) bicliques

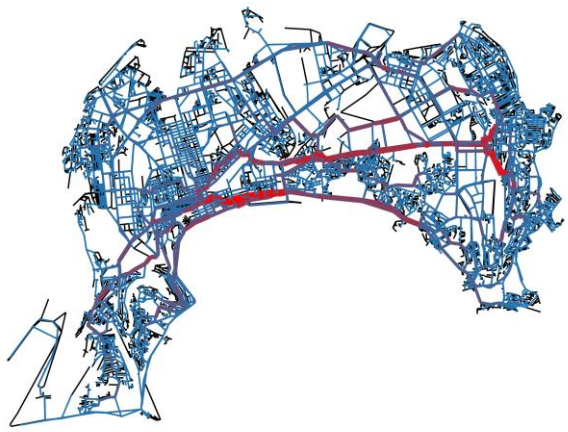

Fig. 8. Heat map of GYD network based on results of TDSP problem solution

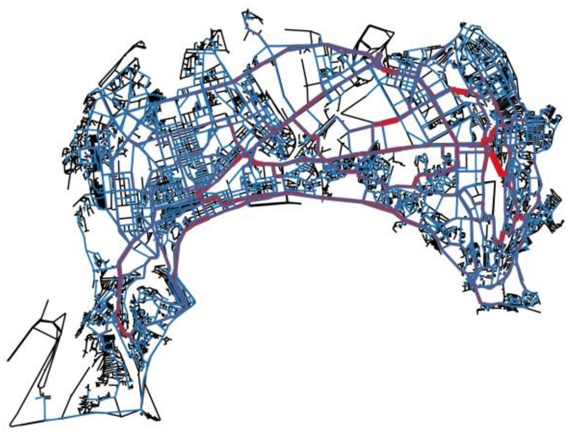

Fig. 9. Heat map of GYD network based on results of RCSP problem solution

Note that percentage of completed requests for the RCSP problem for the GYD network is only 0.539. Thus, the visualization at fig. 9 may not be as informative as at fig. 8. However, even so, there are significant similarities between this heat maps.

Maps of the GYD network with (2, 1) and (2, 2) bicliques are presented at fig. 10 and 11.

Fig. 10. Map of GYD network with (2, 1) bicliques

Fig. 11. Map of GYD network with (2, 1) bicliques

IV. CONCLUSION

The paper considers two combinatorial optimization problems: the shortest path problem and the problem of finding all the maximal induced bicliques. Two extensions of the shortest path problem to the cases of a time-dependent metric network with FIFO condition and a resource constrained network are considered. Computational experiments have been carried out for the following algorithms: modified ALT algorithm, RevTree algorithm, HFindMIB algorithm. Based on the results obtained, an analysis of the road network was accomplished.

According to the results obtained, it can be seen that further development of methods for analyzing road networks is promising. These methods can be based on various problems of the shortest path and the problem of finding the maximal induced bicliques.

REFERENCES

[1] V. V. Bykova, and A. A. Soldatenko, "Optimal routing by landmarks in the time-dependent networks," PDM, vol. 37, pp. 114–123, 2017. (in Russian)

[2] A. A. Soldatenko, "On accuracy of approximation for the resource constrained shortest path problem," Journal of Siberian Federal University. Mathematics & Physics, vol. 12(5), pp. 621–627, 2019.

[3] A. A. Soldatenko, and D. V. Semenova, "On Problem of Finding all Maximal Induced Bicliques of Hypergraph," Journal of Siberian Federal University. Mathematics & Physics, vol. 14(5), pp. 638–646, 2021. (in press)

[4] M. Garey, and D. Johnson, Computers and Intractability, Moscow: Mir, 1982. (in Russian)

[5] T. H. Cormen, C. E. Leiserson, R. L. Rivest, and C. Stein, Introduction to Algorithms, 3rd ed., Moscow: «Vil'yams», 2013. (in Russian)

[6] S. Russell, and P. Norvig, Artificial Intelligence: A Modern Approach, 4th ed., Moscow: «Vil'yams», 2021. (in Russian)

[7] M. M. Nejad, L. Mashayekhy, R. B. Chinnam, and A. Phillips, "Hierarchical time-dependent shortest path algorithms for vehicle routing under ITS," J. IIE Transactions, vol. 48, pp. 158–169, 2016.

[8] D. Delling. and D. Wagner, "Landmark-based Routing in Dynamic Graphs," In Proc. International Workshop on Experimental Algorithms (WEA), Springer, 2007, 4525 of LNCS, pp. 52–65.

[9] D. Delling, "Time-Dependent SHARC-Routing," J. Algorithmica, vol. 60, pp. 60–94, 2011.

[10] D. Wagner, and T. Willhalm, "Speed-up techniques for shortest-path computations," In Proc. STACS, Springer, 2007, 4393 of LNCS, pp. 23–36.

[11] A. Goldberg, H. Kaplan, and R. Werneck, "Better landmarks within reach," In Proc. International Workshop on Experimental Algorithms (WEA). Springer, 2007, 4525 of LNCS, pp. 38–51.

[12] A. Goldberg, H. Kaplan, and R. Werneck, "Reach for A*: Efficient point-to-point shortest path algorithms," Technical Report MSR-TR-2005-132, Microsoft Research. Microsoft Corporation, 2005.

[13] H. C. Joksch, "The Shortest Route Problem with Constraints," Mathematical Analysis and Applecation, vol. 14, pp. 191–197, 1966.

[14] D. Eppstein, "Finding the k shortest paths," Proceedings 35th Annual Symposium on Foundations of Computer Science, 1994, pp. 154–165.

[15] P. Van Mieghem, F. A. Kuipers, T. Korkmaz, M. Krunz, M. Curado, E. Monteiro, and et al., "Quality of Service Routing," In Quality of Future Internet Services, 2003, 2856 of LNCS, pp. 80–117.

[16] I. Dumitrescu, and N. Boland, "Improved preprocessing, labeling and scaling algorithms for the weight-constrained shortest path problem," Networks, vol. 42, pp. 135–153, 2003.

[17] R. Hassin, "Approximation Schemes for the Restricted Shortest Path Problem," Mathematics Oper. Res., vol. 17, pp. 36–42, 1992.

[18] X. Zhu, and W. E. Wilhelm, "A three-stage approach for the resource-constrained shortest path as a sub-problem in column generation," Computers & Operations Research, vol. 39(2), pp. 164–178, 2012.

[19] K. Mehlhorn, and M. Ziegelmann, "Resource constrained shortest paths," In Algorithms ESA, 2000, 1879 of LNCS, pp. 326–337.

[20] M. Horvath, and T. Kis, "Solving resource constrained shortest path problems with LP-based methods," Computers, vol. 73, pp. 150–164, 2016.

[21] M. Jepsen, B. Petersen, S. Spoorendonk, and D. Pisinger, "A branch-and-cut algorithm for the capacitated profitable tour problem," Discrete Optimization, vol. 14, pp. 78–96, 2014.

[22] Y. Bejerano, Y. Breitbart, A. Orda, R. Rastogi, and A. Sprintson, "Algorithms for computing QoS paths with restoration," IEEE/ACM Transactions on Networking, vol. 13(3), pp. 648–661, 2005.

[23] G. Xue, W. Zhang, J. Tang, and K. Thulasiraman, "Polynomial Time Approximation Algorithms for Multi-Constrained QoS Routing," IEEE/ACM Transactions on Networking, vol. 16(3), pp. 656–669, 2008.

[24] L. Di Puglia Pugliese, and F. Guerriero, "A survey of resource constrained shortest path-problems: exact solution approaches," Networks, pp. 183–200, 2013.

[25] B. Lyu, L. Qin, X. Lin, Y. Zhang, Z. Qian, and J. Zhou, "Maximum biclique search at billion scale," Proc. VLDB Endow, 2020, pp. 1359–1372.

[26] G. Alexe, S. Alexe, Y. Crama, S. Foldes, P. L. Hammer, and B. Simeone, "Consensus algorithms for the generation of all maximal bicliques," Discrete Applied Mathematics, vol. 145, pp. 11–21, 2004.

[27] E. Prisner, "Bicliques in graphs I: bounds on their number," Combinatorica, vol. 20, pp. 109–117, 2000.

[28] D. Hermelin, and G. Manoussakis, "Efficient enumeration of maximal induced bicliques," Discrete Applied Mathematics, vol. 303, pp. 253–261, 2021.

[29] J. Li, G. Liu, H. Li, and L. Wong, "Maximal Biclique Subgraphs and Closed Pattern Pairs of the Adjacency Matrix: A One-to-One

Correspondence and Mining Algorithms," IEEE Transactions on Knowledge and Data Engineering, vol. 19(12), pp. 1625−1673, 2007.

[30] P. Damaschke, "Enumerating maximal bicliques in bipartite graphs with favorable degree sequences," Inf. Process. Lett., vol. 114(6), pp. 317−321, 2014.

[31] DIMACS Implementation Challenge (2006). Shortest Paths: road graphs database. [Online]. Avaible: http://www.dis.uniroma1.it/challenge9/

[32] G. Boeing, "OSMnx: New Methods for Acquiring, Constructing, Analyzing, and Visualizing Complex Street Networks," Computers, Environment and Urban Systems, vol. 65, pp. 126−139, 2017.

[33] V. V. Bykova, and A. A. Soldatenko, "Adaptive landmark selection in shortest-paths problem for a big graph," J. Software & Systems, vol. 1(113), pp. 60−67, 2016. (in Russian)

Social and Economic Effect Estimation of the Cycling Development of Azerbaijan

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***Abstract*— This study aims to estimate the social impact of the development of bicycle usage by citizens and the partial effect on the cars use on the example of Azerbaijan. The authors review experience of bicycle usage to found out main contributing factors to the development in this sector. Moreover, in order to implement the state program of the Republic of Azerbaijan for 2019-2023 and promotion of bicycle usage, an example is given of a significant leverage necessary for its implementation. Using a regression analysis, the authors analyze the impact of environmental and social factors? As well as the level of air pollution and life expectancy on the number of bicycles from 2005 to 2017.Results indicate a possible social effect and social impact of bicycle usage on the well-being in Azerbaijan. Based on empirical results the authors propose policy recommendations to promote bicycle usage in Azerbaijan.**

Keywords*— *bicycle, life expectancy, econometrics, bicycle route, road density.

I. Introduction

Improving road infrastructure, expanding roads in a short-term period might help to reduce the level of traffic. However, such policies may cause even more car overload, which, in turn, again may worsen the roads condition.[1]. Switching to an alternative mode of transport can increase the level of safety on the roads and reduce the number of deaths from traffic accidents [2]. A bicycle is one of such those modes of transport.

II. Theoretical Framework

Cycling improves the viability of cities, human health, reduces the pressure on the environment [3], leads to significant economic boom , and also creates a number of other favorable social conditions. This is very promising mode of transport which provides a large number of economic and social benefits, including jobs creation.

It was estimated that, cycling generates number of vacancies appear in five different sectors of the economy [4]:

• Bicycle trade (mainly sales and repairs),
• Bicycle industry (production and wholesale)
• Bicycle infrastructure,
• Bicycle tourism (accommodation and restaurants) – people enjoy cities with a great bicycle culture, because they are less crowded, less noisy and the air is less smog-burdened. In addition, many countries are discovering the economic benefits of cycling. The development of interregional relations is a weighty argument in favor of cycling [5].
• Bicycle services - operating costs for the existing services for trucks are reduced, replacing some trucks with bicycles, which also favorably affects the speed of delivery services, reducing the number of cars on the roads.

The bicycle provides mobility over short distances. According to the State Statistical Committee of the Republic of Azerbaijan (SSCAR) the average distance traveled by a car by one person is about 14 km in 2017. Taking into account these figures, we came to the conclusion that a large proportion of trips in our country occur over short distances that can be covered by bicycle, especially during rush hours in order to avoid congestion. Such turning capacity of cycling provides an opportunity to create new local jobs, especially more jobs for low-skilled people[6].

Other than creation of new jobs, the use of bicycles also improves quality of life, and this, in turn, labor productivity [7].According to numerous studies people who come to work on a bicycle work more productive than people who came by car or public transport. The psychological effects of riding a bicycle [8] are mood improvement, stress relieve, and suppressing negative emotions; in other word, it is a strong anti-depressant [9]. In addition, the bicycle is a means of getting rid of cardiovascular diseases, diseases of the lungs and respiratory tract and their prevention [10]. According to WHO (World Health Organization) in 2018, 91% of the world's population lived in areas where the level of pollution exceeds the values set in the WHO air quality guidelines. Reduction of air pollution, according to WHO, can be achieved if, for example, the average annual value for nitrogen dioxide, poisonous gas, which is part of the gases released from exhaust pipes of automobiles, is 40 µg / m3. According to SSCAR, in Azerbaijan, and in particularly in Baku, since 2007, these figures ranged from 50 to 70 µg / m3, and even in 2010 approached to the level of 90 µg / m3. In 2018, the average annual value for nitrogen dioxide was 70 µg / m3, which is 75% higher than the benchmark level.

III. INTERNATIONAL EXPERIENCE

One euro invested in a bicycle gives the society 450 euros of aggregate economic effect. This calculation was carried out by scientists from Germany, and there is no doubt about its accuracy (Yanyshev, 2014).

In addition to Germany, we have compiled a chart of statistics from the other 9 countries with the highest percentage of cyclists among other countries of the world:

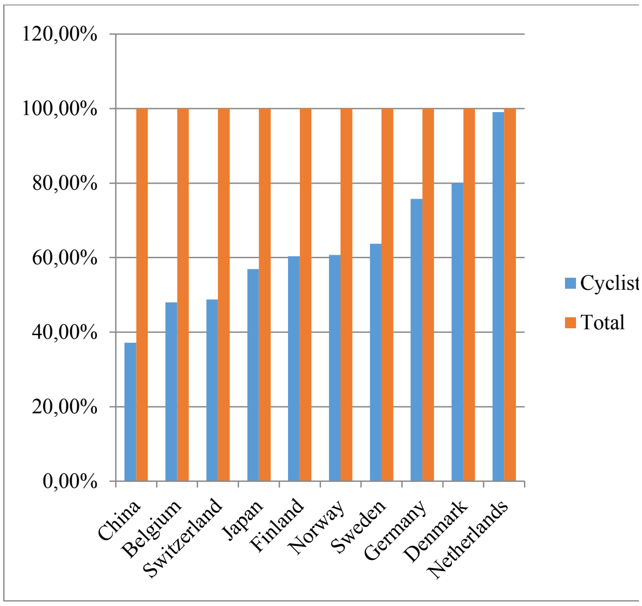

Fig. 1. Percentage of cyclists as a share of the total population in countries with developed bicycle infrastructure

As can be seen from the diagram, the countries with the largest percentage of cyclists among all residents are developed countries, which is not a coincidence. Taking into account such a popularity of bicycle usage, the European network of cycling routes project Euro Velo has been founded in November 21, 1997 with the aim of to promote development of cycling tourism and to introduce common road standards [11] Robert Coleman, Director of Transport for the European Commission, expressed that the hidden potential of international cycling can be realized with the help of an effective marketing strategy [12].Today, this route covers almost the whole of Europe and new routes are being agreed upon, which increasingly cover the Eastern part of Europe.

As can be seen from the roadmap[1] of the cycle route, the accession of Azerbaijan to this project is inevitable in the future, since the route initially took its origin from the Western part of Europe and only then began to spread towards the Eastern part. The neighboring countries of Azerbaijan - Russia and Turkey have already joined this route. Obviously, to support this project country is required to invest large investments. But as the experience of European countries shows, a huge turn over bicycle sector pays for all costs.

According to the ECF (European Cyclists Federation), there are more than 250 million cyclists in Europe, of which 61 million use the bike daily. The economic effect of bicycles in Europe is more than 513.19 billion euro [13].

The bicycle sharing system (Bike Sharing) is gaining popularity and motivates to ride bicycles in the cities. The idea of introducing such system originates from the Netherlands. However, its first widespread use belongs to the United States, France, and Great Britain. Since 2013, among the CIS countries this system began to operate in Russia, Latvia, Lithuania, in Kazakhstan since 2014, in Ukraine since 2015. It is a system that allows a short-term (no more than 3 hours) trip around the city for residents and tourists as an alternative to four-wheeled vehicles [14]. The key convenient aspect of such a system is the close proximity of stations one another at any point where a bicycle can be returned (Qiu &He, 2018). So China, a country once known as the center of all cyclists, after the era of the "automobile society" with the advent of public bicycle market has regained the status of the country's cyclists [16].

Today, in many cities of Europe and North America, there is a new trend among people aged 20 to 30 years who move to the city centers, prefer compact buildings, prefer the bicycle and public transportation to cars [17]. Such a cultural shift will contribute to the growth of cycling in the future.

Transport economists around the world have developed a methodology [18] to determine the benefits of reducing congestion, such as reduction in car maintenance costs, parking costs, accidents and medical care, and reduced environmental impact. For some of these effects, estimating quantitative impact is difficult due to data limitation.

On December 27, 2018, the President of the Republic of Azerbaijan approved a decree on the creation of a state program[2] to ensure road safety in the Republic of Azerbaijan for 2019–2023 years. In subparagraph 7.4.1.4 paragraph 7.4 states the need to conduct promotion of traffic rules and use safety equipment, as well as the use of bicycles as an alternative mode of transport.

Our rough calculation suggests that only in 2017, there were about 64 thousand bicycles – about 7 bikes for every 1,000 people in Azerbaijan (for example in Switzerland -. 451, Denmark - 780, in the Netherlands - 964 in world - about 330 in Russia - about 240 in Turkey - about 375 bicycles per 1,000 people). Today, a bicycle in our country is limited to use mainly as entertainment, sports, or as an alternative to expensive transport in rural areas. But it should be noted that there are other factors before deciding on the importance of the mass use of this type of transport in our country.

Considering the above mentioned points, we were able to determine the degree of importance of the bicycle as an effective policy to ensure safety and prevent deaths on the

roads, and its role in environmental preservation, both for households and for Azerbaijan as a whole. In addition, we precisely found how much cycling depends on the density of roads.

[1]http://en.eurovelo.com/

[2] STATE PROGRAM// Road traffic safety in the Republic of Azerbaijan for the years 2019-2023/ https://president.az/articles/31388

IV. Methods

A. Positive environmental impact

This analysis was carried out using data on share of pollutants emitted by vehicles into the atmosphere and the number of bicycles and cars per 100 households in the form of a regression model (the method of least square, Eviews software), where the first parameter acts as a dependent. The dynamics was taken from 2005 to 2017.

TABLE I. Dynamics of changes in the number of bicycles and cars per 100 households and the share of pollutants emitted by motor vehicles in Azerbaijan

Year	Number of cars per 100 households, pcs.	Number of bicycles per 100 households, pcs.	The share of pollutants emitted by motor vehicles into the atmosphere, in %
2005	20.3	2.5	47
2006	21.2	2	61
2007	20.4	2	60
2008	19.9	1.8	69
2009	19.8	1.9	70
2010	23.4	1.9	78
2011	24.7	2.4	78
2012	27.1	2.3	79
2013	32.0	2.3	83
2014	36.0	2.4	84
2015	38.5	2.8	85
2016	36.0	2.7	84
2017	36.7	2.7	84
2018	37.0	3.0	85
2019	37.8	3.0	84
2020	39.4	3.2	82

B. Direct and indirect effects on human health

By the direct influence we meant the effect of bicycle usage as an improving physical fitness, and life expectancy. Indirect impact implies that this will lead to less use of the car and, consequently, fewer deaths from accidents (Pérez et al., 2017).

TABLE II. Life expectancy in Azerbaijan (2005-2019)

Year	Number of bicycles per 100 households, pcs.	Life expectancy, year
2005	2,5	72.4
2006	2	72.4
2007	2	73
2008	1.8	73.4
2009	1.9	73.5
2010	1.9	73.6
2011	2.4	73.8
2012	2.3	73.9
2013	2.3	74.2
2014	2.4	74.2
2015	2.8	75.2
2016	2.7	75.2
2017	2.7	75.4
2018	3.0	75.8
2019	3.0	76.4

Life expectancy was chosen as an indicator of people's health. Effects of cycling were reflected in the regression model (the method of least square) with statistics for 2005-2020.

C. Road density as a leverage

As already mentioned, Azerbaijan, due to its geographical location, can easily join a single European bicycle network. However, to implement this project, one location is not enough. In the foreground the policy aimed at providing a safe route for a potential cyclist [19] and, accordingly, on the development of bicycle infrastructure. It is obvious to assume that the bicycle infrastructure directly depends on the density of roads, because most often bicycle paths are laid either in a strip on the roadway or as a separate path parallel to the roadway. The second option is considered the safest [20].

We have comparedthe statistics ofcountries those were included in the top most bicycle used countries and Azerbaijan, the corresponding density of roads (road network length relationship to the territory covered area) and population density:

TABLE III. Density of roads and population amoung countries with highest popularity of cycling and in Azerbaijan

Country	The density of roads, m / km2	Population density, pers / km2
Netherlands	3270	404
Denmark	1677	128
Germany	1805	230
Sweden	1288	20
Norway	244	13
Finland	310	16
Japan	3225	336
Switzerland	1696	185
Belgium	5018	341
Azerbaijan	681	115

V. Results

Table 1 shows that the proportion of pollutants emitted by motor vehicles into the atmosphere, in a total amount of pollutants in Azerbaijan reached more than 80% during the past 8 years. The average annual growth rate is about 5%. We can influence this reality by using the data from the resulting equation:

$$P = 59.64 - 12.62*NB + 1.49*NC, \qquad (1)$$

R-squared 0.895303
Adjusted R-squared 0.857231
Durbin-Watson stat 1.813221

where

P - the percentage of pollutants emitted by vehicles into the atmosphere (in percent);
NB - number of bicycles per 100 households, pcs.;
NC - the number of cars per 100 households, pcs.;

The model can be interpreted as follows: about 4 units of bikes will be required to reduce emissions from cars by 13 percentage points, while the use of bicycles, of course, leads to less use of the car, and this, in turn, directly affects the reduction of air emissions. Separately, a decrease in the number of cars by one unit per 100 households will lead to a reduction in atmospheric emissions by 1.49 percentage points.

The study of the dependence of life expectancy on the number of bicycles and cars per 100 households and the number of deaths from road accidents for the period from 2005 to 2019 (Table 2) showed the following relationship:

$$LE = 2.39*NB + 68.69 \quad (2)$$

R-squared	0.883089
Adjusted R-squared	0,870099
Durbin-Watson stat	1,616854

where,
LE - life expectancy, years;
NB - number of bicycles per 100 households, pcs.;

Looking at the model, it can be noted that, increasing the number of bicycles to 5 in every 100 households increases the life expectancy of up to 2,4 years.

In conclusion, in order to compare with the situation in Azerbaijan, we separately analyzed countries with a high rate of cycling development in relation to road density to population density (Table 3), and we obtained the following regression equation:

$$DR = 409.66 + 8.87*PD, \quad (3)$$

R-squared	0.775024
Adjusted R-squared	0.742885
Durbin-Watson stat	1.863497

where,
DR - densities of automobile roads of countries, m/km2;
PD - population density of countries, pers./km2.

With the help of it, we have come to the conclusion that in countries where cycling is very popular an increase in the population by 1 person per sq km will lead to an expansionof the road network by 8.9 meters per sq km. It is easy to determine that today these figures are approximately 5.9 meters per sq km for Azerbaijan.

VI. Discussion

A polluted atmosphere is a slow death for the entire population of the Earth. Technological progress became the originator of such a global problem. Azerbaijan against has also suffered significantly from air pollution. According to the results of regression analysis, we foundthat increase in the number of bicycles in Azerbaijan by about 1% will reduce in the share of atmospheric emissions by 13 percentage points. And taking into account the fact that the number of plants and factories that also affect the environment in the country has significantly decreased in recent years, it can be assumed that the atmosphere will generally improve.

The last model was aimed at identifying road density standard, depending on the population density in the country. The figures obtained for cyclist countries could be larger, if not Norway and Finland, countries with a large share of the territory unsuitable for living in connection with the cold climate. Yet, the immediate result gives cause for reflection.

VII. Conclusion

Bicycling will lead to a social results - people's behavior and attitude to each other will change, being human capital, their physical and mental endurance will improve and thereby will bring longer economic benefits for the country.This process may eventually qualitatively change society for the better.

Azerbaijan, a country that seeks to redirect the dependence of sustainable economic development from the oil sector to other sectors, in particular tourism, should already have to take measures to join the project of a single bicycle road. There are a number of issuesthat must first be solved. The main problemis that the road infrastructure condition of which , taking into account the population, today is significantly inferior to the road network of bicycle countries. The main advantage of the density of the road network is a significant increase in bicycle mobility, which is so important during peak hours. In order to introduce such changes in roads, an initial boost to the mass transfer of population from cars to bicycles, which can result in the following activities:

1. Subsidizing the production and sale of bicycles;
2. The development of safe bicycle infrastructure in the existing road network with priority of laying a separate bike path from the roadway;
3. An increase in bicycle rental stations with an aim of increasing the rate of (or popularize) bicycle sharing (Bike Sharing);
4. The establishment of special parking spaces for bicycles along with parking spaces for cars.

In addition all above mentioned points, it must be pointed outthat people will only ride bicycles when riding thembecomes a safe option. As full-fledged road users, they should be informed about the rules, receive a fine in case of non-compliance, and sometimes have advantages on the roads.

Our results on the example of Azerbaijan can be used for further research in this area and have practical significance for the representatives of state executive bodies, the private sector, as well as interested parties in this area.

References

[1] О. В. Сагинова and Н. Б. Завьялова, “Велосипед в транспортной системе современного мегаполиса,” Russ. J. Entrep., 2019, doi: 10.18334/гр.19.12.39663.

[2] G. Deenihan and B. Caulfield, “Estimating the health economic benefits of cycling,” J. Transp. Heal., 2014, doi: 10.1016/j.jth.2014.02.001.

[3] G. Hitchcok and M. Vedrenne, “Cycling and urban air quality - a study of european experiences,” Eur. Cyclist’ Fed., 2014.

[4] T. Blondiau, B. Van Zeebroeck, and H. Haubold, “ScienceDirect Economic benefits of increased cycling,” Transp. Res. Procedia, 2016, doi: 10.1016/j.trpro.2016.05.247.

[5] P. Piket, E. Eijgelaar, and P. Peeters, “European cycle tourism: a tool for sustainable regional rural development,” Appl. Stud. Agribus. Commer., 2016, doi: 10.19041/apstract/2013/2-3/19.

[6] A. Neslen, “Europe’s cycling economy has created 650,000 jobs,” Guardian, 2014.

[7] B. De Geus, E. Van Hoof, I. Aerts, and R. Meeusen, “Cycling to work: Influence on indexes of health in untrained men and women in Flanders. Coronary heart disease and quality of life,” Scand. J. Med. Sci. Sport., 2008, doi: 10.1111/j.1600-0838.2007.00729.x.

[8] F. Spotswood, T. Chatterton, A. Tapp, and D. Williams, “Analysing cycling as a social practice: An empirical grounding for behaviour change,” Transp. Res. Part F Traffic Psychol. Behav., 2015, doi: 10.1016/j.trf.2014.12.001.

[9] T. Litman, “Evaluating Active Transport Benefits and Costs,” 2018.

[10] R. L. Mackett and R. Thoreau, “Transport, social exclusion and health,” J. Transp. Heal., 2015, doi: 10.1016/j.jth.2015.07.006.

[11] K. Kaloyanov, “Cycling Tourism Routes as an Instrument for Regional Development and Transnational Cooperation within the Lower Basin of the Danube River,” Bulg. Acad. Sci. Probl. Geogr., 2016.

[12] R. Weston et al., “The European cycle route network Eurovelo,” Dir. Gen. Intern. policies. Policy Dep. b Struct. Cohes. policies. Transp. Tour., 2012.

[13] The European Cyclists’ Federation, “The eu cycling economy,” Book, 2016.

[14] О. Н. Боровских, “Развитие велоинфраструктуры как решение транспортных и экологических проблем современного города,” Russ. J. Entrep., 2017, doi: 10.18334/rp.18.15.38172.

[15] L. Y. Qiu and L. Y. He, “Bike sharing and the economy, the environment, and health-related externalities,” Sustain., 2018, doi: 10.3390/su10041145.

[16] L. Zhang, J. Zhang, Z. Y. Duan, and D. Bryde, “Sustainable bike-sharing systems: Characteristics and commonalities across cases in urban China,” J. Clean. Prod., 2015, doi: 10.1016/j.jclepro.2014.04.006.

[17] J. Pucher and R. Buehler, “Cycling towards a more sustainable transport future,” Transp. Rev., 2017, doi: 10.1080/01441647.2017.1340234.

[18] D. Glavic, M. Milenkovic, and M. Pavlović, “Cost benefit analysis of bicycle infrastructure,” Put i saobraćaj, 2018, doi: 10.31075/pis.64.03.08.

[19] T. Götschi, J. Garrard, and B. Giles-Corti, “Cycling as a Part of Daily Life: A Review of Health Perspectives,” Transp. Rev., 2016, doi: 10.1080/01441647.2015.1057877.

[20] T. Koglin and T. Rye, “The marginalisation of bicycling in Modernist urban transport planning,” J. Transp. Heal., 2014, doi: 10.1016/j.jth.2014.09.006.

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Basics of Control and Maneuvering a Multi-Wheeled Electric Motor Vehicle

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***Abstract*—At the LEPL Raphael Dvali Institute of Machine Mechanics has developed, created and is testing a new original construction of physical model of remote-controlled mobile machine-robot, hybrid type, special purpose, with high cross-country ability and maneuverability, with universal platform. The vehicle is eight-wheeled, with electric motors mounted directly in the wheels. The vehicle is supplied by independent balancer suspension with oscillating levers and torsional springing in the longitudinal and transverse planes. The vehicle is controlled and maneuvered on the principle of caterpillar driving, for which an appropriate algorithm has been developed and the relevant program has been created.**

Keywords — vehicle, mobile machine, hybrid vehicle, electric motor.

I. Introduction

Hybrid and electric vehicles are one of the new promising directions in the automotive industry today. The rapid development of this direction has led to the creation of new types of highly efficient electrical aggregates, units and their control systems. It has been processed in a short time and is currently in serial production brush less different power electric motor-generators with dual action. The characteristics of electric battery packs have been significantly increased. The works in this field continues today and some results have been obtained. From this can be distinguished electric vehicles by electric motors located directly in the wheels, in which there is a possibility of controlling each motor individually with appropriate programs adapted to the road conditions. All this gives great opportunities to create a new construction, wide-ranging highly efficient mobile machine-robots. Works on this topic at the Institute of Machine Mechanics are carried out since 2011. During this period, at the Institute were developed, created and tested different several types of a physical models of an operating mobile machine-robots.

II. MAIN PART

The object of control is the vehicle with an eight non-steering wheels and electric motors located directly in the wheels (Fig.1).

In vehicles with ungovernable wheels, in case of violation of wheel rotation frequency synchronization, namely at the time of turn, the wheel that rotates at a large radius of rotation starts working in a brake mode, which worsens the turning process as well as increases an energy losses also. According to the road conditions due to instant change of the vehicle's center of rotation and accordingly changing rotation of wheels, it is very important to work in a constant synchronization mode of the wheel rotation frequency ratios.

Fig.1. *Experimental sample of vehicle with eight non-steering wheels.*

All this are possible by modern vehicle electrical control technologies with proper algorithms and microprocessor control. Depending on the road conditions, the control of the wheels and their coordinated work, is carried out by the joint action of the operator and the microprocessor located on the presented vehicle board. The operator transmits commands to the microprocessor in the form of electrical signals via an intermediate link – joystick, from which the information obtained using the appropriate algorithm is also transmitted in the form of electrical signals to the control units of electric motors, from which each drive is controlled and powered (Fig. 2).

The vehicle is maneuvered by changing the rotation frequency ratios of the wheels located relative to the longitudinal axis of the vehicle. The wheels have a common center of rotation O and different radii of rotation - R_D, R_C, R_c, R_E (Fig. 3), which is why speeds both the left and right board of the vehicle and also the wheels are different, because the wheels move in different radius circles.

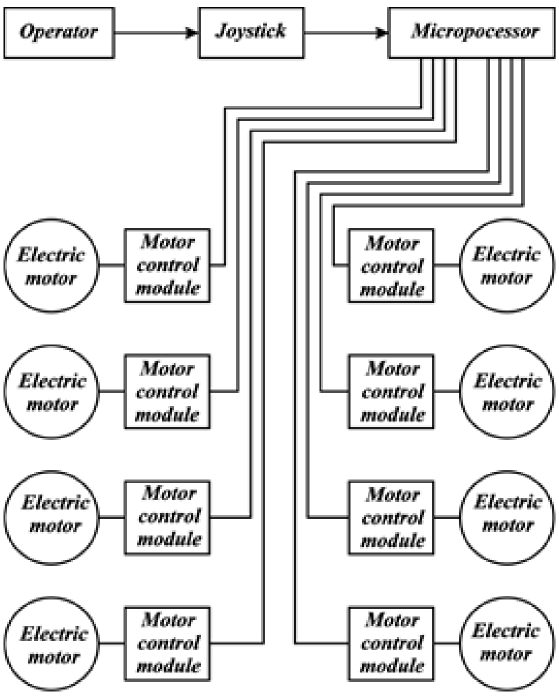

Fig.2. *Electrical control block diagram of the vehicle.*

Vehicle rotation maneuvering can be performed:

1. By synchronizing the rotation frequency of the wheels located on the vehicle board while braking the rear D wheel.
2. By synchronizing the rotation frequency of the wheels located on the vehicle board while braking the rear D and F wheels.
3. With synchronized control of the rotation frequency ratios of the wheels located on opposite sides of the vehicle.
4. By changing the direction of rotation of the wheels located on opposite sides of the vehicle (turning of the vehicle in relation to its own geometric axis).

To develop a vehicle control and maneuvering algorithm let's consider point 3, vehicle control and maneuvering with synchronized control of the rotation ratios of the wheels located on opposite sides of the vehicle. In this case the turning radius of the vehicle will pass through the middle points A and B of its wheel base b, with center of rotation radius O, which is permanently changing due to road conditions and depends on the ratio of the vehicle outer and inner wheels rotation frequencies. The location of the O center of rotation in relation to the boards of vehicle determines of its rotation direction (left, right). To determine the center of rotation O, consider the triangle ANO (Fig. 4) where $\vec{V_A} = \overline{[AN]}$ is the outer board motion instant velocity at point A and $\vec{V_B} = \overline{[BM]}$ – is the inner board motion instant velocity at point B.

Based on the similarity of the ANO and BMO triangles we will have:

$$\frac{V_A}{V_B} = \frac{AO}{BO} = \frac{AB + OB}{OB} \tag{1}$$

where,

AB = l - is the track of the vehicle;

OB = R_x - is the vehicle turning inner radius.

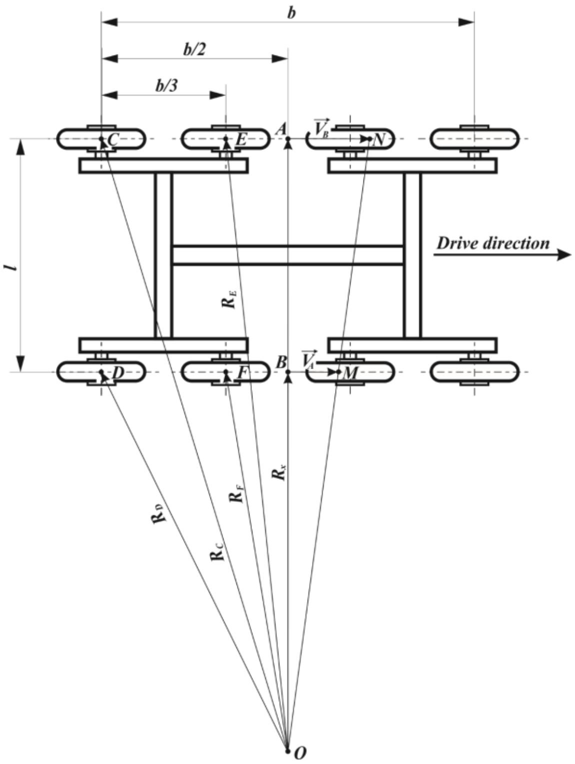

Fig. 3. *Scheme of vehicle with eight non-steering wheels.*

If we place at the points A and B the imaginary wheels identicals of the wheels on the vehicle then the velocities at these points will be equal:

$$V_A = 0{,}1R_A \cdot n_A$$

$$V_B = 0{,}1R_B \cdot n_B$$

here,

R_A and R_B - are the radiuses of the imaginary wheels placed at points A and B, accordingly;

n_A and n_B - are the rotation frequencies of the imaginary wheels placed at points A and B, accordingly.

LEPL Raphael Dvali Institute of Machine Mechanics.

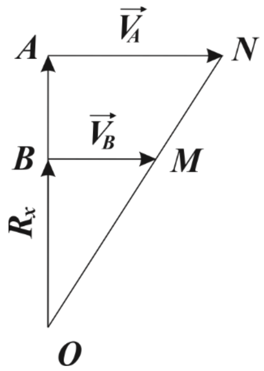

Fig. 4

By entering obtained values in the equation (1) we will have:

$$\frac{0{,}1R_A \cdot n_A}{0{,}1R_B \cdot n_B} = \frac{l + R_x}{R_x}$$

and based on the:

$$R_A = R_B$$

we will have:

$$\frac{n_A}{n_B} = 1 + \frac{l}{R_x} \qquad (2)$$

from where:

$$R_x = \frac{l \cdot n_B}{n_A - n_B} \qquad (3)$$

As can be seen from equation (2) when R_x=∞ then n_A= n_B and the vehicle moves by a linear motion type, and when R_x = 0 then n_B= 0 and the one side of the vehicle brakes and it is turned like a caterpillar.

On the other hand, the rotational numbers n_A and n_B of the imaginary wheels are formed by two electrical signals U_A and U_B supplied from the joystick, which must meet the following condition:

$$\frac{n_A}{n_B} = \frac{U_A}{U_B} = k$$

Where k is not a constant and varies depending on the control signal ratio $\frac{U_A}{U_B}$ received from the joystick.

Considering this the equation (2) will look like:

$$k = 1 + \frac{l}{R_x} \qquad (4)$$

or

$$R_x = \frac{l}{k - 1} \qquad (5)$$

By determining R_x we can find the O center of rotation of the vehicle, according to which the radiuses of rotation of all the wheels are formed:

$$R_D = \sqrt{\left(\frac{b}{2}\right)^2 + \left(\frac{l}{k-1}\right)^2}$$

$$R_C = \sqrt{\left(\frac{b}{2}\right)^2 + \left(\frac{l}{k-1} + l\right)^2}$$

$$R_F = \sqrt{\left(\frac{b}{3}\right)^2 + \left(\frac{l}{k-1}\right)^2}$$

$$R_E = \sqrt{\left(\frac{b}{3}\right)^2 + \left(\frac{l}{k-1} + l\right)^2}$$

After determination of the rotation radius of each wheel, and known that the angular velocity of rotation of all wheels is equal when turning the vehicle, the following can be written for each wheel:

$$\frac{n_D}{n_{R_x}} = \frac{R_D}{R_x} = \frac{U_D}{U_B}$$

$$\frac{n_c}{n_{R_x}} = \frac{R_c}{R_x} = \frac{U_C}{U_B}$$

$$\frac{n_F}{n_{R_x}} = \frac{R_F}{R_x} = \frac{U_F}{U_B}$$

$$\frac{n_E}{n_{R_x}} = \frac{R_E}{R_x} = \frac{U_E}{U_B}$$

where,

n_D,n_c,n_F, n_E are the rotation frequencies of the wheels D, C, F and E, accordingly;

n_{R_x} – is rotation frequency of imaginary wheel at the point B;

R_D, R_c, R_F, R_E - are the rotation radii of the wheels D, C, F and E, accordingly;

R_x - internal turning radius of the imaginary wheel;

U_B - is the support signal on the imaginary wheel obtained by calculation.

Based on all the above equations, the electrical signals supplied to the control block of wheels D, C, F and E were determined:

$$U_D = \frac{R_D}{R_x} U_B$$

$$U_C = \frac{R_C}{R_x} U_B$$

$$U_F = \frac{R_F}{R_x} U_B$$

$$U_E = \frac{R_E}{R_x} U_B$$

Thus, a generalized algorithm for control and maneuvering an eight-wheeled electric vehicle with electric motors was developed.

III. CONCLUSIONS

1. The performed work allows in the process of maneuvering to take individually into account the each wheel rotation frequency of the vehicles with electric motors directly mounted in the wheels . All this ensures maximum maneuverability of the vehicle and minimal energy losses.

2. In case of wheels with the different diameters depending on the type and construction of the vehicle, the proposed method can ensure the normal functioning of the vehicle.

REFERENCES

[1] Dvali R. The theory of the performance properties of the car. Tbilisi, Tbilisi State University, 1986. (In Georgian).

[2] Гладов Г. И. и др. Конструкции многоцелевых гусеничных и колесных машин. Москва, «Академия», 2010.

[3] Иванов В. В., Иларионов В. А., Морин М.М., Мастиков В.А. Основы теории автомобиля и трактора. Москва, «Высшая школа», 1970.

[4] Литвинов А. С., Фаробин Я. Е. Автомобиль. Теория эксплуатационных свойств. Москва, «Машиностроение», 1989.

[5] Платонов В. Ф., Азаев В. С., Александров Е. Б. и др. Энциклопедия. Колесные и гусеничные машины. Т. IV. Москва, «Машиностроение», 1997.

[6] https://www.youtube.com/watch?v=zlsJXYdyBOE

[7] https://www.youtube.com/watch?v=GPz2e-SLgjE

[8] https://www.youtube.com/watch?v=_1JmfoD2_lA

[9] https://www.youtube.com/watch?v=qblfZ63LBrI

[10] https://www.youtube.com/watch?v=dVGVkkpaWIc

[11] https://www.youtube.com/watch?v=l9coMQIcVfw

Main Issues in East-West Transport Corridor Identified with the Range Correlation Method

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***Abstract*—Since the global economic crisis and pandemic situation all the states have been suffering from low levels of investment in transport infrastructure. This has held back the modernization of the transport system. Road and rail infrastructure across the states have been degrading because of too little maintenance. The purpose of this paper is to show the main issues in East-West Trasnport corridor using The Range Correlation Method. A group of 10 specialists assigned ranges to 10 indicators to highlight the main issues. After the results of the study, a new strategic solution is proposed.**

***Keywords*—East-West transport corridor, logistics infrastructure, improvement, export, import**

I. Introduction

Transport is a fundamental sector of economy. It is a strategic sector of the EU economy, which directly affects the daily lives of all EU citizens. Transportation services provide about 11 million jobs. They are a cornerstone of European integration, with fully interconnected and sustainable transport networks being a necessary condition for the completion and proper functioning of the European single market. Efficient transport services and infrastructure are vital to exploiting the economic strengths of all regions of Europe, supporting the internal market and growth, and enabling economic and social cohesion. It is very important to mention the fact that it can influence trade competitiveness, as the availability, price, and quality of transport services have strong implications on production processes and the choice of trading partners. It can be mention that it has a central role in the logistics chain.

Despite the decrease of volume transportation caused by the pandemic situation and microprocessor crises, the East-West Transport Corridor (EWTC) is considered to be the transport corridor with the fastest developing traffic in the East-West direction having more traffic than many other corridors. Even if the volume is high, it is suffering from several obstacles as poor infrastructure, missing effective intermodal transport, low quality of the facilities provided by transport hubs, high volume of emissions, bottlenecks in the rail networks, insufficient motorways, airline, and sea services. From a social perspective, affordability, reliability, and accessibility of transport are missing. However, since the economic crisis of 2008, low investment in transport infrastructure has hampered the modernization of the transport network, with average investment reaching much lower levels than needed. Given the limited availability of public funds, increased private sector investment in strategic transport infrastructure is considered essential.

According to Eurostat's statistics in Europe the volume of goods transported in different ways is as follow (the volumes are represented in thousand tonnes):

Fig 1. Sea transport of goods European Union

Fig 2. Goods transport by road in European Union

Air transport of goods European Union

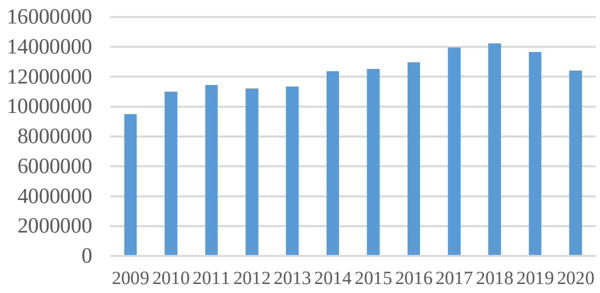

Fig 3. Air transport of goods European Union

In his paper A. Beifert [1] has studied the problem of the development of international transport corridors and F. Günther and others noted the importance of modernizing the transport infrastructure for its development [2]. In his study Liao mentions the urgency of improving the customs escort of goods passing through the corridor [6]. The need to develop international transport corridors and the active participation of the state in creating conditions for their improvement has been repeatedly asserted by researchers [7, 8]. At the same time, considerable attention has traditionally been paid to the problems of modernizing the existing transport and logistics infrastructure [4, 5, 9].

II. METHODS

The methodological basis of the study consists of general scientific methodological approaches, such as Range Correlation Method. The experiment was conducted by choosing factors of influence as the level of infrastructure on the railway on EWTC, level of infrastructure on the motorway on EWTC, level of infrastructure on airline structure on EWTC, affordability, availability of transports, reliability, the volume of emissions

III. RESULTS

Ten specialists were asked to classify the influence factors presented below in the order of their importance. They must award points from 1 to 10 to the factors they consider critical in logistic transport on East-West Transport Corridor and need improvement. The factors noted with Xi were explained as follows:

- X_1 –Affordability

Affordability measures the relative cost that the purchaser is able or not to pay for the transport.

- X_2- Availability of transports
- X_3- IT network development
- X_4 – Volume of emission

Air pollutants are responsible for several adverse environmental effects, such as photochemical smog, acid rain, death of forests, or reduced atmospheric visibility. Emissions of greenhouse gases from the combustion of fossil fuels are associated with the global warming of Earth's climate. Certain air pollutants, including black carbon, not only contribute to global warming but are also suspected of having an immediate effect on regional climates.

- X_5- Level of infrastructure on the railway on EWTC

Rail transport has an important role in raising the level and standards of development of a country, and the railway has been and is generating progress and civilization. The elements that will be evaluated during the railway transport are:

- ➢ railways, bridges, tunnels, viaducts;
- ➢ geotechnical protection and consolidation works;
- ➢ safety and operational management facilities for railway traffic;
- ➢ the network triage of the railway and the lands related to them;
- ➢ telecommunications installations that ensure the transmission of information for safety and operational management of traffic;

- X_6- Level of infrastructure on airline structure on EWTC

Airfreight is an extremely important component of freight. Air transport of goods is the fastest way to transport but also the most expensive. The elements that will be evaluated consist mainly of aircraft, airports, air traffic control, and safety systems.

- X_7- Level of infrastructure on the motorway on EWTC

The elements that will be evaluated during the motorway transport are:

- ➢ road transport network (roads, vehicles);
- ➢ aspects related to design, construction, diagnosis and operation of vehicles, road traffic, management.

- X_8 – Reliability
- X_9 – Facilities provided by transport hubs
- X_{10} –Existence of an intermodal transport

Grade 1 is given for the most important factor and grade 10 for the least important factor. The grades were centralized in the primary data table.

Table 1 Questionnaire

Fact. No.	Description	Grade
X1	Affordability	
X2	Availability of transports	
X3	IT network development	
X4	Volume of emission	
X5	Level of infrastructure on the railway on EWTC	
X6	Level of infrastructure on airline structure on EWTC	
X7	Level of infrastructure on the motorway on EWTC	
X8	Reliability	
X9	Facilities provided by transport hubs	
X10	Existence of an intermodal transport	

All responses were centralized in the below table:

Table 2 Primary data table

Specialists	Influence factors										Σaij
	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	
S1	1	4	3	6	5	8	7	2	10	9	**55**
S2	4	9	5	3	1	7	8	1	6	10	**54**
S3	10	2	5	1	2	4	10	7	8	6	**55**
S4	1	1	1	2	1	1	3	3	3	3	**19**
S5	5	4	7	3	6	10	9	8	1	2	**55**
S6	7	8	1	5	3	4	9	2	10	6	**55**
S7	5	3	4	2	1	9	8	7	6	10	**55**
S8	1	4	7	3	1	5	6	8	10	9	**54**
S9	8	6	10	4	3	5	9	1	2	7	**55**
S10	4	8	3	2	1	10	5	9	7	6	**55**
Σaij	46	45	39	28	18	53	65	40	62	66	**512**
Θj1	3	6	4	2	1	7	10	5	8	9	

Because, in the questionnaires, some respondents gave the same rank to at least 2 factors of influence, it is necessary to link ranks. For this purpose was browsed the primary table line by line and calculate the corrected rank as the ratio of the sum of the order numbers of places occupied by factors of the same rank and the number of factors of the same rank. With the corrected values, a second table is completed.

Table 3. Secondary data table

Specialists	Influence factors										Σaij
	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	
S1	1	4	3	6	5	8	7	2	10	9	**55**
S2	4	9	5	3	1.5	7	8	1.5	6	10	**55**
S3	10	2	5	1	2	4	10	7	8	6	**55**
S4	3	3	3	6	3	3	9	9	9	8.5	**55**
S5	5	4	7	3	6	10	9	8	1	2	**55**
S6	7	8	1	5	3	4	9	2	10	6	**55**
S7	5	3	4	2	1	9	8	7	6	10	**55**
S8	1.5	4	7	3	1.5	5	6	8	10	9	**55**
S9	8	6	10	4	3	5	9	1	2	7	**55**
S10	4	8	3	2	1	10	5	9	7	6	**55**
Σaij	49	51	48	35	27	65	80	54	69	74	**550**
Θj1	4	5	3	2	1	7	10	6	8	9	

The adequacy of the data in the primary table with the data in the secondary table is realized by comparing the hierarchy provided by the primary table Θ1 with that of the secondary table Θ_2, by calculating the correlation coefficient r_s:

$$r_s = 1 - \frac{6\sum_{j=1}^{n}(\theta j1-\theta j2)^2}{n^3-n} \quad (1)$$

where n is the number of influence factors (x);

(1) refers to the data in the primary table;

(2) refers to the data in the secondary table

In the case studied, rs =0.66 which shows that data from the primary and secondary tables are in agreement.

Verifying the degree of agreement between the points of view of the specialists is made calculated The consensus coefficient W:

$$W = \frac{10\sum \Delta^2 j}{m^2(n^3-n)-m\sum Ti} \quad (2)$$

where: m is the number of specialists;

n is the number of influence factors

$$\Delta j = \sum_{i=1}^{m} aij - \frac{1}{n}\sum_{j=1}^{n}\sum_{i=1}^{m} aij \quad (3)$$

$$T_i = \sum_{j=1}^{n}(t^3 j - tj) \quad (4)$$

where tj is the number of identical ranks, of a certain value, assigned by specialist i.

After calculations, the value of the consensus coefficient is w = 0.59. The statistical significance of the coefficient w is estimated using the statistical criterion χ^2, as 10 influence factors (n> 7) were studied. The value of criterion χ^2 is calculated if the relation:

$$\chi^2_{calc} = m(n-1)w \quad (5)$$

The graphical representation of the results was made in the form of a histogram showing on the axis OY the influence factors noted $X_1, X_2, \ldots, X_{10}$. And it also ranks the factors from the most important, which obtained the lowest rank, to the least important, which is the one who obtained the sum of the highest rank.

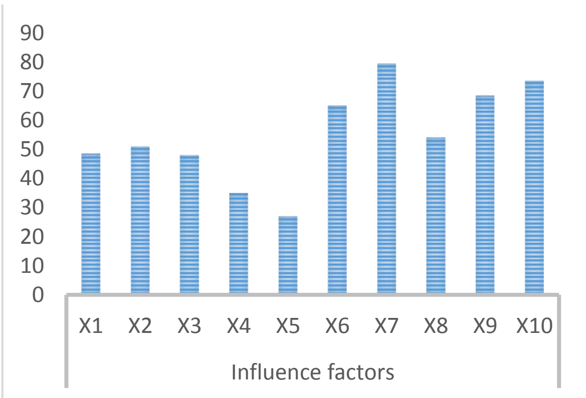

Fig 4. Hierarchy of influencing factors

The data representation was chosen in the form of a histogram (fig. 1), which has the influence factors on the axis Ox, and on the axis Oy, the significance index Is, expressed by the ratio (m / Aij).

According to the specialists' answers, the railway infrastructure, the gas emissions, and the IT network are the main areas that require immediate intervention.

Railways are a climate-smart and efficient way to move people and freight. Railways promote economic growth while cutting greenhouse gas emissions. They are a clean and compact way to move millions of passengers and millions of tons of goods across countries and continents. The environmental benefits include:

- Decreased energy consumption
- Reduced accidents
- Reduced air pollution and emissions
- Reduced land for auto and air facilities
- Intensified and reuse of urban area lands around stations
- Reduced wetland and water resource impact by reuse of existing rail routes.
- A larger volume of goods to transport for long distances

Unfortunately, the railway network is not sufficiently developed to support a larger volume of goods and an increase in speed. Not only the investments in infrastructure but also its maintenance were neglected, which determined, for safety reasons, the permanent reduction of the maximum allowed traffic speed, respectively the increase of the journey time, thus diminishing the attractiveness of the system and the offered services.

To increase the speed Maglev train should be a solution. The operating principle of the system consists in using the forces of attraction or rejection between the poles of permanent magnets, for the transport of goods. The bounce forces between the N-N or S-S magnetic poles determine the propulsion, that is, the displacement in the direction of transport.

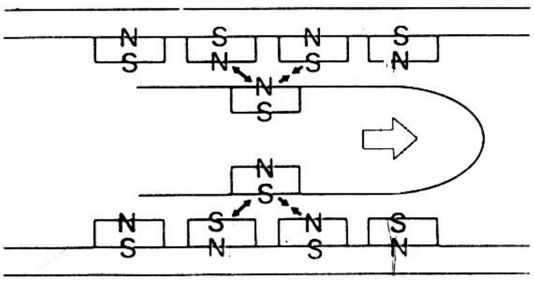

Fig 5. The operating principle of the system

The coils (magnets) are made of superconducting material (niobium-titanium alloy) whose resistance is canceled out at temperatures of -269 ° C (cryogenic domain). Helium is used as a cooling agent to maintain such a temperature. When moving vertically, the variable magnetic field determines the induction of electric current in the coils (magnets) in the path that will act as a vertical suspension. The electromagnets in the path are connected to an electrical circuit. Thus, at a lateral displacement, the variable magnetic field induces in the circuit an electric current resulting in attractive or repulsive lateral forces that will guide the transport unit along the central axis of the path.

The big disadvantage is that these types of trains cannot be used with the existing infrastructure, but must be designed from the beginning and are very expensive.

Increasing the competitiveness of railway transport must be considered the approach with the greatest chances of success in terms of the recovery of railway transport and, implicitly, in terms of the economic and financial recovery of railway companies.

IV. Conclusions

The study shows that according to the specialists' answers, the railway infrastructure, the gas emissions, and the IT network are the main areas that require immediate intervention. It is a clear fact that railways are a climate-smart and efficient way to move goods across countries and continents. The solution proposed with Maglev trains has the advantage that they reach much higher speeds than ordinary trains, have better acceleration, and can climb steeper slopes. Energy efficiency is superior and they are much safer, there is no risk of derailment. Although not as quiet as expected, magnetic trains are much quieter than usual. But Maglev trains also have many disadvantages. They cannot be used with existing infrastructure, and the high cost of building new taxiways is very high.

V. References

[1] A. Beifert, Y. Shcherbanin, and E.Vinokurov, “Trans-Eurasian land transport corridors: assessment of prospects and barriers” in IIASA Report, Laxenburg, Austria, 2018.

[2] F. Günther, N. Otsuka, I. Tosoni and C. Braun, “Developing Trans-European Railway Corridors: Lessons from the Rhine-Alpine Corridor” in Case Studies on Transport Policy, vol. 5 (4), pp. 527-536, 2017.

[3] Nichci, E Cicala, R. Mee Prelucrarea datelor experimentale – curs şi aplicaţii, Centrul de multiplicare Timişoara, 1996

[4] O. Pokrovskaya, “Terminalistics as the methodology of integrated assessment of transportation and warehousing systems” in MATEC Web of Conferences, Vol. 216, 2018. DOI: https://doi.org/10.1051/matecconf/201821602014

[5] O. Pokrovskaya, R. Fedorenko, and E. Khramtsova, “Study of the typology of logistic entities using functional and logistic approach” in The European Proceedings of Social & Behavioural Sciences, vol. LVII (10), pp. 91-101, 2018. DOI:https://dx.doi.org/10.15405/epsbs.2019.03.10

[6] R. Liao, “Supernetwork-based risk management of customs logistics monitoring system” in Complex Systems and Complexity Science, vol. 14 (2), pp. 39-45, 2017.

[7] S. Chibukhchyan, “Transit capabilities of the Eurasian Economic Union” in Logistics, vol. 9 (118), pp. 28-31, 2016.

[8] V. Tsvetkov, K. Zoidov, and A. Medkov, “Formation of a new evolutionary concept of increasing the cargo base of transport corridors "East-West": current state, geopolitical conditions, and economic prerequisites” in Regional problems of economic transformation, vol. 5 (43), pp. 43-63, 2014.

[9] Y. Chizhkov, “International transport corridors - the communication frame of the economy” in Transport of the Russian Federation, vol. 5 (60), 2015, pp. 9-15.

Digital Integrated Maintenance Technology for Cooperative Cranes

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***Abstract*—The paper presents the final stage and shape of an integrated digital technology created to support cooperative overhead cranes maintenance strategies. The technology involves online self-analysis layers for parameter calibration and data processing, measurement of dependencies on degradation data with copula approach, simulation-based risk modeling with implemented variance reduction techniques and well-established heuristic algorithms to solve maintenance scheduling optimization with implemented parallel computing. The tool is a compilation of efforts that aims a robust and comprehensive contribution in the field of informatic technologies. The paper describes the overview architecture and relationship between all the research involved to reach at the final tool.**

***Keywords*—Digital Twins, Maintenance, Risk Assessment**

I. Introduction

Today continuous process industry is highly automated, and every system involved in each process is made up of a large number of components. Due to the complexity and size of the system, coordination of operation and maintenance is a constant challenge, especially the decision-making behind these two processes. One way to compensate these challenges is to use new methodologies and technological features to create comprehensive tools that achieve fast and smart coordination, even in extremely complex system.

Digital Twins concept is a framework that unites system engineering methodology and technology by proposing five-dimensions as pillars for building solutions and tools in modern industry. This concept provides clear guidelines for describing each key component in an engineering solution. Conceptually, the five dimensions are: *physical object*, *virtual counterpart*, *connection*, *data*, and *services*. Therefore, each study case must define each of these dimensions.

This contribution intends to describe the final stage and shape of a digital integrated maintenance technology using the Digital Twins framework.

That said, the remaining sections of this document are organized as follows: first, a definition of the Digital Twins five dimensions applied to the technology under study, then a description of all the variables and functional connections involved in the architecture of the digital platform. At the same time, during the descriptions, we show the links to previous research. Then we describe future works and next steps from a research point of view, ending the paper with the conclusions section.

II. Digital Platform

A. Physical object

The platform proposed in this paper was created with the intention of improving the maintenance coordination of a real running process, resulting in another contribution in the transition to the digital industry. Practical examples like the one presented are common when a process is well known and can be replaced and optimized by smart software. Particularly, the proposed solution (integrated maintenance technology) is focused on supporting the maintenance department strategies of a steel plant, which has the role of managing this process in cooperative overhead cranes. Maintenance strategies is the research subject here because it continues to be a permanent need in the industry, as discussed in reference [15].

The technology is a tool oriented to assess risks holistically at the system level (cooperative overhead crane system or set of overhead cranes). The selection of the approach is an agreement with the maintenance department and is connected in some way to the system characteristics, while there may be other approaches such as cost-based experiences [2] or using two levels [4]. The technology, as a whole, practically and methodologically introduces notable improvements in the process under study and is supported by previous solutions applied in other cases with similar problems [5], [11] and [16].

In this paper, the *physical object* is the coordination of maintenance strategies for a set of overhead cranes in a steel plant.

B. Virtual counterpart

The integrated maintenance technology is made up of layers, separated into three functional blocks: Processed Data, Risk Model and Maintenance Scheduling. The integrated digital platform architecture is shown in Figure 1, as well as the connection between the functional blocks. The functions that make up blocks are separated and encapsulated by independent layers to ensure flexibility, and all are robustly implemented in Matrix Laboratory (MATLAB).

In the proposed technology, Risk Model and Maintenance Scheduling functional blocks together form the *virtual counterpart*.

The parameters and variables needed to run the Risk Model are transferred from a database to the Risk Model with an independent layer, once the data has been processed by the block Processed Data (in our case the *connection* dimension of the Digital Twins framework), along with the configuration selected by the user (maintenance department manager).

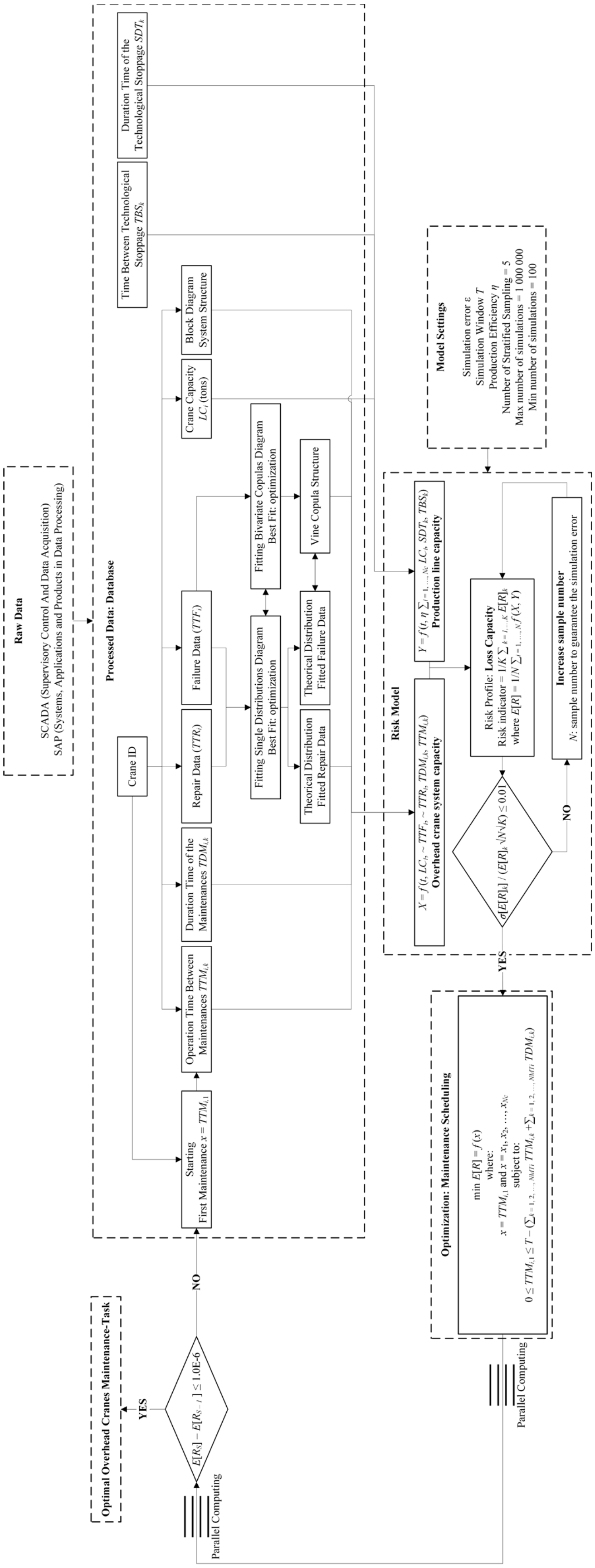

Fig. 1. Digital Paltform Architecture.

Fig. 2. The output of the Risk Model is an indicator (Loss Capacity) that measures the potential losses in tons in the steel plant due to the unavailability of overhead cranes. The reasons why overhead cranes may be unavailable are unexpected failures and scheduled maintenance. Previous studies prove that the model is well-defined even when the variable data changes over time. The sensitivity analysis performed to address this conclusion is discussed in the contribution [18].

The method implemented to estimate the risk indicator (a convolution product between the system capacity and system requirements) is the Monte Carlo method. We select a simulation method because it is the only reasonable way to construct the compound distribution of the system, combination of the stochastic time-to-failure (*TTF*) and time-to-repair (*TTR*) concatenation of each crane through the series-parallel block diagram.

Based on previous experience, e.g., contributions [3], [6], [10] and [14], we can say that simulation approaches allow us to achieve memorable results because they introduce modelling flexibility by considering functional and random variables.

Even using a simulation method, the time needed to estimate the indicator is quite fast because we implemented variance reduction techniques (stratification in our case) to reduce the variance of the estimator and reduce the time. The performance of the model before and after applying the variance reduction technique is analyzed in the contribution [17]. The method has simulation error control, and the estimation is always accurate for any scenario in which it is evaluated.

One of the inputs to the Risk Model is the maintenance lifecycle of each crane under consideration. The graphical representation of maintenance over time depends on the starting time of the maintenance cycle. This variable can be fixed or variable in the Risk Model. This relationship defines the connection between the Risk Model and the Maintenance Scheduling routine. Leaving the starting time of each i (index referring to each crane) lifecycle maintenance time-to-maintenance $TTM_{1,i}$ free as a variable allows a heuristic optimization algorithm to search for the best scheduling maintenance for the system using the Loss Capacity indicator to discriminate the combination with lowest risk for the system, therefore, as a solution we get a risk oriented coordinated maintenance scheduling. The optimization flow diagram is presented in [12] and the convergence of the optimization model is fully discussed in the contribution [21].

The implemented optimization routine is a heuristic method as we pointed out above, but thanks to parallel computing, the candidate scenarios are evaluated independently and the time to reach the final solution is also quite fast for this type of algorithm, knowing that it is dependent on the computer power. The improvements introduced by the parallel computing are discussed in the contribution [17].

The connection between the user (maintenance department manager) and the three functional blocks composing the technology is a dynamic window that visualizes the performance of the Risk Model (risk indicator convergence, empirical histogram of the risk indicator, stochastic convolution between the system capacity and system requirements) and plots the graphical representation of the maintenance scheduling.

C. Connection

The Processed Data block plays an important role and is the most complex block because it provides the Risk Model with all the variables and parameters needed to assess the selected scenario or regime. Therefore, the output of Processed Data is a database with all the inputs of the Risk Model. The Processed Data functional block is the *connection* dimension between the *data* and the *virtual counterpart* in the proposed technology.

Now, we describe the overview of the connection between these two blocks (Processed Data and Risk Model) by listing the input variables and parameters of the Risk Model and the processes involved:

- Crane ID

The crane ID is filtered from the Supervisory Control And Data Acquisition (SCADA) system and stored in the database.

- Crane Capacity LC_i (tons).

The crane capacity is filtered from the SCADA system and stored in the database.

- Block diagram of the system structure.

The system block diagram is constructed using information from the Systems, Applications & Products in Data Processing (SAP) system, where the cranes in the same section of the production line are considered in series and cranes in different sections are considered in parallel. A filtered location code from the SAP system is used to determine the series-parallel block diagram of the system. This practice is common in the field of reliability engineering and in our case, we adopted the methodology, knowing that it has been successfully applied in previous experiences [1].

- Simulation window T.

The simulation window is a parameter set by the user of the digital platform (manager in our case). Usually, the window can vary between one week and one year, and by default the tool sets this parameter to one year.

- Theoretical distribution fitted to failure data of each crane considered / Theoretical distribution fitted to repair data of each crane considered.

Complexity arises at this stage. The platform works online, therefore, each time a scenario is evaluated, the following process is executed: For each crane i, we filter from the SCADA system the historical Failure Data ($TTF_{i,k}$) and Repair Data ($TTR_{i,k}$) and applying the formal fit selection flow diagram presented in [13] and validated in [19], we select the best statistical theoretical distribution based on the Akaike Information Criterion (AIC) criterion. The diagram is applied independently to $TTF_{i,k}$ and $TTR_{i,k}$ variables.

- Maintenance lifecycle of each crane considered (operation time between maintenance $TTM_{i,k}$ and duration time of the maintenance $TDM_{i,k}$).

Each crane has associated a lifecycle maintenance provided by the manufacturer and international crane-related standards. The raw information is stored in the SAP system of the steel company, and an independent layer filters and moves the information from the SAP system to the database using a unique crane ID.

- Degradation dependency structure of the crane system.

In order to measure the dependencies between crane degradation data, i.e., cranes working under the same regime, cranes with same capacities, etc., we selected the vine-copula approach. We decided to introduce the copula approach into the model because it is flexible enough to capture both dependent and independent functional conditions. The decision is accompanied by the analysis of the relationship between the copula approach and the conditional expected value (Loss Capacity) in reference [20] and how it is finally introduced into the model in contribution [23] by generating dependent random structures. This practice was even tested with previous case studies, specifically gantry cranes in a container terminal, as we described in reference [9].

The process to measure the dependencies is complex, and like the fitting process, this layer is also executed each time a scenario is evaluated. The overview of the process is as follows: For each pairwise cranes considered in the system, i.e., Crane 1 – Crane 2, we filter from the SCADA system the historical Failure Data and apply the formal selection flow diagram presented and validated in [22], then we select the best statistical copula distribution for each pairwise cranes combination in the considered system based on the AIC criterion. Then applying a two-step selection process, we search for local concatenations of copulas using the AIC criterion, and then once the best local selections are found (local minimum), the final dependency structure is the option with minimum AIC criterion, resulting this option in the global selection step (global minimum).

- Information related with the production line (time between technological stoppage TBS_k, and duration of the technological stoppage SDT_k).

In the SAP system is stored the planification of the production line. Then, an independent layer captures and transfers the information to the database created for maintenance strategies purposes.

D. Data

The proposed technology is made to work without human intervention in the most sensitive steps of the model to avoid human errors and to select decisions at all times based on data collected by professional systems. SCADA and SAP systems are the main sources of raw information used by the proposed tool and together they form the *data* dimension. Both systems have different functions and were created for different purposes, so an intermediate database (digital *connection*) was created for maintenance purposes to filter and process the information needed for the platform.

E. Services

The tool is easy to understand, and by looking at a global indicator, the manager (user of the tool) can evaluate the performance of decisions and at the same time improve the decision-making by changing parameters and variables in the model. Thanks to the implemented tool, it is possible to analyze various scenarios and regimes in the modelled system, it is possible predict and analyze potential decisions, and always, as a main result, the tool provides the best risk-oriented maintenance scheduling scenario for the input setting and regime selected by the user.

The features and flexibilities of the technology define the services dimension in the Digital Twins framework.

The process of building such a tool is not easy because it is necessary to consider all potential scenarios to be evaluated. Moreover, it takes time to redesign the tool in order to achieve the ultimate goal of the contribution. Regardless of the above, a previous experience in this field allows us to travel in a suitable way, for instance, a similar situation happened with the contribution [7]. This reference initializes the journey of the contributions, then, the analysis of the interrelation with other system resulted in the contribution [8], and then the final shape of the proposal was published in [16] under the guidance of the digital twins concepts.

Having described all the dimensions, we introduce the future work, from the research point of view, related to the proposed technology.

III. Achivements and Future Work

The proposed technology is a unique engineering solution; therefore, comparisons are difficult. At this point, after all the validation and modelling tests performed, the tool is ready to be applied in practice in the steel plant. Once the economic achievements related to the introduction of the technology are known, a new contribution will discuss the results.

IV. Conclusions

The paper summarizes the effort of two years of work to create a technology oriented to solve a specific problem, but during the journey memorable methodological and technological goals have been achieved, leaving a bunch of papers describing how a running system can be improved by means of digital technologies.

Acknowledgment

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References

[1] Yorlandys Salgado Duarte and Alfredo M. del Castillo Serpa (2016). Heuristic method for the evaluation of the reliability in a subsystem of transmission lines. Ingeniería Energética, 2016: XXXVII (1):3-14, Enero / Abril, ISSN 1815-5901.

[2] Yorlandys Salgado Duarte, Alfredo Martínez del Castillo Serpa and Ariel Santos Fuentefría (2018). Optimum scheduling of generator preventive maintenance of power system with wind presence. Revista de Ingeniería Energética, 2018, vol. 39, n. 3, septiembre /diciembre, p. 157-167. ISSN 1815-5901.

[3] Yorlandys Salgado Duarte and Janusz Szpytko (2018). Electric Public Bus Charging Stations Topography Modelling. Springer Nature Switzerland AG 2018. J. Mikulski (Ed.): TST 2018, CCIS 897, pp. 197–217, 2018. https://doi.org/10.1007/978-3-319-97955-7_14.

[4] Janusz Szpytko and Yorlandys Salgado Duarte (2019). Integrated Maintenance Decision Making Platform for Offshore Wind Farm with Optimal Vessel Fleet Size Support System. International Journal on Marine Navigation and Safety of Sea Transportation, Vol. 13, Issue 4, 2019. DOI: 10.12716/1001.13.04.15.

[5] Janusz Szpytko, Lenier Aleman Hurtado and Yorlandys Salgado Duarte (2019). Liquefied Petroleum Gas Transport Service Improvement via Telematics Support. Springer Nature Switzerland AG 2019. J. Mikulski (Ed.): TST 2019, CCIS 1049, pp. 230–249, 2019. https://doi.org/10.1007/978-3-030-27547-1_18.

[6] Janusz Szpytko and Yorlandys Salgado Duarte (2019). Cloud Computing Based Speed Control Optimization of Electric Bus Fleet with Fast Charging Infrastructure. Archives of Transport System Telematics. Vol 12, Issue 2, May 2019.

[7] Janusz Szpytko and Yorlandys Salgado Duarte (2019). Integrated Maintenance Decision Making Platform for Gantry Cranes in Container Terminal. 978-1-7281-0933-6/19, 2019, IEEE.

[8] Janusz Szpytko and Yorlandys Salgado Duarte (2019). Digital Twins Model for Cranes Operating in Container Terminal. IFAC PapersOnLine 52-10 (2019) 25–30.

[9] Janusz Szpytko and Yorlandys Salgado Duarte (2020). Predictive Maintenance Model with Dependent Stochastic Degradation Function Components. Springer Nature Switzerland AG 2020. C. Debruyne et al. (Eds.): OTM 2019 Workshops, LNCS 11878, pp. 1–11, 2020. https://doi.org/10.1007/978-3-030-40907-4_6.

[10] Janusz Szpytko and Yorlandys Salgado Duarte (2020). Markov chain Monte Carlo simulation model for risk assessment the power systems for electromobility use. Journal of KONBiN 2020. Vol. 50, Issue 1, DOI 10.2478/jok-2020-0002.

[11] Yorlandys Salgado Duarte, Janusz Szpytko and Alfredo M. del Castillo Serpa (2020). Monte Carlo simulation model to coordinate the preventive maintenance scheduling of generating units in isolated distributed Power Systems. Electric Power Systems Research 182 (2020) 106237.

[12] Janusz Szpytko and Yorlandys Salgado Duarte (2020). Exploitation Efficiency System of Crane based on Risk Management. DOI: 10.5220/0010123200240031. In Proceedings of the International Conference on Innovative Intelligent Industrial Production and Logistics (IN4PL 2020), pages 24-31. ISBN: 978-989-758-476-3.

[13] Janusz Szpytko and Yorlandys Salgado Duarte (2020). Integrated maintenance platform for critical cranes under operation: Database for maintenance purposes. Preprints of the 4th IFAC Workshop on Advanced Maintenance Engineering, Service and Technology. September 10-11, 2020. Cambridge, UK.

[14] Janusz Szpytko, Pawel Hyla and Yorlandys Salgado Duarte (2020). Autonomous vehicles energy based operation capacity planning. Journal of Machine Engineering, 2020, Vol. 20, No. 4, 126–138.

[15] Janusz Szpytko and Yorlandys Salgado Duarte (2020). Maintenance strategies overlook for devices under operation. Journal of KONBiN 2020, Volume 50, Issue 4. DOI 10.2478/jok-2020-0077.

[16] Janusz Szpytko and Yorlandys Salgado Duarte (2020). A digital twins concept model for integrated maintenance: a case study for crane operation. Journal of Intelligent Manufacturing. https://doi.org/10.1007/s10845-020-01689-5.

[17] Janusz Szpytko and Yorlandys Salgado Duarte (2021). Robust simulation method of complex technical transport systems. Transport Problems 2021, Vol. 16, Issue 2, DOI: 10.21307/tp-2021-026.

[18] Janusz Szpytko and Yorlandys Salgado Duarte (2021). Technical Devices Degradation Self-Analysis for Self-Maintenance Strategy: Crane Case Study. Proceedings of the 17th IFAC Symposium on Information Control Problems in Manufacturing Budapest, Hungary, June 7-9, 2021.

[19] Janusz Szpytko, Jorge Rosales Contreras and Yorlandys Salgado Duarte. Degradation Data Self-Analysis Layer for Integrated Maintenance Strategies. Journal of Computers & Industrial Engineering. Paper in editorial process. Submitted in March 2021.

[20] Janusz Szpytko and Yorlandys Salgado Duarte. Measuring Dependencies in Cyber-Physical Systems: Overhead Cranes Case Study. Manuscript submitted to Springer Series. Selected papers of the International Conference on Innovative Intelligent Industrial Production and Logistics (IN4PL 2020). Submitted in May 2021

[21] Janusz Szpytko and Yorlandys Salgado Duarte. Industrial Information Integration Approach for Risk-based Self-Maintenance strategies: Study Case for Crane Distributed System. International Journal of Production Research. Paper in editorial process. Submitted in July 2021.

[22] Janusz Szpytko and Yorlandys Salgado Duarte. Digital Platform for Overhead Cranes Maintenance Strategies: Measuring Dependencies on Degradation Data with Vine Copulas. Manuscript submitted to 14th IFAC Workshop on Intelligent Manufacturing Systems. Submitted in July 2021.

[23] Janusz Szpytko and Yorlandys Salgado Duarte. Assessing Impacts of Vine-copula Dependencies: Case Study of a Digital Platform for Overhead Cranes. Manuscript submitted to Workshop on Enterprise Integration, Interoperability and Networking - EI2N 2021. 25 – 27 October 2021, in conjunction with the 2nd International Conference on Innovative Intelligent Industrial Production and Logistics - IN4PL 2021. Submitted in July 2021.

Purpose of the Height of Earth Filling from Salt Soils on the Example of the Syrdarya Region

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***Abstract*—The article provides an analysis of regulatory documents, literature, as well as research work on the appointment of the height of embankments from salted soils common in Uzbekistan used in practice. Taking into account the level and type of soil salinity in the field, the length of public roads passing along them was determined. As a result of processing, the calculated characteristics of saline soils were determined, numerical values of the height of road embankments were recommended in accordance with the degrees of salinity**

***Keywords*—density coefficient, chloride, sulfate, saline soils, low salinity, salted, non-saline, moderately saline, highly saline**

I. Introduction

All soils contain salts, the amount of which depends on climatic, morphological, soil and climatic factors, hydrological systems of the territory. When the amount of soluble salts (sulfates, chlorides and bicarbonates of sodium, potassium, calcium and magnesium) becomes excessive to such an extent that it adversely affects the road surface.

Salinization is a typical process in environments where there is not enough rainfall to remove salts in the soil. Usually, the phenomenon is accentuated in the presence of shallow aquifers, from which water, moving upward, carries salts to the surface.

A certain amount of salt can also accumulate in moderately humid climates, in basins with impermeable bottoms, where waters coming from adjacent territories, the soils or sediments of which contain salts [1].

One type of salinization, called secondary salinization, is common in irrigated land. This is due to various factors:

- supply of unusable irrigation water, the salts of which are concentrated in the soil due to evapotranspiration. For example, when irrigating with "fresh" water containing 0.5% salts, and taking into account the volume of 4000;. 5000 m² per year, from 2 to 2.5 tons of salts per hectare are applied to the soil. They, if not washed away by rains in the autumn-winter period, can accumulate in the soil;

- raising the level of groundwater, which can bring salts to the ground directly or by climbing capillary or prevents the leaching of excess salts [2].

The sharp increase in the type and number of vehicles moving on the roads of the country and the load on their rear axles require the solution of such tasks as the improvement of existing regulations. Therefore, it is important to rework the norms of road lifts listed in them: in particular, the height values to ensure their strength and stability [3].

II. Method

Classification of soils of roads passing through the saline areas of the Republic by salinity level is given in such normative documents as SHNK 2.05.02-07 [4], VSN 47-73 [5], IKN 56-10 [6] and in the literature on road construction. According to them, soils are divided into weak, medium, strong and very strong types by the sum of the amount of lightly soluble salts (in% of dry soil mass), chloride, sulfate-chloride and sulfate, chloride-sulfate by type of salt.

The sharp increase in the type and number of vehicles moving on the roads of the country and the load on their rear axles require the solution of such tasks as the improvement of existing regulations. Therefore, it is important to rework the norms of road lifts listed in them: in particular, the height values to ensure their strength and stability.

In SHNK 2.05.02-07 the height values of saline soils are not given, in which clay and lyossimon soils are proposed (Tables 31 and 32 on SHNK). In particular, Table 32 states that for lyossimon soils, the rise of the coating surface above groundwater level should be increased by 20% in low and moderately saline soils.

According to VSN 47-73, the height of the pavement in places 2 and 3 (at the lowest point of the cross section) should not be less than the value given in Table 1 above the ground.

TABLE I. The height of the pavement according to VSN 47-73

Roadside soils	The height of the road surface, m, not less, in the ground		
	non-saline	slightly and moderately saline	highly saline
Medium and fine sand, light coarse supes	0,2	0,3	0,4
Dusty sand, light supes	0,3	0,4	0,5
Heavy suglinok, glina	0,4	0,5	0,6
Dusty and heavy dusty supes, light, lightly dusty and heavy dusty supes	0,4	0,6	0,7

Note. In irrigated areas, where the calculated groundwater level cannot be determined with the required probability, as well as in areas that need to be developed and irrigated during the service life between road repairs, the values given in Table 1 are 30% for level IV-V roads and 50% for level I-III roads. increased by%.

According to IQN 56-10, in order to increase the strength and stability of the hoist, as well as to reduce the height of the hoist, its upper part to a depth of 0.4 m at a low humidity (W = 0.70-0.75WOQ) to a maximum standard density (KZ = 1 , 01-1.03) condensation is proposed. In addition, it was stated that it is advisable to compact the natural base of the lift to 0.2-0.3 m. However, it is not specified what the density coefficient is.

According to V.F. Babkov [7], low and medium salinity soils can be used in standard structural elevations, as well as in the upper working layer, provided that the accepted norms for non-saline soils are followed. Strongly saline soils can be used on road sections in Round I areas under wet conditions, using measures to prevent the top layer from additional salinity. Extremely saline soils can be used by taking the necessary measures to neutralize their negative properties, which are basically accepted by laboratory studies.

It is necessary to increase the height of the coating surface from the level of ground or surface water by 20% compared to the norm in low and moderately saline soils, by 30% for loam and clays, and by 40-60% in strongly saline soils [8].

V.D. Kazarnovsky [9] The height of the coating surface, such as VF Babkov, depends on the level of ground or surface water, in low and moderate salinity soils by 20% of the norm (30% for loam and clays), in strongly saline soils 40 Proposes an increase of -60%.

S.V. Konovalov [10] proposes to increase the height of the coating surface in strongly saline soils by 20% above the norm above the ground or surface water level.

According to V.M. Sidenko and N. Ilyasov [11], the height of the footpath above the groundwater level should be determined in accordance with Table 2.

TABLE II. The height of the footpath

Soil	Road eyebrow height, in soils, m	
	low salinity	salted
in subsoil soils	1,1	1,3
in dusty supes	1,2	1,4
in dusty suglinoks	1,6	1,8
in dusty	1,9	2,1
The amount of water-soluble salts is from 3% in dusty and dusty-loamy soils, which are abundant	2,2-2,3	

According to E.M. Sergeev [12], the height and speed of water rising from the capillaries are affected by the chemical composition of the soil and the mineralization of porous water. An increase in the amount of salts increases the capillary rise height as a result of an increase in surface gravitational forces. The presence of various salts in the water increases the value of the capillary rise height more or less. B.B. Polinov's research shows that during capillary rise, the same salts rise higher and others lower. In particular, at the same mineralization and under other equal conditions, sodium chloride waters rise higher than sodium sulphate.

To study the subgrade, field experimental work was carried out on highways in the irrigated areas of the Syrdarya region on the roads 4R-32 and M-34 (Fig. 1).

Fig. 1. Geographical location of the study area

During the research, it was revealed that during the construction of the roadbed of highways in the areas under study, the designated height of the embankment did not take into account the salinity of the soils. As a result, there was some kind of deformation of the coatings, as well as the slopes of the subgrade.

III. Results and Discussion

Analysis of the above-mentioned normative documents and literature, which increase the height of the coating surface, the level of ground or surface water, mainly in low and moderate saline soils by 20% (30% for loam and clays), in strongly saline soils by 40-60% indicates the designation. They also do not take into account the specific characteristics of saline soils, including the composition and amount of salts, the structural and mechanical properties of the uplift during construction (compaction), density norms, as well as the influence of water-salt regime on them. This leads to an increase in the cost of their use, the establishment of unreasonable side slopes.

In order to increase the strength and stability of the road lift, as well as to reduce the height of the lift, it is proposed to compact its base to a density of 0.2-0.3 m at a comfortable humidity of 1.0. It is proposed to design the structure of high-density elevation on a compacted natural foundation in road sections where the groundwater level in the spring does not exceed the height of the compacted natural foundation, and in the summer it lies at a depth of more than 1.5-2.0 m above the ground. The structure of the proposed lift is shown in Table 3.

TABLE III. Depth of pavement layer to the surface of the pavement

Depth of layer to surface, m	Layer thickness, m	Density coefficient	Density, kg / m^3
H + 0.4 each	0,40	1,03	1936
(H+0,4)÷1,0	0,60	1,00	1880
(H+1,0)÷1,5	0,50	0,98	1840
Natural foundation	0,30	1,00	1880

H -road pavement thickness

In saline soils, the height of the pavement surface above the groundwater level depends on the density, salinity and level of salinity. The height corresponding to this relationship, i.e. the distance from the surface of the coating to the groundwater level in saline soils of different densities, is given in Table 4 for heavy dusty supes and lightly dusty loamy soils.

TABLE IV. Depth of pavement layer to the surface of the pavement

Soils	Distance from the surface of the pavement to the groundwater level, m	
	chloride and sulfate-chloride salinity	sulfate and chloride-sulfate salinity
	density coefficient	

	0,96	0,98	1,00	1,02	0,96	0,98	1,00	1,02
slightly saline	1,30	1,10	0,90	0,70	1,10	0,90	0,70	0,50
moderately saline	1,43	1,21	0,99	0,77	1,21	0,99	0,77	0,55
highly saline	1,56	1,32	1,08	0,84	1,32	1,08	0,84	0,60
extremely saline	1,69	1,43	1,17	0,91	1,43	1,17	0,91	0,65

IV. Results and discussion

Based on the above, to make changes to the elevation standards based on the study of their strength and current density and to implement them in practice, the construction of saline soils in different territorial conditions of Uzbekistan, including the Republic of Karakalpakstan, Bukhara, Kashkadarya, Surkhandarya, Fergana, Khorezm and Syrdarya regions and in the diagnosis, as well as in the laboratory, a certain amount of experimental work was carried out [13].

The main factors in the formation of saline soils are mineralized groundwater and saline rocks lying close to the surface. The main condition of salinization is the impossibility of water flow in places and the fact that the evaporation process exceeds the amount of precipitation. Therefore, saline soils and soils are found in impermeable plains, deserts and steppes and hilly areas [14]. In most cases, the height of road embankments built of saline soils in these areas does not exceed 1.5-2 m.

In conclusion, in the design of elevations consisting of saline soils, the density specified in Table 3 and the height given in Table 4 can be noted that the service life is extended and the cost required after their repair is significantly reduced [13,15].

References

[1] Regione Campania Direzione Generale per le Politiche Agricole, Alimentari e Forestali Centro Direzionale- isola A6- 80143 Napoli / all'indirizzo web: http://www.agricoltura.regione.campania.itlpedologialsuoli.html

[2] Shuai Huang, Yuejun Lyu, and Yanju Peng Application Research of New Cementitious Composite Materials in Saline Soil Subgrade Aseismic Strengthening Advances in Civil Engineering Volume 2020, Article ID 7525692, 18 pages

[3] Roads and Salinity ISBN:0734753772//Department of Infrastructure, Planning and Natural Resources-26 b (2003)

[4] ШНК 2.05.02-07. Автомобиль йўллари. Давархитект курилиш, Тошкент, (2007) [In Russian: ShNK 2.05.02-07. Highways. Davarkhitekt Qurilish, Tashkent, (2007)]

[5] ВСН 47-73. Технические указания по проектированию и возведению земляного полотна автомобильных дорог в районах искусственного орашения засушливой зоны. Оргтрансстрой, 31 (1973) [In Russian: VSN 47-73. Texnikheskie ukazaniya po proektirovaniyu i vozvedeniyu zemlyanogo polotna avtomobilnyx dorog v rayonax iskusstvennogo orasheniya zasushlivoy zony. Orgtransstroy, 31 (1973)]

[6] ИҚН 56-10. Шўрланган грунтларда йўл пойини лойиҳалаш ва куриш бўйича тавсиялар. “Ўзавтойўл” ДАК. Тошкент, 73 (2010). [In Russian: IQN 56-10. Recommendations for the design and construction of footpaths in saline soils. Uzavtoyol State Unitary Enterprise Tashkent, 73 (2010)]

[7] Бабков В.Ф., Андреев О.В. Проектирование автомобильнкх дорог. –М.: Транспорт, 415 (1987) [In Russian: Babkov V.F., Andreev O.V. Road design. –M .: Transport, 415 (1987)]

[8] Мотылев Ю.Л., Казарновский В.Д. Уточнить требования к крутизне откосов. Журнал «Автомобильные дороги», **№6** (1967). [In Russian: Motylev Yu.L., Kazarnovsky V.D. Clarify the requirements for the steepness of the slopes. Journal "Automobile Roads", **No. 6** (1967).]

[9] Казарновский В.Д. Проектирования автомобильных дорог. Под ред. Г.А.Федотова. М.: Транспорт, 437 (1989) *[In Russian: Kazarnovsky V.D. Road design. Ed. G.A. Fedotova. M .: Transport, 437 (1989)]*

[10] Коновалов С.В. Технология и организация строительства автомобильных дорог. Под ред. Н.В.Горелышева. –М.: Транспорт, 551 (1992). *[In Russian: Konovalov S.V. Technology and organization of road construction. Ed. N.V. Gorelysheva. –M .: Transport, 551 (1992)]*

[11] Сиденко В.М., Ильясов Н. Проектирование, строительство и органзации возведения земляного полотно в зашуливкх районах. –Ташкент, 288 (1983). *[In Russian: Sidenko V.M., Ilyasov N. Design, construction and organization of the erection of the roadbed in the hustling areas. –Tashkent, 288 (1983)]*

[12] Грунтоведения. Под ред. Академика Е.М.Сергеева. –М.: Изд-во МГУ, 392 (1983) *[In Russian: Soil science. Ed. Academician E.M. Sergeev. –M .: Publishing house of Moscow State University, 392 (1983)]*

[13] Каюмов А.Д., Агзамова И.А., Худайкулов Р.М. Шўрланган грунтли йўл кўтармалари. ТошДТУ, 122 (2013) *[In Russian: Kayumov A.D., Agzamova I.A., Xudaykulov R.M. Saline ground elevations. ToshDTU, 122 (2013)]*

[14] Khight M.I. Some aspects of compaction in arid. «Austraiailan Road Research», 45-73, 32-44, (1969),

[15] Худайкулов Р.М. «Обоснование расчетных характеристик засоленных грунтов насыпей земляного полотна». Диссертация на доктора философии (PhD) по техническим наукам. – Ташкент. 2018 г., 134 с. [In Russian: Khudaykulov, R.M. (2018) Justification of the design characteristics of saline soils of the subgrade. Thesis on the Doctor of Philosophy (PhD) on technical sciences. Tashkent]

Industrialization, Innovation and Infrastructure: from Road Quality to Quality of Life, Modern Vehicle Weighing Technologies

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***Abstract*—The Belt and Road Initiative (BRI), Silk Road transportation programs have markedly developed the roads and highways networks in Kazakhstan and other Central Asian (CA) countries. The transportation services require the proper maintenance and the tracking of loads. Monitoring needs to be improved in Kazakhstan, CA. A Weigh in Motion (WIM) technology can be used as an effective traffic management control system. We are testing the WIM application in Nur-Sultan city, Kazakhstan currently. These works create many challenges and innovative approaches to testing sensors in harsh environments, from extreme cold to hot temperatures, with intensive dust distortions. Our Talapker WIM sensors can detect different driving patterns, including everyday driving, acceleration or deceleration of more than 10km/h/s, eccentric driving (partial contact with the platform to avoid excessive weighting). Every 10th car passing through the WIM site is registered as an overloaded vehicle by gross weighting, and every 5th car is considered overloaded by axle weighting. GIS-based location allocation analysis (LAA) was performed, which revealed potential future 43 WIM locations. The WIM applications have been in development for more than sixty years already in many countries. However, the CA region is still missing the proper investigations.**

Keywords*—*WIM, Weight-in-Motion, defects, Quality, roads, industrialization, damage

I. INTRODUCTION

Economic growth, social development and climate protection measures depend largely on investment in infrastructure, sustainable industrial development and technological progress In view of the rapidly changing global economic landscape and growing inequality, sustained growth must include industrialization that, first, provides all people with access to opportunities and, second, relies on innovation and sustainable infrastructure.

Why is this goal important?

Inclusive and sustainable industrialization, together with innovation and infrastructure, can unleash dynamic and competitive economic forces that generate employment and income. They play a key role in introducing and promoting new technologies, facilitating international trade and ensuring the efficient use of resources.

Nevertheless, the world still has a long way to go to realize that potential. In particular, least developed countries need to accelerate the development of their productive sectors if they are to meet the 2030 target and increase investment in research and innovation [1].

What is the problem?

Many developing countries still lack basic infrastructure, including roads, information and communication technology, sanitation, electricity and water.

Quality roads are a guarantee of the economic security of the State and the well-being of the population. A key condition for investment, regional industry, urban and rural development, export growth and tourism development

Every year, substantial financing is allocated from the national and local budgets to improve regional road and transport infrastructure. Nevertheless, as noted by the National Centre for the Quality of Road Assets, there is still many regions in Kazakhstan where the roads infrastructure should be improved dramatically. There is an intensive planning to increase the transportation network and road quality.

The durability of asphalt concrete is important for the long-term operation of roads, expressways. However, with increasing motorization of the population and increasing interregional traffic, the road network of mega-cities has become overwhelmed by clearly non-trade traffic loads.

Traffic on studded tires in winter, as well as frequent temperature fluctuations - road workers call them the «zero crossover». Under these conditions, regional roads cannot withstand heavy traffic. For this reason, the top asphalt concrete is renewed every three years [2].

Another solution is to improve road quality and durability. With the increase in traffic on the Kazakhstan's regional roads, the problem of increasing the durability and resistance of road surfaces to cracks and the formation of gauges has seriously confronted the road complex.

II. Causes of Damage to Pavement

Incorrect design of the asphalt concrete road leads to the destruction of the road surface. Inaccurate studies, calculations and errors in the determination of traffic flow may contribute to defects on the asphalt concrete road and lead to the destruction of the road structure, Namely, the asphalt layer on the pavements will break down; the substrate will seep; the ground will weaken the pillow; and the asphalt floor will wear [3].

1. The outdated methods with technologies are often applied and materials of poor quality were used to fix roads with asphalt concrete coating. More recently, hot asphalt-concrete mixtures containing bad bitumen have been used to install and repair the roads. It caused damage to the pavement and degraded the strength of the finished mixture for asphalting the road surface. However, the construction is not on the ground, and already today the latest polymer-bitumen materials are being developed and introduced, which can significantly increase the properties of the material and the future route. Various additives to the mixture have become popular for: improved adhesion, increased water resistance and fracture formation. These additives ensure the road's resistance to minus temperatures. In order to avoid defects and deterioration of the road, it is necessary not only to use new mixtures for the laying of asphalt, but also to choose new technologies that will make it possible to stabilize and strengthen the weakened moving soils of the ground. In order to prevent damage to the coatings, use a reinforcement mesh that strengthens the road structure and extends the life of the asphalt liner.

2. Defects and wear on the asphalt concrete surface are caused by an incorrect process in road construction. Damage is caused by mistakes in laying asphalt and repairing the track. Contribute to defects in the transport of asphalt concrete solution, resulting in an incorrect temperature. When the packed mixture was compacted, the air bubbles were not removed or, conversely, the solution was too dense so that the asphalt would start to crack and disintegrate. The destruction of the track may result from poor land preparation and road construction.

3. The most frequent defects on the road surface are caused by weather conditions, when moisture penetrates the asphalt during the rainy season and the hot sunlight disturbs the upper layer of the track - the hardness of the asphalt concrete deteriorates, which leads to potholes. At sub-zero temperatures, accumulated moisture in asphalt concrete layers can increase in volume and thus destroy the structure and compaction of asphalt

4. High transport load High loads from vehicles lead to breakage of the road. The high load on the track surface is due to the heavy traffic flow, which results in the excess of the 24-hour capacity limit and as a consequence, the service life of the track is reduced. Increase in axle load due to use of road surfaces by heavy vehicles resulting in break-up of asphalt concrete, formation of tracks and cracks.

III. How do we Prevent Road Damage

At the current stage of development of the global road industry, there is a wide range of technologies and effective ways to address premature road surface wear and tear.

The measures taken will prevent further destruction of the road.

The prevention of asphalt concrete break-ups includes comprehensive measures to deal with problematic sections of the route. Timely detection of damage will prevent further formation of potholes, faults and improve the strength of the asphalt.

Damage control techniques maintain the proper traffic and performance of the track, maintain the integrity of the design and cover, and extend the life of the vehicle surface.

Currently, the freight traffic management system that controls and monitors traffic flow is poorly developed in Kazakhstan, CA. To reduce the number of overloaded vehicles and control weight parameters, a Weigh in Motion (WIM) technology can be used as an effective traffic management control system in the Kazakhstan, CA region. The WIM technology is designed to control axle and gross vehicle weight in motion. It has a wide range of applications, including pavement and bridge weight control, traffic legislation and state regulations. The WIM technology has advantages over conventional static weighing as it does not interrupt traffic flow by creating queues at monitoring stations. The WIM technology can be used not only as a weight control tool but also will perform a comprehensive analysis of other traffic flow parameters. Apart from its primary goals, detecting the weight of vehicles, WIM technology can also be viewed as a financial tool used by enforcement police to collect penalties from overloaded vehicles.

The application of WIM in Kazakhstan has considerable potential as there are no specific weight control systems. As for now, state transportation agencies developed regulations on the permissible mass of vehicles. However, these regulations are not maintained both by regulating agencies and truck drivers. Currently, there is one WIM pilot site located in Talapker, Kostanay Region, Kazakhstan. The Talapker WIM site was installed in September 2020, and it performs Gross Vehicle Weight (GVW) and Axle of Weight (AOW) analysis. The Talapker WIM sensors are capable of detecting different driving patterns, including everyday driving, acceleration or deceleration more than 10km/h/s, eccentric driving (partial contact with the platform to avoid excessive weighting [4].

3.1 Working principle of WIM

The WIM system consists of several components: data acquisition system, communication system, power supply station, sensors for load detection, inductive loop sensors used to measure vehicle parameters and camera for automatic number plate recognition. The WIM system can provide information about the vehicle's gross and axle weight, structure and class of vehicle, number of axles, daily freight traffic flow and number of overloaded vehicles. These results can be used for pavement and bridge design and control, transportation policies to control congested traffic flow and transportation survey and data evaluation. One of the significant advantages of WIM is direct enforcement policy (Figure 1). Direct enforcement is an automatic process developed to control overloaded traffic flow on-site. Vehicle parameters are automatically recorded by the WIM system to evaluate them with permissible weight limits. If a vehicle is overloaded, enforcement authorities send official penalties to the truck owner or driver. Thus, the WIM system represents a fully automatic process for detecting overweight cases [5].

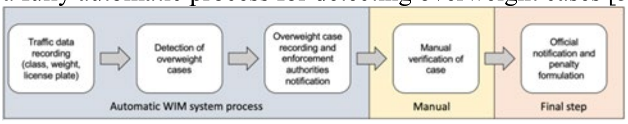

Figure 1. The WIM system working procedure

3.1.2 Comparison of different weight measuring technologies: static and dynamic (WIM)

For live load measurements, two different measuring systems can be used: static and dynamic. The dynamic measurement systems or Weight-in-Motion (WIM) technologies can detect and record vehicle parameters in motion. Static or stationary load measuring systems can determine vehicle parameters in non-moving conditions or at very slow speed.

The traditional method of load measurement on the roads used in Central Asia is applying the static measurement technique. The significant advantage of this method is the accuracy of the system and its applicability as a reference point for conducting experiments and calibrating weighing equipment. The stations are portable, the carryover process and installations are simple, but the difficulty is that the measurement of each axle should be performed separately, which is time-consuming. One measurement on average takes up to 45 minutes, and the process requires two people: the driver, to move the truck, and the operator, to monitor the process. Such time-consuming operations usually create traffic jams on the road [6].

Stationary scales called Truck Weigh Stations perform the load measurement of non-moving or slowly moving trucks. The stations are located off the road, and trucks need to exit the road to go through the scales. The appearing problem is that overloaded trucks can choose alternative routes not to have to go through the Truck Weigh Stations (ibid). In addition, if several trucks are already selected to pass by the weighting station, there is a possibility that during the measurement of those trucks, other overloaded vehicles will pass by and get unnoticed by the operators (Jacob and Bernard, 2010). Therefore, static weight measuring is not reliable, complicated and takes a lot of time.

The alternative way is applying weight-in-motion technology, which is a modern way of monitoring vehicle weight on roads. The sensors of the WIM system are built up inside the pavement and can report the wheel load, axle load and configuration for trucks in motion. The technology showed its efficiency and is widely used worldwide [7].

3.2 Concept of pilot High Speed WIM implementation in Talapker

The Talapker WIM station is the first test site in Kazakhstan, which was chosen to identify local features of freight traffic to solve the overloaded vehicle problem. The WIM sensors were installed in September 2020, and it is working to this day. From September 2020 to April 2021, 159,114 vehicles crossed the WIM platform on the Talapker site. A methodological analysis of vehicle flow in Talapker was conducted to evaluate Gross Vehicle Weight (GVW) and Axle of Weight (AOW) separately in relation to the total number of passing vehicles, their types, speed, time and driving manner.

Vehicle parameters are conducted on-site and has full range vehicle flow data: time of crossing, license plate, speed, acceleration, gross and axle vehicle weight and type of vehicle (Figure 2).

Figure 2. Talapker WIM data acquisition

3.3 Spatial analysis using Location Allocation algorithm

The methodology includes WIM location analysis using ArcGIS software. For this purpose, the location-allocation algorithm (LAA) was used to analyze the most suitable and effective sites for WIM installation. LAA represents the geospatial analysis designed to determine the optimal location for service provision. It is widely used in retail business and public institutions, e.g., schools, hospitals and police, to locate their branches across the city or specific area. The main principle of the algorithms lies in connecting different facilities that provide services and their demand points to which services should be efficiently supplied, taking into account human, financial and time resources. The LAA was applied to identify suitable locations for WIM stations across the road network in Kazakhstan.

To conduct analysis, it was necessary to identify demand points to which WIM sensors should be allocated. For this purpose, data was taken from the geofabrik.de online geospatial database for determining the country boundaries and road network. In this type of analysis, road branches were considered demand points to which WIM sensors are assigned. The more elaborate investigation of WIM sensors distribution has revealed evasive flow capturing problems, referred to as locating law enforcement facilities to detect traffic violations where drivers deviate from their initial route to avoid any penalties imposed from overweighting or speeding. Taking into consideration extensive road networks, it is possible to suggest that overweight truck drivers will avoid routes with WIM sensors installed on and, as a result, will follow “WIM free” road branches. Therefore, it was necessary to cover the whole road network system in Kazakhstan, including minor road branches, to ensure there is no evasive flow of traffic. However, from an economic point of view, it was reasonable to include only primary and secondary road types that have either international, state or regional significance. Another essential factor for this type of problem was population density. Input characteristics were assigned in such a manner to ensure that a higher number of WIM sensors are installed on areas with the highest density[8].

IV. RESULTS

4.1 Talapker pilot HS - WIM site results

According to the results obtained in the Talapker WIM site, the total number of passing vehicles differs significantly from month to month. As shown in the graph below, freight traffic flow substantially increases during the summer-autumn season. Despite overloaded vehicles (GVW > 44 tons, AOW > 11 tons) represent a small portion of the total number of passing vehicles, there is still a significant presence. For example, in October, the busiest traffic flow was a total of 24,423 vehicles passing (Figure 3). Among the total number of passing vehicles in October 2020 (7,37%) of vehicles are recorded to have excessive gross vehicle weight and 3,270 (13,39%) excessive axle vehicle weight.

Taking into consideration comparison of GVW and AOW distributions, it is seen that, although some of vehicles meet gross weight requirements, they might have an overloaded axle weight (Table 1).

Taking into account type of vehicles that have excessive weight parameters in both GVW and AOW distributions, following can be distinguished:

1. Single Unit 3 or more axle (Figure 4).
2. Semitrailer 4 or more axle (Figure 5).

It was important to identify driving patterns to evaluate its effect on GVW and AOW distribution (Figure 6).

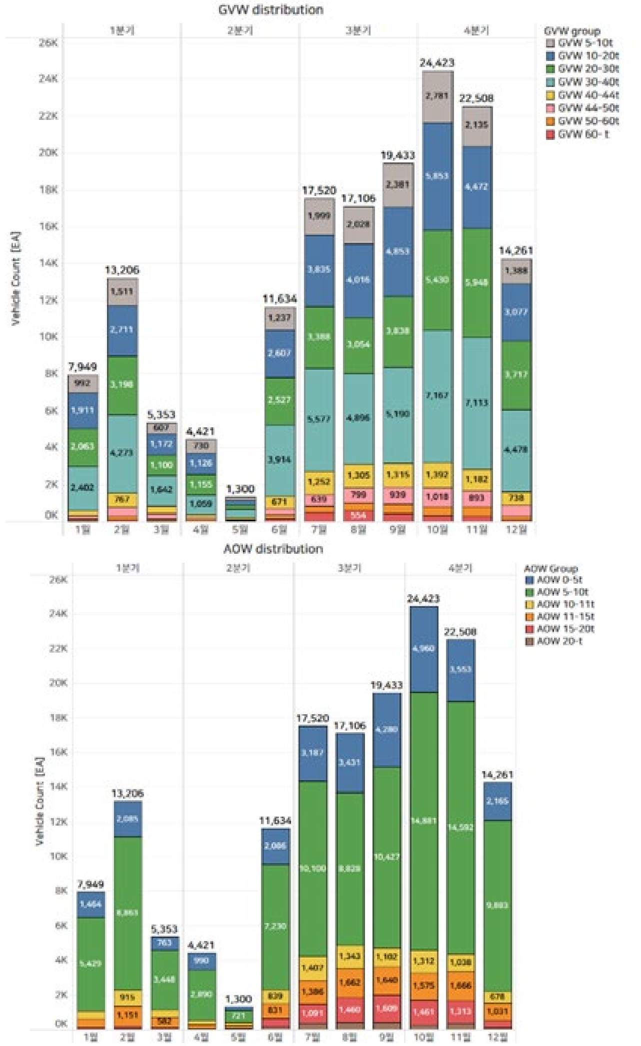

Figure 3. Analysis of the total number of passing vehicles per month by GVW and AOW distribution

Tab. 1.
Number and percentage of overloaded vehicles per month by GVW and AOW distribution

	GVW distribution			AOW distribution		
Month	Total number	Number of Overloaded	Percent of overloaded	Total number	Number of Overloaded	Percent of overloaded
1	7949	313	3,94	7949	593	7,46
2	13206	746	5,65	13206	1343	10,17
3	5353	408	7,62	5353	695	12,98
4	4421	165	3,73	4421	279	6,31
5	1300	108	8,31	1300	212	16,31
6	11634	678	5,83	11634	1479	12,71
7	17520	1469	8,38	17520	2826	16,13

8	171 06	1807	10,56	171 06	3504	20,48
9	194 33	1856	9,55	194 33	3624	18,65
10	244 23	1800	7,37	244 23	3270	13,39
11	225 08	1658	7,37	225 08	3325	14,77
12	142 61	863	6,05	142 61	1535	10,76

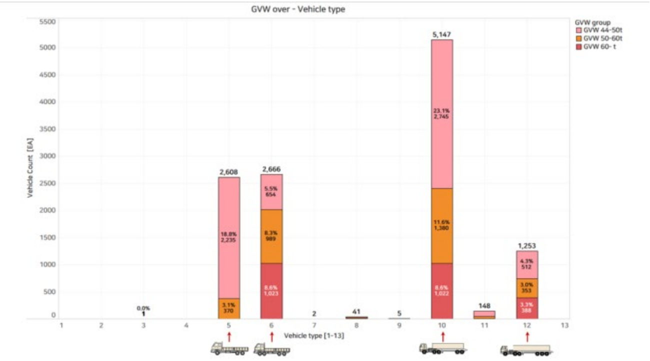

Figure 4. Analysis of the GVW overloaded number of passing vehicles per type

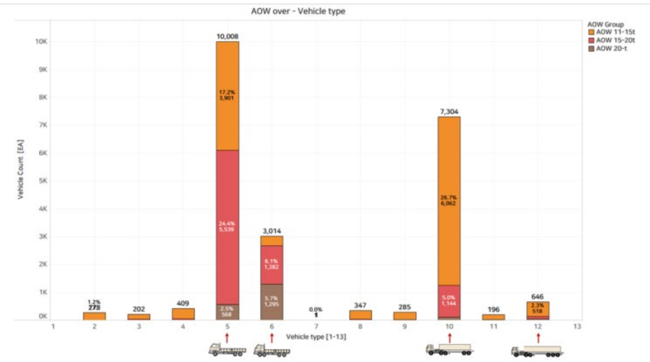

Figure 5. Analysis of the AOW overloaded number of passing vehicles per type

According to results, the most common driving pattern in normal GVW distribution is “normal” driving, while in overloaded GVW distribution, drivers tend to follow “out of lane” driving pattern. This feature can be explained by the fact that drivers prefer to escape weight control censors. An abnormal driving pattern refers to partial contact of the axle with the platform to avoid overloading. Unexpectedly, eccentric driving is present in the same portions both in normal and overloaded GVW distribution. A more significant number of eccentric driving pattern cases was expected in the overloaded GVW distribution, where drivers cheat and “hide” overloading by having partial contact (Figure 7).

In normal AOW distribution, most drivers follow a normal driving pattern; about 18% have an eccentric pattern, and approximately 7% are in the “out of lane” pattern. As in normal AOW, in overloaded AOW distribution, most drivers follow the typical driving pattern; about 40% and 15% have an “out of plane” or eccentric driving pattern.

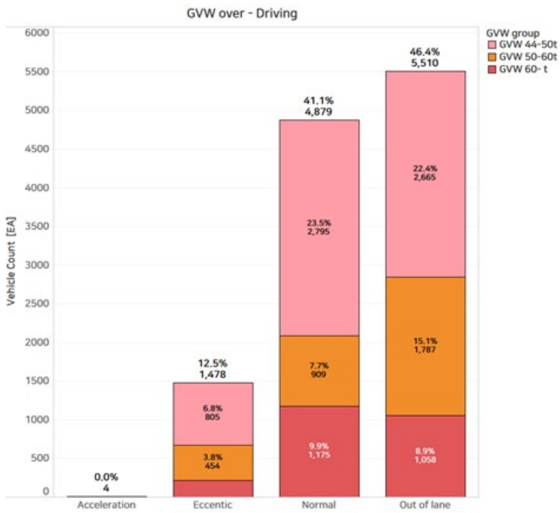

Figure 6. Analysis of the GVW normal and overloaded number of total vehicles per driving pattern

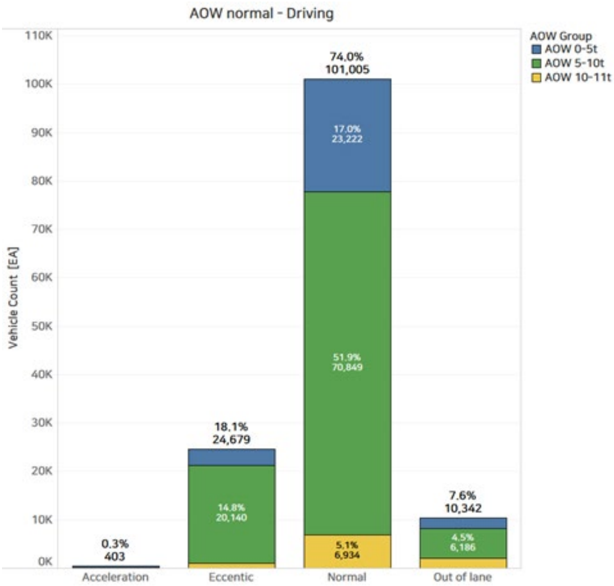

Figure 7. Analysis of the AOW normal and overloaded number of total vehicles per driving pattern

In general, results demonstrate that the normal driving pattern is the standard option. Since the Talapker site is an HS-WIM station, drivers are not required to reduce speed while passing the platform. In this regard, the acceleration or deceleration pattern is insignificant. It is also important to notice that in both overloaded GVW and AOW distribution, the “out of lane” pattern has a significant portion.

Results from the pilot Talapker HS WIM site demonstrated the significant necessity in adopting WIM technology in Kazakhstan. According to the results, up to 10% and up to 20% of passing vehicles have overloaded gross vehicle weight and axle vehicle weight, respectively. The significant scale of the problem of overloaded vehicles can be considered a severe problem for road conditions and safety.

REFERENCES

[1] Rys, Dawid, Jozef Judycki, and Piotr Jaskula. 2015. "Analysis of Effect of Overloaded Vehicles On Fatigue Life Of Flexible Pavements Based On Weigh In Motion (WIM) Data". International Journal of Pavement Engineering 17 (8): 716. doi:10.1080/10298436.2015.1019493

[2] Jacob, Bernard, and Véronique Feypell-de La Beaumelle. 2010. "Improving Truck Safety: Potential Of Weigh-In-Motion Technology". IATSS Research 34 (1): 11-12. doi:10.1016/j.iatssr.2010.06.003.

[3] Bacharz, Magdalena, Jacek Chmielewski, Sylwia Stawska, Kamil Bacharz, and Andrzej Nowak . 2020. Rep. COMPARATIVE ANALYSIS OF VEHICLE WEIGHT MEASUREMENT TECHNIQUES - EVALUATION OF SIWIM SYSTEM ACCURACY.

[4] Burnos, Piotr, and Janusz Gajda. 2016. "Thermal Property Analysis Of Axle Load Sensors For Weighing Vehicles In Weigh-In-Motion System". Sensors 16 (12): 1. doi:10.3390/s16122143.

[5] Lansdell, Andrew, Wei Song, and Brandon Dixon. 2017. "Development And Testing Of A Bridge Weigh-In-Motion Method Considering Nonconstant Vehicle Speed". Engineering Structures 152: 709. doi:10.1016/j.engstruct.2017.09.044.

[6] Lydon, Myra, S. E. Taylor, D. Robinson, A. Mufti, and E. J. O. Brien. 2015. "Recent Developments In Bridge Weigh In Motion (B-WIM)". Journal Of Civil Structural Health Monitoring 6 (1): 70. doi:10.1007/s13349-015-0119-6.

[7] Moses, Fred. 1979. "Weigh-In-Motion System Using Instrumented Bridges". Transportation Engineering Journal Of ASCE 105 (3): 233-249. doi:10.1061/tpejan.0000783.

[8] https://www.un.org/sustainabledevelopment/ru/infrastructure-industrialization/

Mathematical Model of a Hexacopter-Type Unmanned Aerial Vehicle

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***Abstract*—At present, the East-West transport and communication corridor is in the center of attention of the world community as an international logistics project, and ensuring the security of its infrastructure is one of the important issues. The use of unmanned aerial vehicles as a means of operational control over the safe operation of both the railway infrastructure and the road system is considered to be very cost-effective. Due to its maneuverability, the use of hexocopters may be more appropriate among these types of devices. The article is devoted to the study of the dynamics of the Hexocopter type unmanned aerial vehicle (UAV), which can more effectively perform control functions. The motion of hexacopter is assumed as the motion of rigid body. The system of differential equations has been derived that represents the Cartesian coordinates of the orientation of hexacopter with respect to the inertial coordinate system and the relationship between quaternion based orientation of hexacopter and the rotational speed of its propellers. In order to illustrate the computer simulations of the flight these equations are discretized and solved by numerical methods. Computer simulations allow to determine the qualitative dependence of flight of the physical and technical parameters.**

Keywords—East-West transport and communication corridor, unmanned aerial vehicles, hexacopter, Newton-Euler equations, quaternions, system of differential equations, inertia tensor, inertial coordinate system, mathematical model

INTRODUCTION

Nowadays unmanned aerial vehicles are widely chosen in military and civil applications. Therefore, different types of unmanned aerial vehicles are created depending on the purpose of use [1, 2, 3]. Among the multicopters tricopter, quadrocopter and fila type unmanned aerial vehicles are very popular. The quadrotor type unmanned aerial vehicle increasingly attract the attention of researchers and widely manufactured among the multicopters. However, it is hardly controlled while one or more engine failures appear. Therefore, the multicopters with more than four rotors like hexacopters are reliable thanks to the stationary flight and high maneuverability.

Several type of unmanned aerial vehicles are created in Azerbaijan. The hexacopter type unmmanned aerial vehicles is called Əqrəb 5.0 (fig. 1). This article focuses on the simulation system of this hexacopter.

Fig. 1. General description of Əqrəb 5.0.

Hexacopter type unmanned aerial vehicle consist of 6 robotic arms. Each arm is equipped with rotor located on the vertices of hexagon. The axis of these rotors are parallel to the axis of symmetry passing through the center of mass of the hexacopter. The rotors create force and rotational torque. The hexacopter is controlled by adjusting the rotational frequencies of the rotors. In order to control the hexacopter by changing the rotational frequencies of the rotors it is necessary to write the formulas for the relationship between rotational frequencies and current orientation of hexacopter. The purpose of this article is to illustrate the mathematical model of the control of hexacopter type aircraft. The quadrotor type unmanned aerial vehicles with 4 rotors has been in the focus of researchers due to the stationary flight and stable hovering by balancing the forces that the four rotors produced. Nowadays, multicopters with more than 4 rotors are attracting the researcher attention like hexacopters and octocopters.

In order to test the characteristics of the flight and obtain the robust control of the unmanned aerial vehicle computer simulations are commonly illustrated.

Several type of unmanned aerial vehicles are created in Azerbaijan. In this work issues of creating simulation system are illustrated in order to experiment the flight of the hexacopter type unmanned aerial vehicle called Əqrəb 5.0.

MATHEMATICAL STATEMENT OF THE PROBLEM

As mentioned above, hexacopter consists of 6 robotic arms equipped with electric motors that are equidistant from the center of mass [5]. The rotors create force and rotational torque.

Let's numbering the rotors of the hexacopter as shown in the figure 2. It is assumed that the 1st, 3rd and 5th rotors are rotating clockwise, the 2nd, 4th and 6th rotors are rotating counterclockwise. The schematic illustration of the rotation are shown in the figure 2.

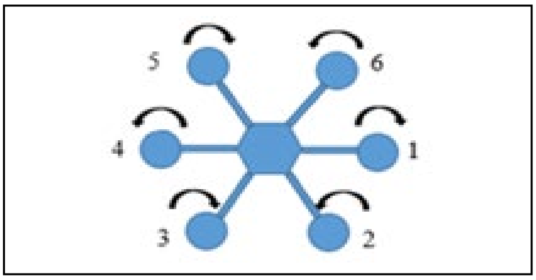

Fig. 2. The direction of rotation of the propellers of hexacopter.

In order to describe the equations of motion of the hexacopter two reference systems are necessary: the earth inertial coordinate system $OXYZ$ and body fixed coordinate system $oxyz$.

Suppose that, the origin of the inertial frame is fixed in a point located on the surface of earth. The OY axis of the inertial frame is directed to the North, OX is directed to the East and OZ axis is directed upwards perpendicular to the OXY plane.

Assume that, Ox axis of the body fixed frame is directed towards the 1st robotic arm of the hexacopter, Oy axis is perpendicular to Ox axis and Oz is directed upwards perpendicular to Oxy plane along the line of symmetry of hexacopter (fig 3).

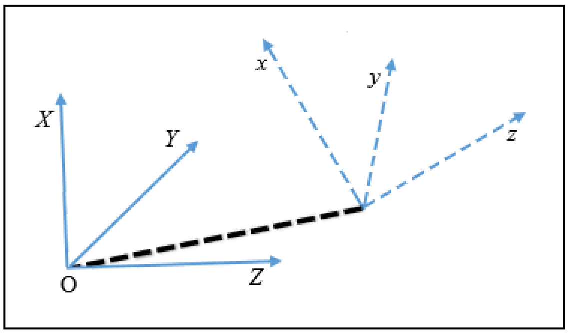

Fig. 3. Inertial and body fixed coordinat systems

As is obviously known that, in order to describe the rotation of an unmanned aerial vehicle Euler angles are used [7]. The orientation of the body fixed frame with respect to the earth inertial frame is usually described by the means of Euler angles. If these angles are known, then any vector in the body fixed frame can be transformed to the inertial frame. The transformation from the body fixed frame to the earth inertial frame is obtained by using ration matrix R [11].

However, the description of the orientation of hexacopter by means of Euler angles suffer from singularities at certain orientations. For overcoming these problems, a new parametrization, the quaternions, are commonly used [4]. Here is a brief information about the quaternion based rotation of aircraft.

It is known that, in theoretical mechanics the rotation of rigid body is described by rotation vector [7]. The rotation vector is characterized by the rotation axis and angle of rotation. If α is angle of rotation about the unit vector (u_x, u_y, u_z), then the rotation vector is $u = \alpha \cdot (u_x, u_y, u_z)$, here $u_x^2 + u_y^2 + u_z^2 = 1$. As is clearly seen that, the rotation angle is represented by means of 4 quantities α, u_x, u_y, u_z.

Quaternions are generally represented in the form of $q_0 + q_1 i + q_2 j + q_3 k$ where q_0, q_1, q_2, q_3 are real numbers, i, j, k are imaginary units. They form a four dimentional associative division algebra denoted by H(Hamilton) and satisfy the following terms:

$$i^2 = j^2 = k^2,$$

$$ij = k,\ jk = i,\ ki = j,$$

$$ji = -k,\ kj = -i,\ ik = -j.$$

The characteristics of quaternions allow them to be used in order to express the angles of rotation. The rotation vector u is represented as follows via quaternion formulation:

$$q_0 = \cos\frac{\alpha}{2},$$

$$q_1 = u_1 \sin\frac{\alpha}{2},$$

$$q_2 = u_2 \sin\frac{\alpha}{2},$$

$$q_3 = u_3 \sin\frac{\alpha}{2}.$$

The transformation of any vector from the inertial coordinate system to the body fixed coordinate system can be expressed by means of the transformation matrix Q:

$$\begin{bmatrix} q_0^2+q_1^2-q_2^2-q_3^2 & 2(q_1q_2+q_0q_3) & 2(q_1q_3-q_0q_2) \\ 2(q_1q_2-q_0q_3) & q_0^2-q_1^2+q_2^2-q_3^2 & 2(q_2q_3+q_0q_1) \\ 2(q_1q_3+q_0q_2) & 2(q_2q_3+q_0q_1) & q_0^2-q_1^2-q_2^2+q_3^2 \end{bmatrix}. \quad (1)$$

The following hypotheses and agreements are taken into account:

- It is assumed that during the translational motion the shape of the hexacopter does not play an important role. Therefore, it can be assumed as rigid body.
- The gyroscopic forces created by the rotation of hexacopter can be ignored due to the small angular velocities
- Gravity and aerodynamic forces do not create a torque, because they affect the center of mass of hexacopter
- It is assumed that, the constructive parameters of hexacopter are illustrated as shown in the figure 4 and the mass of the vehicle is distributed only along its 6 robotic arms and the gravity center of the central block.

At the considered instant t, the current coordinates of hexacopter relative to $OXYZ$ coordinate system are denoted by $X(t), Y(t), Z(t)$, the components of the quaternion that represent the transformation from the body fixed coordinate system to the inertial coordinate system are denoted by $q_0(t) + q_1(t)i + q_2(t)j + q_3(t)k$ and the rotational frequency of the propellers of arms are represented by $\omega_i, \; i = 1, \ldots, 6$.

The setting a mathematical relationship between the quantities $x(t)$, $y(t)$, $z(t)$, $q_0(t)$, $q_1(t)$, $q_2(t)$, $q_3(t)$ and the rotational frequency of propellers $\omega_1, \omega_2, \ldots, \omega_6$ is the mathemamtical model of hexacopter.

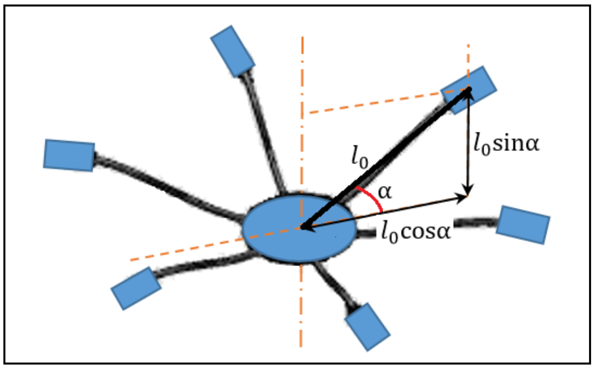

Fig. 4. Constructive dimensions of the hexacopter

SOLUTION OF THE PROBLEM

First of all, we need to represent the equations of translation. Assume that, the mass of the rotors of hexacopter centered at the gravity are denoted by m_6, the mass of the central block in the center of gravity of drone is denoted by m_0. According to the Newton's second law of motion in the inertial frame the force acting on the object is equal to the multiplication of acceleration and mass of the object. Taking into account the hypothesis and agreements mentioned above, let's calculate the forces acting on the hexacopter:

Gravitational force acting on the hexacopter.

$$\boldsymbol{F}_G = m \cdot (0, 0, -g)^T, \qquad (2)$$

where $m = m_0 + 6m_*$ is the total mass of hexacopter, $g = 9.81 \frac{m}{san^2}$ is gravitational constant and T is sign of transpose.

Thrust force of the rotors.

The main force affecting the movement of hexacopter is thrust force created by the propellers and rotors that lift the unmanned aerial vehicle in the air. As shown in the construction of the hexacopter all rotors of hexacopter generate a force towards the vector $(0, 0, 1)$. Therefore, the trust force generated by every rotor i is represented as follow:

$$\boldsymbol{f}_i = (0, 0, k\omega_i^2)^T.$$

Then the total thrust force is denoted by:

$$\boldsymbol{f}_M = \sum_{i=1}^{6} \boldsymbol{f}_i = k(0, 0, \sum_{i=1}^{6} \omega_i^2)^T.$$

The thrust force $\boldsymbol{F}_M$ generated by the motors with respect to the inertial coordinate system $OXYZ$ can be obtained by applying the rotation matrix Q on the force f_M at the considered instant $t \geq 0$.

$$\boldsymbol{F}_M = \boldsymbol{Q}^{-1} \cdot \boldsymbol{f}_M = k \cdot \boldsymbol{Q} \cdot (0, 0, \sum_{i=1}^{6} \omega_i^2)^T. \qquad (3)$$

Aerodynamic forces acting on hexacopter.

The velocity of motion of the hexacopter with respect to the inertial coordinate system is represented by the derivatives of its current coordinates: $(X'(t), Y'(t), Z'(t))$.

If the velocity of the vehicle with respect to the body fixed coordinate frame is denoted by $(v_x(t), v_y(t), v_z(t))$, then the following equation is derived:

$$\left(\boldsymbol{v_x(t)}, \boldsymbol{v_y(t)}, \boldsymbol{v_z(t)}\right)^{\boldsymbol{T}} = \boldsymbol{Q} \cdot (\boldsymbol{X'(t)}, \boldsymbol{Y'(t)}, \boldsymbol{Z'(t)})^{\boldsymbol{T}}.$$

As is obvious that the drag force acting on the hexacopter is opposite to the direction of movement of rigid body. Therefore, this force is denoted by the following formula with respect to the body fixed coordinate system:

$$f_A = -c_A \left(v_x(t), v_y(t), v_z(t)\right)^T \left|\left(v_x(t), v_y(t), v_z(t)\right)\right| =$$

$$= -c_A \boldsymbol{Q}^{-1} \left(X'(t), Y'(t), Z'(t)\right)^T \times \left|\left(X'(t), Y'(t), Z'(t)\right)\right|.$$

Then the aerodynamic drag force with respect to the $OXYZ$ coordinate system can be obtained as follows:

$$\boldsymbol{F_A} = \boldsymbol{Q^{-1}} \cdot \boldsymbol{f_A} = -c_A \boldsymbol{Q} \left[\boldsymbol{Q}^{-1} \left(X'(t), Y'(t), Z'(t)\right)^T \times\right.$$

$$\left. \times \left|\left(X'(t), Y'(t), Z'(t)\right)\right|\right]. \qquad (4)$$

Taking into consideration that, the acceleration of the motion is denoted by $(X''(t), Y''(t), Z''(t))$, then according to the Newton's second law the equation of motion of hexacopter is derived as follows:

$$m(X''(t), Y''(t), Z''(t))^T = \boldsymbol{F}_G + \boldsymbol{F}_M + \boldsymbol{F}_A,$$

$$m\left(X''(t), Y''(t), Z''(t)\right)^T =$$

$$= k(0, 0, \sum_{i=1}^{6} \omega_i^2)^T + k\boldsymbol{Q} \cdot (0, 0, \sum_{i=1}^{6} \omega_i^2)^T -$$

$$-c_A \boldsymbol{Q} \times \left[\boldsymbol{Q}^{-1} \cdot \left(X'(t), Y'(t), Z'(t)\right)^T \times\right.$$

$$\left. \times \left|\left(X'(t), Y'(t), Z'(t)\right)\right|\right]. \qquad (5)$$

In order to derive the equation of rotational motion of hexacopter, it is necessary to calculate the elements of inertial tensor of hexacopter:

$$\boldsymbol{J} = \begin{bmatrix} J_{xx} & J_{xy} & J_{xz} \\ J_{yx} & J_{yy} & J_{yz} \\ J_{zx} & J_{zy} & J_{zz} \end{bmatrix}$$

Let's denote the distance between the gravity center of the central block and gravity center of robotic arms of hexacopter by l_0, and α is the angle between the line connecting these 2 points with the plane that central block of the hexacopter located.

According to the figure 4, the elements of the inertial tensor $\boldsymbol{J}$ are obtained:

$$J_{xx} = \sum_{k=1}^{6} m_k (y_k^2 + z_k^2) = 3m_* l_0^2 (1 + \sin^2),$$

$$J_{yy} = \sum_{k=1}^{6} m_k (x_k^2 + z_k^2) = 3m_* l_0^2 (1 + \sin^2),$$

$$J_{zz} = \sum_{k=1}^{6} m_k (x_k^2 + y_k^2) = 6m_* l_0^2 \cos^2,$$

$$J_{xy} = J_{yx} = \sum_{k=1}^{6} m_k x_k y_k = 0,$$

$$J_{xz} = J_{zx} = \sum_{k=1}^{6} m_k \, x_k z_k = 0,$$

$$J_{xz} = J_{zx} = \sum_{k=1}^{6} m_k \, x_k z_k = 0.$$

Thus,

$$\boldsymbol{J} = \begin{pmatrix} J_{xx} & 0 & 0 \\ 0 & J_{yy} & 0 \\ 0 & 0 & J_{zz} \end{pmatrix} = diag(J_{xx}, J_{yy}, J_{zz}).$$

Let's denote the angular rotational angular velocity of hexacopter by $\boldsymbol{w}(t) = \left(w_x(t), w_y(t), w_z(t)\right)$. Then, the following equation can be represented on the basis of total torque M generated by the forces acting on the vehicle [8,9]:

$$\boldsymbol{J}\boldsymbol{w}' + \boldsymbol{w} \times (\boldsymbol{J}\boldsymbol{w}) = \boldsymbol{M}. \tag{6}$$

Or, it can be indicated via components:

$$J_1 w_1' + (J_3 - J_2) w_2 w_3 = M_1$$

$$J_2 w_2' + (J_1 - J_3) w_1 w_3 = M_2$$

$$J_3 w_3' + (J_2 - J_1) w_1 w_2 = M_3$$

According to the agreements mentioned above gravity and aerodynamic forces do not create a torque, the torque M can be derived by the sum of the torques generated by the rotation of propellers.

The sum of the rotation torques created by the rotation of first, third and fifth propellers is $\sum_{i=1,3,5} b\omega_i^2$ and the torque generated by second, fourth and sixth propellers is denoted by $\sum_{i=2,4,6} (-\boldsymbol{b}\boldsymbol{\omega}_i^2)$. Therefore, total yaw moment would be derived by $M^{(Oz)} = b\left(\sum_{i=1,3,5} \omega_i^2 - \sum_{i=2,4,6} \omega_i^2\right)$.

From the geometrical structure of hexacopter represented in the figure 4, it is possible to get information about roll and pitch moments:

$$M^{(Ox)} = -\frac{\sqrt{3}}{2} k l_0 \omega_2^2 \cos\alpha + \frac{\sqrt{3}}{2} k l_0 \omega_3^2 \cos\alpha +$$

$$+\frac{\sqrt{3}}{2} k l_0 \omega_5^2 \cos\alpha \; - \frac{\sqrt{3}}{2} k l_0 \omega_6^2 \cos\alpha =$$

$$= \frac{\sqrt{3}}{2} k l_0 \cos\alpha \, (-\omega_2^2 + \omega_3^2 + \omega_5^2 - \omega_6^2),$$

$$M^{(Oy)} = k l_0 \omega_1^2 \cos\alpha - \frac{1}{2} k l_0 \omega_2^2 \cos\alpha + k l_0 \omega_3^2 \cos\alpha -$$

$$- k l_0 \omega_4^2 \cos\alpha + \frac{1}{2} k l_0 \omega_5^2 \cos\alpha - k l_0 \omega_6^2 \cos\alpha =$$

$$= kl \cos\alpha \left(\omega_1^2 - \frac{1}{2}\omega_2^2 + \omega_3^2 - \omega_4^2 + \frac{1}{2}\omega_5^2 - \omega_6^2\right).$$

Thus,

$$\boldsymbol{M} = \begin{bmatrix} \frac{\sqrt{3}}{2} k l_0 \cos\alpha \, (-\omega_2^2 + \omega_3^2 + \omega_5^2 - \omega_6^2) \\ k l_0 \cos\alpha \left(\omega_1^2 - \frac{1}{2}\omega_2^2 + \omega_3^2 - \omega_4^2 + \frac{1}{2}\omega_5^2 - \omega_6^2\right) \\ b(\omega_1^2 - \omega_2^2 + \omega_3^2 - \omega_4^2 + \omega_5^2 - \omega_6^2) \end{bmatrix}.$$

Taking into consideration the angular velocity $\boldsymbol{w}(t)$ deriven from the equations (6), it is possible to calculate the quaternion form of the current orientation of hexacopter solving the following differential equations:

$$\begin{aligned} q_0' &= \tfrac{1}{2}(-q_1 w_1 - q_2 w_2 - q_3 w_3), \\ q_1' &= \tfrac{1}{2}(q_0 w_1 + q_2 w_3 - q_3 w_2), \\ q_2' &= \tfrac{1}{2}(q_3 w_1 + q_0 w_2 - q_1 w_3), \\ q_3' &= \tfrac{1}{2}(-q_2 w_1 + q_1 w_2 + q_0 w_3). \end{aligned} \tag{7}$$

As is clearly seen, the system (5) – (7) is the system of ordinary differential equations with respect to $X''(t)$, $Y''(t)$, $Z''(t)$, $w_x(t)$, $w_y(t)$, $w_z(t)$, and $q_0(t)$, $q_1(t)$, $q_2(t)$, $q_3(t)$. In order to solve the equations, lets represent the initial conditions:

$$\begin{cases} X(t)|_{t-0} = X_0, \\ Y(t)|_{t-0} = Y_0, \\ Z(t)|_{t-0} = Z_0, \end{cases} \tag{8}$$

$$\begin{cases} X'(t)|_{t-0} = \acute{X}_0, \\ Y'(t)|_{t-0} = \acute{Y}_0, \\ Z'(t)|_{t-0} = \acute{Z}_0, \end{cases} \tag{9}$$

$$\begin{cases} w_x(t)|_{t-0} = w_{x0}, \\ w_y(t)\big|_{t-0} = w_{y0}, \\ w_z(t)|_{t-0} = w_{z0}, \end{cases} \tag{10}$$

$$\begin{cases} q_0(t)|_{t-0} = q_{00}, \\ q_1(t)|_{t-0} = q_{10}, \\ q_2(t)|_{t-0} = q_{20}, \\ q_3(t)|_{t-0} = q_{30}. \end{cases} \tag{11}$$

Thus, the system (4) – (11) represents the equation of motion of the hexacopter. On the basis of angular rotational velocity ω_i $(i = 1,2,\dots,6)$ of propellers of rotors of the hexacopter this system allows to calculate the trajectory and orientation of the vehicle.

In order to generate the controlled computer model of the hexacopter the discrete analog of the system (4) – (11) is indicated. On the basis of this model, computer simulations of the flight make it possible to determine the dependence of the quality of the hexacopter flight on the physical and technical parameters.

CONCLUSION

The "East-West Corridor" project is a global energy and transport project that has solved a number of problems in various fields of science. The use of hexacopter type unmanned aerial vehicle is considered more convenient in terms of more efficient control of transport infrastructure. To create an appropriate vehicle the system of differential equations of the Cartesian coordinates of the orientation of hexacopter with respect to the inertial coordinate system and the relationship between the orientation represented via quaternions and the angular velocity of the propellers of hexacopter rotors are generated. In order to put into practice, the computer simulations of the flight, these equations are discretized and solved numerically. The computer simulation permits to determine the quality dependence of the flight on the physical and technical parameters.

REFERENCES

[1] Alderete, T. S. Simulator aero model implementation / NASA Ames Research Center, Moffett Field, California, – 1997, – 21 p. available at https://aviationsystems.arc.nasa.gov/publications/hitl/rtsim/Toms.pdf

[2] Bekir, Esmat. Introduction to Modern Navigation System / World Scientific Publishing Co Pte Ltd, – 2007, – 256 P.

[3] Cefalo M., Mirats-Tur J. M.. A comprehensive dynamic model for class-1 tensegrity systems based on quaternions // International Journal of Solids and Structures, – 48(5), – 2011, – P. 785–802.

[4] Groÿekatthöfer K, Yoon Z. Introduction into quaternions for spacecraft attitude representation / TU Berlin, 2012– P. 785–802.

[5] Saric I., Masic A., Delic M. Hexacopter Design and Analysis / In: Karabegović I. (eds) New Technologies, Development and Application IV. NT ,– 2021. Lecture Notes in Networks and Systems, Vol.233. Springer, Cham. https://doi.org/10.1007/978-3-030-75275-0_9

[6] Artale V., Milazzo C.L.R. , Ricciardello A. Mathematical modeling of hexacopter // Applied Mathematical Sciences. –Vol. 7, – 2013. – No. 97, – P. 4805-4811. http://dx.doi.org/10.12988/ams.2013.37385

[7] Buchholts, N. N. Basic course in theoretical mechanics / Dynamics of the system of material points. – Vol. 2. – M.: Nauka, – 1966. – 332 P.

[8] Landau L.D. and Lifshitz E.M. Theoretical mechanics. Tutorial in 10 volumes. – Vol. 1, Mechanics. –M: Fizmatlit, – 2019. – 224 P.

[9] Goldstein. H. Classical Mechanics. 2nd Edition, Addison & Wesley Publ. Co., Reading, Massachusetts. – 2002. – 638 P. ISBN 978-0-201-65702-9

[10] Amelkin, N.I. Dynamics of a solid body. Tutorial. – M.: MIPT, – 2010. – 80 P.

Collaborative Block-chain Solution for National eLogistics Systems Connectivity and Data Pipelines in the East-West Transport Corridor

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Abstract—*The innovative approach for the formation of Data Pipelines and connectivity of national eLogistics systems was proposed for the countries participating in the East-West Transport corridors. The concept of digital transport corridors (DTC) was considered and based on creation of federated network of eLogistics platforms. The main requirements to DTC Data Pipelines were analyzed and the collaborative block chain solution was developed to enable digital trust and secure data exchange between the participants of international supply chains in the East-West transport corridors. The application of the proposed solution was demonstrated for digitalization of the transport corridor between GUAM countries, namely – Azerbaijan, Georgia and Ukraine. The digital infrastructure for this corridor can be built on the base of blockchain nodes hosted in the national eLogistics platforms of GUAM countries. The core functional features and requirements were formulated for GUAM corridor Data Pipeline.*

Keywords—data pipelines for supply chains, digital transport corridors, blockchain technologies, national eLogistics systems

I. INTRODUCTION

In 2011 UN/CEFACT experts proposed the Data Pipeline concept as the innovative solution to provide supply chain participants with high quality data exchange for cross-border transactions. Such concept was based on results from three EU projects CASSANDRA, CORE and SELIS [1].

Data Pipeline was considered to be a web-based IT infrastructure that could enable the seamless integration of all data elements from the different sources in the supply chain. The Data Pipeline offers an innovative approach to the exchange of data throughout the international supply chain, as a prerequisite to further establishing secure and reliable supply networks, for business and government.

Data Pipeline core principles are considered to be as follows:

- Original trade data (usually supplied by the consignor) are gathered and shared and can be used by authorized parties in the logistics network to improve their operations;
- Parties participating in a supply chain provide data that can be of relevant to other supply-chain parties in a shared information space;
- Synchronization points (e.g. blockchain nodes) that determine in the integrated data pipeline how shared information can be available to parties in international transactions.

Using Data Pipeline approach in 2015 the concept of digital transport corridors (DTC) was developed by the expert community of Eastern Partnership (EaP) countries in the course of the EU initiative for Harmonization of Digital Markets (HDM initiative). DTC concept is based on the creation of federated network of platforms, which integrates information resources of the participants of international transport corridor to create Data Pipeline for multi-modal cargo transportation. DTC network can provide different services for business and government thus enabling more effective transit, control & monitoring of transcontinental cargo flows via the territories of the EU and EaP countries.

To implement such concept DTC is to be composed of national multimodal eLogistics systems built on the core integration platforms capable to serve multimodal cargo shipments via sea, railway, road and air transportation in the participating countries.

Such platforms are considered to become Building Blocks of digital infrastructure which can be developed for the effective digitalization of international supply chains and cargo transportation via main East-West transport corridors. China National Transport and Logistics Information Platform LOGINK can be taken as one of the most famous and functional example of eLogistics systems. In 2018-2019 the countries of Eurasian Economic Union (EAEU) has developed the concept of DTC ecosystem focused on integration and seamless connectivity of national eLogistics systems in the participating countries.

To provide such connectivity and the proper level of digital trust and security the main requirements to DTC Data Pipeline are considered to be as follows:

- Authorization, identification and authentication of DTC participants;
- Cross-border and interstate transmission of validated data;
- Data protection against modifications;
- Operational and long-term data storage with confidentiality.

The above requirements can be met by building DTC Data Pipeline on the base of the corporate blockchain solution which can take on the role of a mechanism for enabling digital trust between the participants of East-West transport corridors. The application of the proposed solution will be demonstrated for digitalization of the transport corridor between GUAM countries, namely – Azerbaijan, Georgia and Ukraine.

II. Core Participants of East-West Transport Corridors in GUAM Countries

The general composition of supply chain participants in the East-West countries potentially interested in the digitalization of transport corridors in the GUAM countries is presented in the following list:

- Consignor / Shipper
- Consignee
- Freight forwarder
- Stevedore / transport terminal operator
- Carrier
- Carrier agent
- Warehouse / logistics center operator
- Importer
- Exporter
- Customs agent/declarant
- Transport infrastructure operators (maritime, railway, automobile, aviation)
- Transport inspection and traffic police bodies
- Customs
- Border authorities
- Food and quarantine authorities
- Seaport / Airport Operators

In accordance with this list, the core users of the GUAM transport corridor are considered to be ports, shipping companies, forwarders, shippers, road, rail and air transport companies, as well as government agencies. Corporate information logistics systems of users of the GUAM countries can be integrated with the national eLogistics systems in their countries to automatically import/pull data, which significantly reduces the cost of information exchange. In the course of digitalization of GUAM transport corridor, the consolidating task of creating a unified information environment of digital trust between participants in business processes shall be solved, which allows remote conclusion and execution of smart contracts, the formation of electronic transportation and shipping documents, their storage and exchange by DTC users.

III. Collaborative Blockchain Solution for GUAM Corridor Data Pipeline

When developing an appropriate solution, it is necessary to take into account the position of the GUAM member states on the protection of critical trade and transport information and digital sovereignty. The state bodies of the EU and Eastern Partnership countries are not ready yet to recognize the operation of cryptographic facilities of other states on their territories, or to export their own cryptography. At the same time, the GUAM member states have not yet developed well-developed mechanisms for resolving the problems of litigation on transport and logistics transactions based on electronic documents from various jurisdictions. As a standard approach to solve the above problems, developers of eLogistics platforms can use services of a Trusted Third Party, which is capable of providing cross-border information interaction between the parties. But this solution is not exhaustive for the requirements imposed by Data Pipeline principles and latest EU regulations for electronic freight transport (eFTI) data exchange [2].

In addition, in the process of transportation activities in the international transport corridors the large flow of technological level information can be generated from IoT devices - electronic seals, smart containers, IoT and RFID sensors accompanying cargo units. The transactions of this data will also require online validation, not only at the technological and national levels, but also when transferred to a unified trust environment of the GUAM digital transport corridor for monitoring and managing international supply chains. As a result, when creating a regional DTC, it seems appropriate to ensure the provision of legally significative electronic documents and data transactions from both legal entities and individuals, and from IoT "inanimate devices".

Modern views on the creation of the unified digital trust environment for GUAM DTC participants primarily involve the exchange of validated data, and only in a number of necessary cases it is required to provide information in the form of electronic legally significative documents. In this respect it is important to identify and authenticate GUAM DTC users, in order to exclude their anonymity and to give them the appropriate authority to carry out specific actions. In this regard, when developing a conceptual solution, approaches were considered for organizing cross-border information interaction and creating an environment of trust in the GUAM corridor data pipeline based on modern blockchain technologies. In of the above analysis, it was concluded that the solution for authorization, identification and authentication of GUAM users as well as for the cross-border transmission of validated data and protection against their modification can be effectively achieved using a GUAM DTC corporate key infrastructure (Public Key Infrastructure - PKI). Such infrastructure can be built on the base of blockchain nodes hosted in the national eLogistics platforms of GUAM countries, hereinafter referred to as Logistics Block Nodes (LBN). The schematic structure of building a GUAM corridor data pipeline based on typical LBN network located in the participating countries is shown in Fig. 1.

It is advisable to build such an infrastructure using blockchain technologies based on the well-known Hyperledger Fabric platform [3]. This specialized PKI infrastructure is able to create the trust environment for participants of international transport information exchange, as well as to implement on this basis a service infrastructure compatible with the European Blockchain Services Infrastructure (EBSI), which is actively developed in the EU countries. This decision is also in good compliance with the requirements of the new EU eFTI regulations in the field of electronic freight transport information.

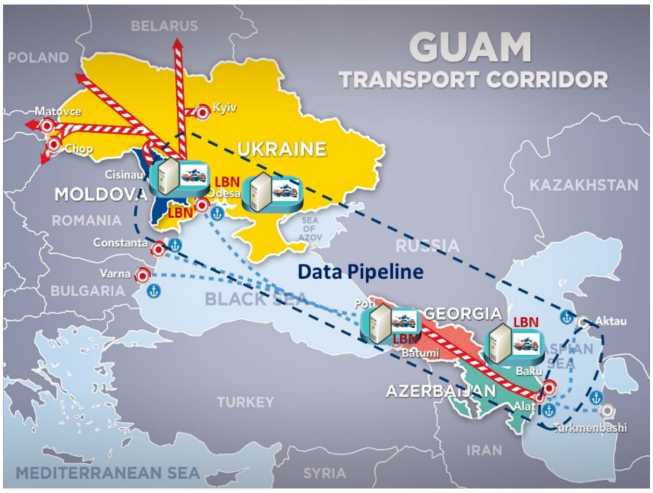

Fig.1 Data pipeline for GUAM transport corridor

IV. Core Functional Features and Requirements for GUAM Corridor Data Pipeline

When developing functional requirements for the GUAM corridor data pipeline, the best practices of building information logistics systems in the countries of the Asia-Pacific region (China, Japan, South Korea, Singapore, etc.) was taken into account, as well as the results of relevant projects of the EU countries to create information systems for the European network of transport corridors TEN-T [4]. As a result of such analysis, the following main functions of the regional GUAM corridor data pipeline were formulated:

- data capture and analysis in GUAM transport corridor for their subsequent collective use and exchange in order to increase the efficiency of interaction of all participants in logistics processes and making management decisions;
- ensuring the interoperability of processes and systems used by various modes of transport (multimodality);
- unification of standards for the exchange of logistics data based on the exchange of standardized electronic documents and structured data.

In this case, the list of functional requirements for the GUAM DTC may include the following bullet points:

1) ensuring the digital sovereignty, quality and integrity of data;
2) ensuring information security and digital trust;
3) collection, storage and processing of initial data received from participants of multimodal transport and logistics processes for the subsequent exchange of structured data packages and exchange of standardized electronic documents;
4) providing visibility of supply chains, including monitoring of national transport infrastructure, logistics processes and cargo tracking;
5) communication and interaction with technological information systems used by various modes of transport;
6) interaction with cross-border platforms and international networks such as FENIX [5] in the EU and NEAL-NET[6] in the countries of North-East Asia;
7) authorization and user management with an appropriate set of client services;
8) supply chain management and information processes with an appropriate set of analytical services;
9) information support of transport, logistics and import - export processes with an appropriate range of services for the public and private sectors.

References

[1] The Data Pipeline. Global Trade Facilitation Conference 2011 https://unece.org/fileadmin/DAM/trade/Trade_Facilitation_Forum/BkgrdDocs/UNPaper_DataPipeline.pdf

[2] Regulation (EU) 2020/1056 of the European Parliament and of the Council of 15 July 2020 on electronic freight transport information, https://eur-lex.europa.eu/eli/reg/2020/1056/oj

[3] Hyperledger Fabric - Blockchain Platform for the Enterprise, https://hyperledger-fabric.readthedocs.io/en/release-2.2/

[4] Trans-European Transport Network (TEN-T), https://ec.europa.eu/transport/themes/infrastructure/ten-t_en

[5] FENIX project, http://www.fenix-project.eu/about-fenix/

[6] Cross-Border Paperless Trade Database NEAL-NET, https://www.unescap.org/sites/default/files/Session2-3_Kim.pdf.

Section #2

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Creating a Surveillance System to Detect License Plate of a Vehicle

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***Abstract*—In order to prevent accidents caused by traffic rule violations, Plate Recognizer tool is developed. Plate Recognizer can monitor the incoming video of traffic and detect the traffic rule violations with using image processing and advanced libraries. With this study, it is hoped to get more direct and accurate data of traffic characteristics and prevent the future problems.**

***Keywords*—Traffic rule violation, plate, image processing**

I. Introduction

In the modern world, cars are involved in every aspect of life. Without them, transportation is unthinkable. However, today, in parallel with the increase in the number of cars, there is an increase in traffic rule violations.

It is certain that a system is needed to examine the causes of these accidents and to prevent similar accidents in the future. The system to be produced should examine the camera images, define objects through them, process pictures and distinguish shapes, detect vehicles and detect their license plates, and report on these plates when necessary [1].

After considering the requirements and researching similar projects, a software written in c# programming language, using AForge, opencv libraries and Tesseract engine was developed.

II. Requirement

A system that uses images from cameras to detect traffic rule violations and can automatically detect problems and help us create a much more seamless transportation system needed to be created [2].

With the requirement that mentioned above, Plate Recognizer application is created. Plate Recognizer focuses on detecting car plates from a picture or from a live footage. Main screen of Plate Recognizer offers user a chance to upload a picture and detect the car license plate and chance to capture a picture from live footage when clicked and then fetch plate text from picture.

III. Technologies

In order to develop a surveillance system, C# programming language with Visual Studio environment tool is used [3].
Used libraries;
- AForge
- Tesseract Engine
- OpenCV

A. AForge

AForge.NET is a C# framework designed for developers and researchers in the fields of Computer Vision and Artificial Intelligence - image processing, computer vision, neural networks, genetic algorithms, machine learning, etc.

AForge.Video.DirectShow:namespace contains classes, which allow to access video sources using DirectShow interface [4].

B. Tesseract Engine

Tesseract is an optical character recognition (OCR) engine for various operating systems. It is free software, released under the Apache License

Tesseract was considered one of the most accurate open-source OCR engines then available [5, 6].

C. OpenCV

OpenCV (Open-Source Computer Vision Library) is a library of programming functions mainly aimed at real-time computer vision. The library is cross-platform and free for use under the open-source Apache 2 License. Starting with 2011, OpenCV features GPU acceleration for real-time operations [7, 8].

IV. PROJECT

Plate Recognizer is a Form Application built in ASP .NET with C# language. It involves 2 main forms and has a simple yet useful interface.

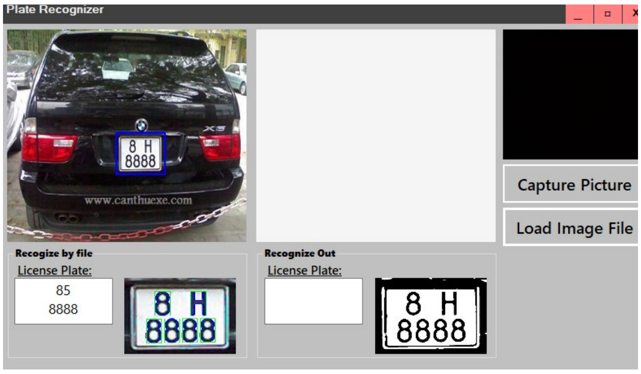

Fig. 1. Main screen of plate recognizer

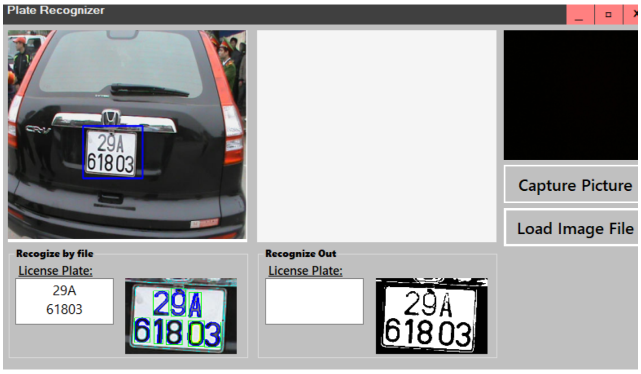

Fig. 2. Detecting plate from image file

Fig. 3. Gathering plate from live camera

MOBESE is a camera security system established in 81 provinces of Turkey to strengthen the hand of security forces fighting against crime and criminals.

Automatically MOBESE can only detect speeding violations but in future works we are planning to prove a project to be possible to detect red light and crossing line violations with same cameras as well.

With the usage of newly developed libraries and increased detecting speed, Plate Recognizer can be embedded into existing system and the open roads would be much safer autonomously.

Working steps of the plate recognizer tool can be simplified as follows;

- **Step #1:** Detect and localize a license plate in an input image/frame
- **Step #2:** Extract the characters from the license plate
- **Step #3:** Apply some form of Optical Character Recognition (OCR) to recognize the extracted characters

V. CONCLUSION

With the proof of concept, results have shown that it is possible to create a survaillance system that can autonomously works on its own and detects traffic violations, create reports and send those reports via email or messages withouth any human interaction.

With positive results, there are next steps for Plate Recognizer. Currently because of the time limitation, licence plate detection is limited with square plates. Overwriting parts of Tesseract Engine will help overcome this issue.

Because the lack of equipments, only one camera is used. With multiple cameras concurrency problems will occurs but these can be handled as well.

REFERENCES

[1] Witold Abramowicz, Dalia Kriksciuniene, Virgilijus Sakalauskas, “Business Information Systems”, Springer Science & Business Media, 2012, pp 158

[2] Ping Jack Soh, Wai Lok Woo, Hamzah Asyrani Sulaiman, “Advances in Machine Learning and Signal Processing: Proceedings of MALSIP”, Springer Science & Business Media, 2016, pp 222.

[3] Robert Bembenik, Lukasz Skonieczny, Henryk Rybinski, “Intelligent Tools for Building a Scientific Information Platform” Springer Science & Business Media, 2013, pp 198

[4] Daisheng Luo, “Pattern Recognition and Image Processing”, Woodhead Publishing, 1998

[5] Wilhelm Burger, Mark J. Burge, “Principles of Digital Image Processing: Advanced Methods”, Springer Science & Business Media, 2013

[6] William K. Pratt, “Introduction to Digital Image Processing”, CRC Press, 2013

[7] Bernd Jähne, “Digital Image Processing”, 2005, pp 25 – 35

[8] Scott E Umbaugh, “Digital Image Processing and Analysis: Human and Computer Vision Applications with CVIPtools”, CRC Press, 2010

Development of a New Measuring Scheme for Determining the Indicators of Horizontal and Vertical Dynamics of a Subway Car

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***Abstract*—The paper analyzes the measuring schemes to determine the vertical and lateral forces, with the help of which the indicators of the vertical and horizontal dynamics of the subway car are calculated. Theoretical studies of the loading of the subway car bogie frame by the finite element method have been carried out. The locations for the installation of strain gauges on the elements of the carriage and the method of signal processing has been determined. A new measuring scheme has been developed to determine the coefficients of the vertical and horizontal dynamics of a subway car, which makes it possible to measure with sufficient accuracy the values of the vertical and lateral forces acting on the bogie frame. Testing of a new measuring scheme during performance trials of the transition type non-motorized subway car model 81-714 Uz confirmed its effectiveness, which is recommended for use in determining the indicators of the dynamic qualities of a car during dynamic performance trials.**

Keywords—running dynamic tests, bogie frame, vertical and lateral forces, locations for the installation of strain gauges, connection scheme of strain gauges, dynamic qualities of a subway car.

I. INTRODUCTION

Rolling stock is a complex mechanical system, which, when moving along the railway track, is subject to various operational loads, which are usually random in nature [1-3]. Modern analytical and numerical methods for studying the dynamic processes arising from the interaction of rolling stock and a railway track are constantly being improved and become more and more effective in assessing the dynamic qualities of rolling stock using mathematical modeling, which is implemented using modern automated software systems [4]. However, theoretical methods are approximate, since they have simplifications when taking into account various factors, therefore, to develop the design of innovative rolling stock with the best dynamic qualities and indicators of its impact on the railway track, along with theoretical methods, experimental methods are provided, which are the most important component of scientific research in the design and construction of rolling stock units [5-7].

According to American and European standards [8-10], the forces acting from the wheel to the rail during running dynamic tests are determined by measuring the deformations on the axle of the wheel pair or wheel disc using strain gauge wheel pairs equipped with strain gauges and data transmission devices [11-14].

Most strain gauge wheel pairs do not provide continuous measurement of dynamic forces, since the determination of loads is carried out by the "point" method - at the moment the strain gauge is located above the point of contact between the wheel and the rail [15]. In addition, this measurement method has a high cost of equipment and does not allow the assessment of forces without replacing conventional wheel pairs.

On 1520 mm gauge railways, a simpler and cheaper method of determining forces is used. For this, the test bogie frames with glued strain gauges are used themselves as measuring elements, since vertical and lateral forces are transmitted through them (through the frames) [16, 17]. In this case, the processing of the measurement results is simplified, since the forces are measured continuously.

Based on the results of measurements of the forces of interaction of a wheel with a rail on railways with a gauge of 1520 mm, indicators of the dynamic qualities of a car are calculated, which are directly related to safety issues during the movement of rolling stock [7, 18, 19]:

- coefficient of vertical dynamics;
- coefficient of horizontal dynamics;
- coefficient of roll stability reserve;
- coefficient of the stock of resistance against derailment.

II. Analysis of Existing Methods for Determining Indicators of Vertical and Horizontal Dynamics of a Subway Car

According to the current regulatory document State Standard 34451-2018 [16], to determine the dynamic qualities of a multi-unit rolling stock (for example, in our case, a subway car), standard locations for the installation of strain gauges are not given, but only the requirements for their installation are described:

- for the indicator of the vertical dynamics of the first stage of spring suspension – on the elements of the bogie so that the influence of horizontal forces on it is maximally excluded;
- for the indicator of vertical dynamics of the second stage of spring suspension – on the elements of the carriage part in such a way that the influence of horizontal forces on it is maximally excluded;
- for the indicator of horizontal dynamics – on the elements of the bogie in such a way that the influence of vertical and longitudinal forces on it is maximally excluded.

The specific installation locations of the strain gauges can only be determined when performing theoretical studies or numerous experiments [6, 18].

Since the bogies of passenger cars and subway cars are structurally similar to each other, it is possible to take as a basis the presented measurement scheme for passenger cars of locomotive traction, according to the State Standard 33788-2016 [17].

According to the current normative document State Standard 33788-2016 for measuring the vertical force, with the help of which the coefficient of dynamic addition (coefficient of vertical dynamics) of the spring suspended parts of the passenger car bogie is determined, two active strain gauges 1 and 2 are installed in the middle part of the side longitudinal beam of the bogie frame from above and below in sections A-A and A′-A′, as shown in Fig. 1.

The use of this measurement scheme for a subway car is difficult, since the possibility of symmetrical installation of strain gauges is excluded, since the upper and lower reinforcing plates (gussets) are welded to the frame along the entire perimeter and additionally above the longitudinal beams (Fig. 2, *a*), including in the middle part, by means of holes completely welded along the contour, and from the bottom due to the presence of support for hydraulic oscillation damper (Fig. 2, *b*).

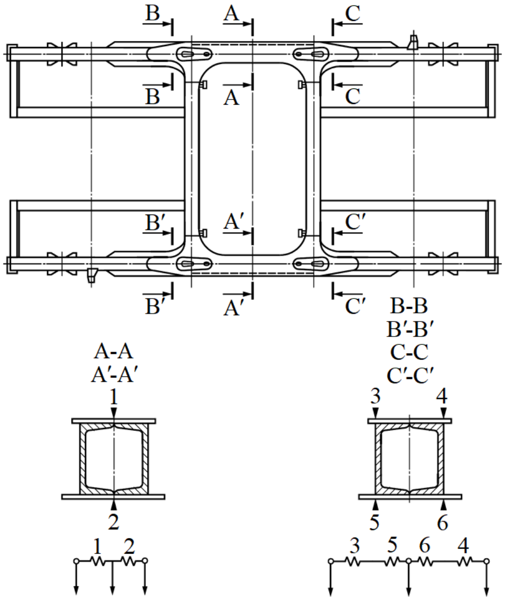


Fig. 1. Installation and connection scheme of strain gauges for measuring the horizontal force and the coefficient of dynamic addition (coefficient of vertical dynamics) of the passenger carriage bogie spring suspended parts: 1-6 – numbers of strain gauges.

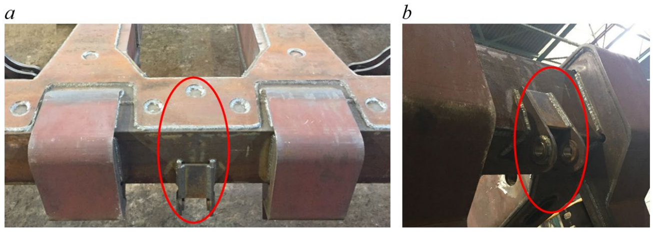


Fig. 2. Side longitudinal beam of the frame with welded reinforcing linings (gussets) and supports for hydraulic oscillation damper: *a* – top view; *b* – bottom view.

The horizontal force with which the frame force is calculated, according to State Standard 33788-2018, is determined by four strain gauges 3-6 installed above and below along the edges of the side longitudinal beam of the bogie frame in sections B-B, B′-B′, C-C, C′-C′ as shown in Fig. 1.

This scheme can be used to determine the indicator of the horizontal dynamics of a subway car, since the installation of strain gauges, according to State Standard 33788-2018, on the side longitudinal beam of the frame does not prevent its constructive implementation.

Taking into account the above, in order to determine the vertical dynamics indicator of the first stage of the spring suspension of a subway car, it was necessary to find the locations for the installation of strain gauges on the bogie elements and a method for processing the received signals, which, according to the requirements of State Standard 34451-2018, make it possible to maximally exclude the influence of horizontal forces on the bogie.

III. Development of a New Method for Measuring Vertical and Lateral Forces Acting on the Bogie Frame of a Subway Car

The purpose of the research was to choose the locations for the installation of strain gauges on the elements of the bogie and the method of signal processing – the development of a measuring scheme for indicators of the vertical and horizontal dynamics of a subway car.

At the first stage of the research, a design model of the subway car bogie frame of Model 81-717/714 (Fig. 3) was developed, which is an H-shaped all-welded structure, consisting of two longitudinal and two transverse beams, butt-connected with overlapping of the joint with reinforcing linings.

For calculations by the finite element method, the ANSYS Workbench software suite, version 18 was used. The finite element mesh applied to the model of the bogie frame included 60362 elements and 185701 nodes. Finite elements of the Solid186 type with a size of 10 mm were used.

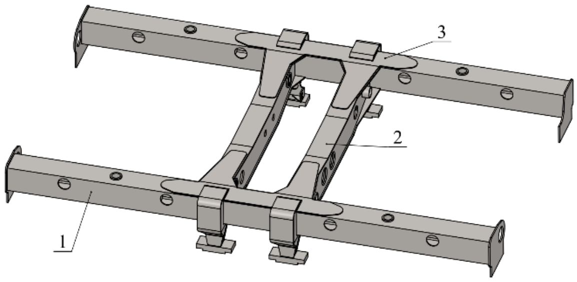


Fig. 3. Design model of the subway car bogie frame: 1 – longitudinal beam; 2 – transverse beam; 3 – reinforcing lining.

The coordinate system was adopted as follows: the x – axis is the longitudinal axis; y – axis is the lateral axis; and z – axis is the lateral axis.

In the next stage, load studies of the subway car bogie frame were carried out using the finite element method. As a result of multivariate calculations, diagrams of stress distribution on the bogie frame were obtained under the action of vertical, longitudinal and lateral forces on it.

Analysis of the results of calculations and diagrams of stress distribution on the bogie frame showed that the most promising is the determination of the vertical and lateral forces, with the help of which the indicators of the vertical and horizontal dynamics of the car are calculated, by measuring the normal stresses (along the longitudinal x – axis) with the installation of four strain gauges on both sides on the side longitudinal beam of the bogie frame in sections A-A, A′-A′, B-B, B′-B′, as shown in Fig. 4.

This will allow, when determining vertical forces, to exclude the influence of horizontal forces on the bogie as much as possible, and when determining lateral forces – the influence of vertical and longitudinal forces.

Then the values of the vertical and lateral forces, expressed in terms of deformations ε_{xi}, have the form

$$P_{ver} = C_{ver} \cdot \frac{E}{1-\mu^2}\left(\varepsilon_{x1} - \varepsilon_{x2} + \varepsilon_{x3} - \varepsilon_{x4}\right), \quad (1)$$
$$P_{lat} = C_{lat} \cdot \frac{E}{1-\mu^2}\left(\varepsilon_{x1} + \varepsilon_{x2} - \varepsilon_{x3} - \varepsilon_{x4}\right).$$

Where C_{ver} and C_{lat} – are constant coefficients for measuring vertical and lateral forces, respectively, determined when calibrating strain gauge schemes; E – is the modulus of elasticity; μ – is Poisson's ratio; ε_{xi} – linear deformations caused by normal longitudinal stresses σ_{xi}, measured by strain gauges installed on the side longitudinal beam of the bogie frame.

If we consider that

$$S_1 = \varepsilon_{x1} - \varepsilon_{x4}, \quad (2)$$
$$S_2 = \varepsilon_{x2} - \varepsilon_{x3},$$

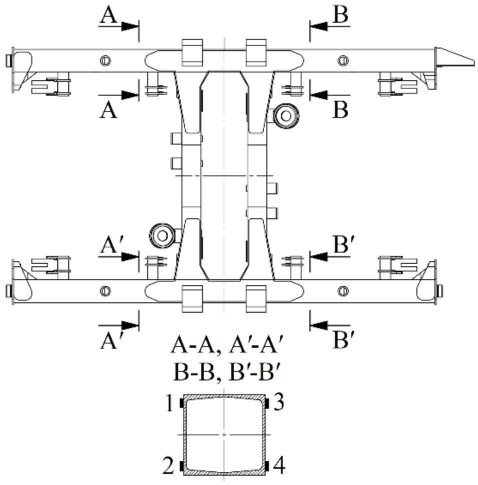


Fig. 4. Installation scheme of strain gauges for measuring vertical and lateral forces on the bogie frame of a subway car: 1-4 – numbers of strain gauges.

then formula (1) can be written as follows:

$$P_{ver} = C_{ver} \cdot \frac{E}{1-\mu^2}\left(S_1 - S_2\right), \quad (3)$$
$$P_{lat} = C_{lat} \cdot \frac{E}{1-\mu^2}\left(S_1 + S_2\right).$$

In this case, to determine the vertical force acting on the bogie frame, four strain gauges 1-4 (Fig. 4) must be connected into a full bridge connection scheme, as shown in Fig. 5, *a*. For determining the lateral force, gauges should be connected as shown in Fig. 5, *b*.

Therefore, in order to apply the installation scheme of strain gauges shown in Fig. 4 for the simultaneous measurement of vertical and lateral forces, according to expression (3), it is advisable to connect the strain gauges in two full bridges with a four-wire connection scheme, as shown in Fig. 6.

Thus, the new measurement scheme, when the strain gauges are connected into two full bridges with a four-wire connection scheme, as shown in Fig. 6, and with further signal processing, according to expression (3), will provide simultaneous measurement of the vertical and lateral forces acting on the bogie frame of a subway car. This makes it possible to determine with sufficient accuracy the values of the coefficient of vertical and horizontal dynamics, to reduce the number of strain gauges for determining the indicators of the dynamic qualities of a subway car while running dynamic tests.

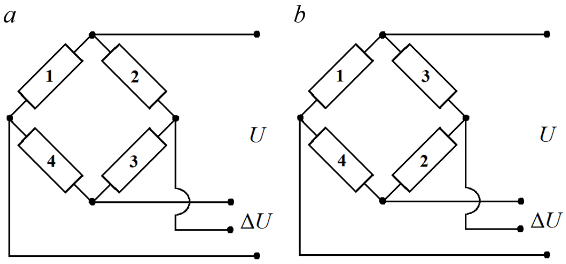


Fig. 5. Connection schemes of strain gauges for measuring vertical force (*a*) and lateral force (*b*) on the bogie frame: 1-4 – numbers of strain gauges; U – is the voltage of the measurement bridge; ΔU – change in the output voltage of the measurement bridge.

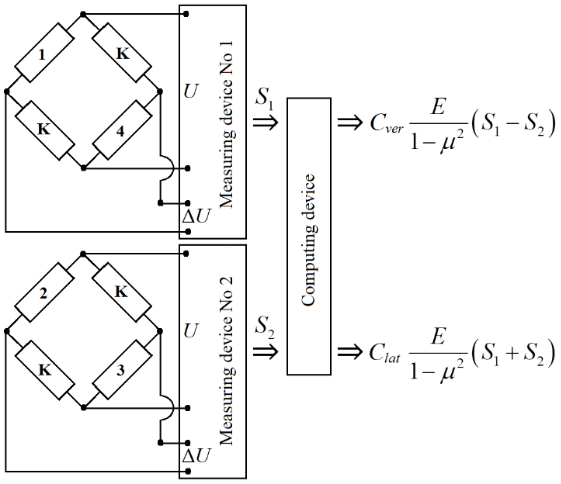


Fig. 6. Connection scheme of strain gauges for measuring vertical and lateral forces on the bogie frame of the subway car: 1-4 – numbers of strain gauges; K – compensatory strain gauges.

IV. Testing of a New Measuring Scheme for Determining the Vertical and Lateral Forces Acting on the Bogie Frame of a Subway Car

The proposed measuring scheme was tested during performance trials to assess the dynamic qualities of the transition type non-motorized metro car model 81-714 Uz manufactured by JSC "Tashkent plant for construction and repair of passenger cars" on the Chilanzar line of the Tashkent metro.

Before testing the side longitudinal beams of the bogie frame closest to the head car of the metro, strain gauges were installed, according to the scheme shown in Fig. 4 and connected to measuring bridges according to Fig. 6.

Placement of strain gauges on the bogie frame of the transition type non-motor subway car of the model 81-714 Uz is shown in Fig. 7.

To determine the experimental dependencies between the readings of the measuring schemes and the acting forces, the calibration loads of the subway car bogie frame were carried out. An example of an oscillogram of deformations in the process of loading and unloading of a subway car bogie frame, registered according to the new measuring scheme, is shown in Fig. 8.

To determine the scale of the strain gauge measuring scheme, graphs of the dependence of the readings of the device on the loading and unloading of the subway car bogie were built. The obtained values were approximated by the least squares method, and as a result of the statistical analysis of the data obtained, the average value of the measurement scale of the strain gauge measuring scheme was chosen.

During performance trials, the vertical and lateral forces acting on the subway car bogie frame were measured and recorded. Evaluation of the dynamic qualities of a subway car was carried out in empty and loaded modes in the entire range of operating speeds, every 10-20 km/h up to the design speed.

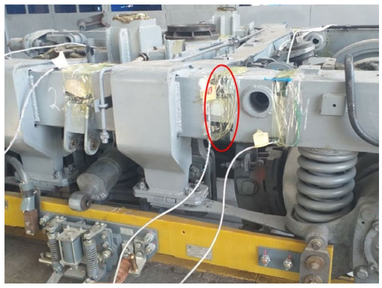


Fig. 7. Placement of strain gauges and their connection on the bogie frame of the transition type non-motor subway car of the model 81-714 Uz.

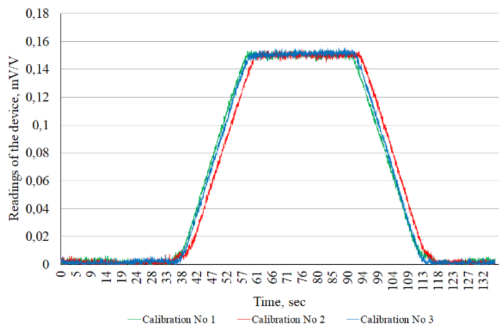
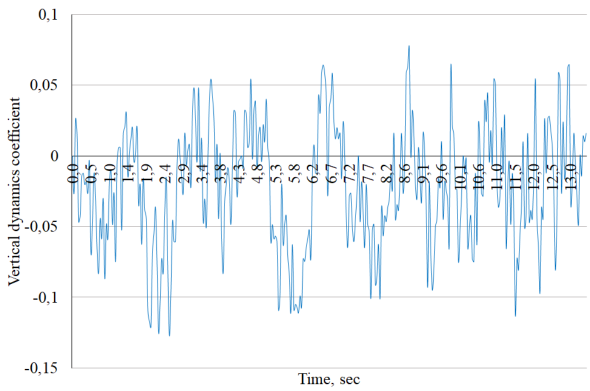


Fig. 8. Oscillogram of the loading and unloading process of a subway car bogie frame.

Examples of the graphs of continuous registration of the vertical dynamics coefficients of the first stage of spring suspension and horizontal dynamics, recorded according to a new measuring scheme as a result of performance trials to assess the dynamic qualities of the transition type non-motorized subway car model 81-714 Uz, are shown in Fig. 9-10.

a



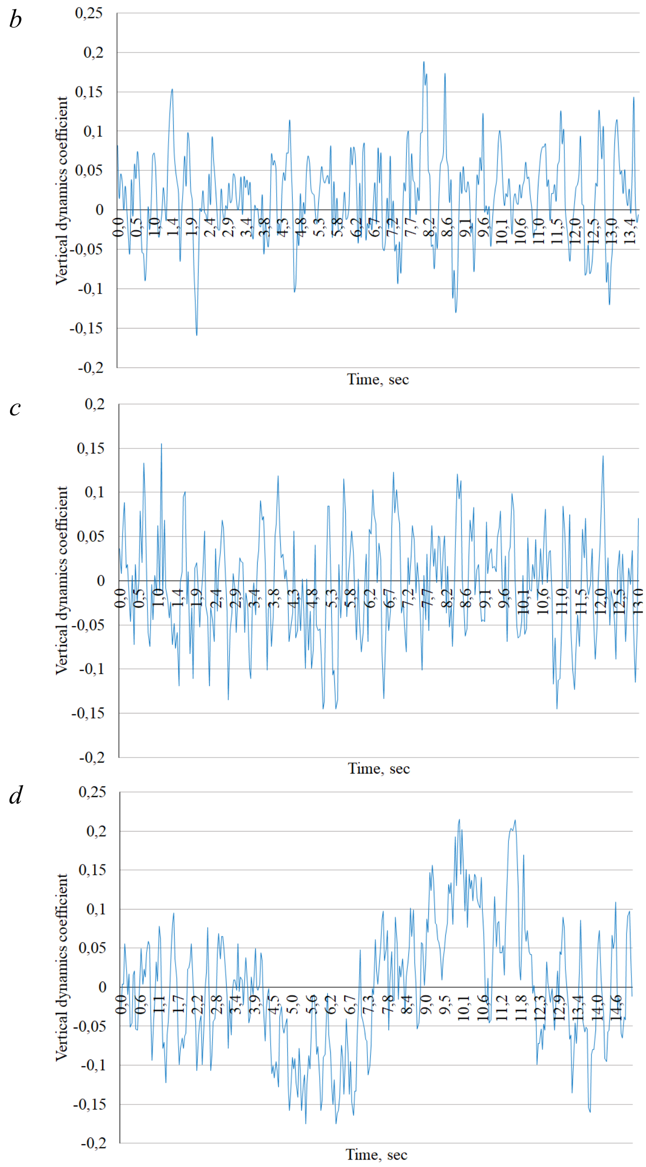
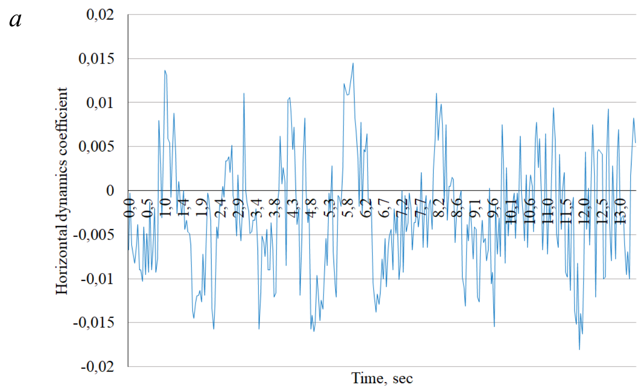


Fig. 9. Dependences of the vertical dynamics coefficient of the first stage of spring suspension on time (empty mode): *a* – on tangent tracks at a speed of 20 km/h; *b* – on tangent tracks at a speed of 50 km/h; *c* – on the middle radius curved tracks at a speed of 50 km/h; *d* – on small radius curved tracks of at a speed of 50 km/h.



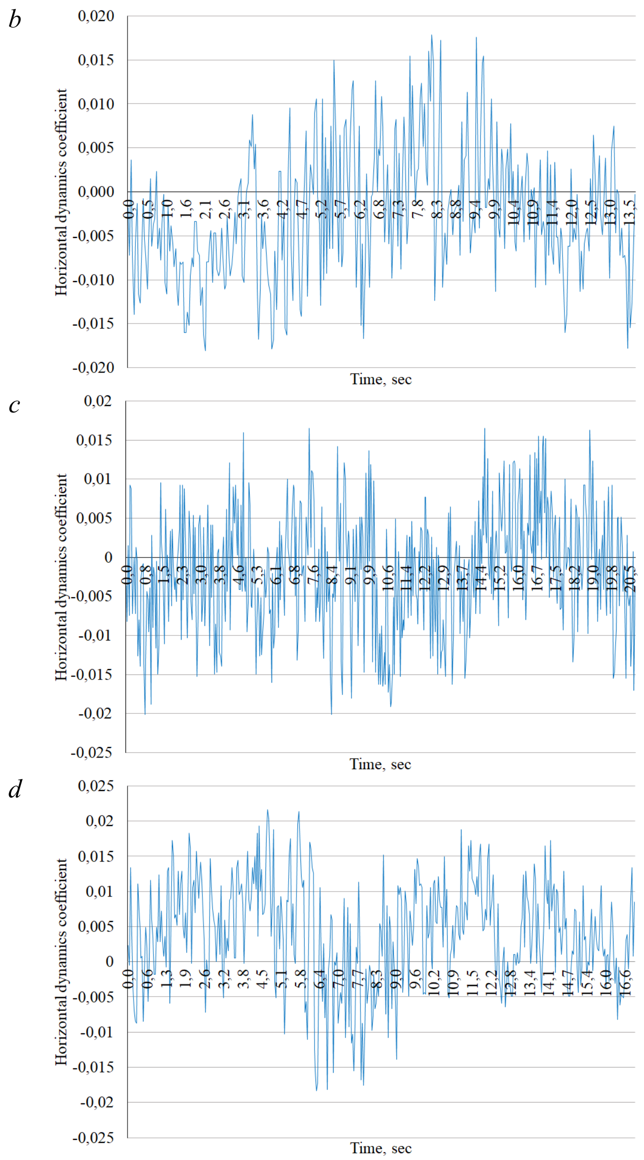


Fig. 10. Dependences of the horizontal dynamics coefficient on time (empty mode): *a* – on tangent tracks at a speed of 20 km/h; *b* – on tangent tracks at a speed of 50 km/h; *c* – on the middle radius curved tracks at a speed of 50 km/h; *d* – on small radius curved tracks of at a speed of 50 km/h.

Thus, the results of the performance trials carried out to assess the dynamic qualities of the transition type non-motorized subway car model 81-714 Uz confirmed the effectiveness of the developed measuring scheme for determining the vertical and lateral forces acting on the subway car bogie frame.

V. Conclusion

- In the work, a set of studies was carried out and a new measuring scheme was developed, theoretically substantiated and tested during dynamic performance trials for determining the indicators of vertical and horizontal dynamics of a subway car.
- It was found that the most promising is the determination of vertical and lateral forces, with the help of which the indicators of the vertical and horizontal dynamics of the car are calculated, by measuring the normal stresses (along the longitudinal axis) with the installation of four strain gauges on both

sides on the side longitudinal beam of the bogie frame (Fig. 4).

- It has been determined that the new measuring scheme, when the strain gauges are connected to two full bridges with a four-wire connection scheme, will provide simultaneous measurement of the vertical and lateral forces acting on a subway car bogie frame (Fig. 6). This will allow, when determining vertical forces, to exclude as much as possible the influence of horizontal forces on the bogie, and when determining lateral forces – the influence of vertical and longitudinal forces.
- The performance trials carried out to assess the dynamic qualities of the transition type non-motorized subway car model 81-714 Uz confirmed the effectiveness of the developed measuring scheme for determining the vertical and lateral forces acting on the subway car bogie frame.
- Thus, the developed measuring scheme is recommended for use in determining the coefficients of the vertical and horizontal dynamics of a subway car, which will allow to determine with sufficient accuracy the values of the vertical and lateral forces acting on the bogie frame and reduce the number of strain gauges to determine the indicators of the dynamic qualities of the car during performance trials.

REFERENCES

[1] E. M. Bromberg, M. F. Verigo, V. N. Danilov, M. A. Frishman, Interaction between rail track and rolling stock, Moscow: Transzheldorizdat, 1956.

[2] M. F. Verigo, A. Ya. Kogan, Interaction between rail track and rolling stock, Moscow: Transport, 1986.

[3] A.Ya. Kogan, Dynamics of railway track and its interaction with rolling stock, Moscow: Transport, 1997.

[4] R. V. Rahimov, Estimated determination of indicators of the impact of rolling stock with increased axial loads on the track in the conditions of the railways of the Republic of Uzbekistan, Vestnik transporta Povolzhya, vol. 5, pp. 23–33, 2019.

[5] P. S. Anisimov, Testing of wagons, Monograph, Moscow: Marshrut, 2004.

[6] N. Wilson, R. Fries, M. Witte, A. Haigermoser, M. Wrang, J. Evans, A. Orlova, Assessment of safety against derailment using simulations and vehicle acceptance tests: a worldwide comparison of state-of-the-art assessment methods, Vehicle system dynamics, vol. 49, no. 7, pp. 1113–1157, 2011.

[7] Yu. P. Boronenko, R. V. Rahimov, Experimental determination of forces through measurements of strains in the side frame of the bogie, Transport problems, vol. 16, iss. 3, pp. 199–211, 2021.

[8] EN 14363: 2005, Railway applications – testing for the acceptance of running characteristics of railway vehicles – testing of running behaviour and stationary tests, European Committee for Standardization.

[9] UIC Code 518: 2009, Testing and approval of railway vehicles from the point of view of their dynamic behaviour – safety – track fatigue – ride quality, 4th ed., Paris: Union Internationale des Chemins de Fer.

[10] 49 CFR 213. Title 49 – Transportation, Part 213 – Track safety standards. Subtitle B – Other regulations relating to transportation (continued), Chapter II – Federal railroad administration, Department of Transportation, 2011.

[11] H. H. Zuck, Determination of wheel/rail forces by means of measuring wheelsets on Deutsche Bundesbahn, Proceedings international conference on wheel/rail load and displacement measurement techniques, Ed. by P. Tong, R. Greif, U.S. Department of Transportation, Cambridge: Massachusetts, pp. 1–22, 1981.

[12] R. L. Higgins, D. E. Otter, R. W. Martin, High accuracy load measuring wheelset, Pueblo, USA, American railroads association, Test transport Centre Publ., pp. 86–89, 1992.

[13] A. V. Tretyakov, A. A. Petrov, K. V. Yeliseev, M. Z. Zymakova, Running dynamic trials of freight wagons with strain-gauge wheel pair application, Proceedings of Petersburg Transport University, vol. 14, iss. 1, pp. 127–136, 2017.

[14] J. Stow, Field testing and instrumentation of railway vehicles, Handbook of Railway Vehicle Dynamics, 2nd ed., Ed. by S. Iwnicki, M. Spiryagin, C. Cole, T. McSweeney, Boca Raton: CRC Press, pp. 723–760, 2019.

[15] A. V. Tretyakov, A. V. Nekrasova, R. V. Rahimov, M. V. Zimakova, A. A. Petrov, O. A. Tretyakov, Monitoring of the technical condition of railway track using the strain gauges wheelset and navigation aids, Proceedings of XV International scientific-technical conference “Rolling stock of the XXI century: ideas, requirements, projects”, St. Petersburg: PGUPS, pp. 134–137, 2021.

[16] GOST 34451-2018, Motor railway rolling stock, Methodology of dynamic-strength tests, Moscow: Standartinform, 2019.

[17] GOST 33788-2016, Freight and passenger railcars, Methods of testing structural strength and dynamic performance, Moscow: Standartinform, 2016.

[18] Yu. P. Boronenko, R. V. Rahimov, A. V. Belyankin, Developing new methods for measuring vertical forces acting on the bogie side frame from the wheelset of a moving wagon, Proceedings of Petersburg Transport University, vol. 17, iss. 1, pp. 7–22, 2020.

[19] N. Wilson, H. Wu, A. Klopp, A. Keylin, Railway vehicle derailment and prevention, Handbook of railway vehicle dynamics, 2nd ed., Ed. by S. Iwnicki, M. Spiryagin, C. Cole, T. McSweeney, Boca Raton: CRC Press, pp. 373–413, 2019.

Development of a Methodology for Creatıng an Agent Based Model of Transport Hubs in Suburban Area

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***Abstract*—The article emphasizes the importance of transport hubs in urban public transport and the need to create them. The reasons for the loss of passengers' time found in the course of a study carried out in settlements around Baku were explained. In order to improve the quality of passenger service, it was proposed to create a transport and transfer hub to coordinate the work of a high-speed railway line with bus routes. In the Anylogic 8.4.2 program, an algorithm was developed for constructing a simulation model to coordinate the schedules of buses and trains. The model also makes it possible to visually monitor the transplantation process.**

***Keywords*—transport hubs, bus, high speed train, simulation, Anylogic.**

I. INTRODUCTION

The demand for relocation grows as urban populations grow, their financial situation improves, and urban areas expand. These movements are carried out by different types of transport. Research shows that most of the city's population makes complex journeys from point of departure to destination. Most of these complex movements are also performed using two or more vehicles. At the same time, an increase in the number of modes of transport serving passengers and the number of passenger exchange points between them gives rise to the problem of coordination between them. To do this, it is advisable to create transport-interchange hubs in order to ensure the transfer of passengers between vehicles conveniently, safely and in the shortest possible time.

Transport hubs are the main elements of the transport hub of cities. It provides interconnection between the existing types of urban and mainline passenger transport. These nodes are formed by the interaction of two or more types of urban transport. Correct planning and technical organization and their placement help to improve accessibility conditions, to reduce the time spent on passengers.

II. FEATURES OF TRANSPORT HUBS

The development of transport infrastructure, the introduction of new types of transport into the operational process (light tram, monorail transport, etc.) complicate the planning and technical organization of transport interchange hubs. However, when designing transport hubs, it is necessary to find an optimal solution that meets the following requirements [1]:

- the convenience of passengers at transfer hubs;
- minimum time consumption;
- passenger safety;
- informativeness.

The transfer process in a transport hub includes movement from a stop (station) of one transport to a stop (station) of another, waiting for vehicles and boarding a vehicle.

The transport hub combines three major components: transport, road network and passenger traffic [2]. This integration serves to improve passenger comfort, simplify the operation of the transport system and reduce traffic congestion.

Actors in the field of mobility are now familiar with the term “interchange hub” (“transport hub” is also widely used, sometimes with the adjective “multimodal” to reinforce the idea of various modes of transport connecting there). The expression refers to a building and a space; its meaning encompasses various realities, functions and practices [3]. The efficiency of public transport depends on network effects and on the connectedness between transport modes or between the different lines of a mode. Multimodal transport hubs (MTHs), as both meeting places between modes and points of interconnection, play a crucial role in ensuring the good use of public transport. Interchange hubs help organise urban mobility systems. Their role is to facilitate transfers between different means of transport, and as part of the urban environment, act as interfaces between cities and transport networks. Offering mobility, accessibility and attractiveness, multimodal transport hubs differ vastly from one country or city to another, depending on the structuring modes of transport and on the maturity of the urban fabric.

The physical integration of the public transport network is considered as one of the most important factors of seamless transport. Measures essential to its implementation are [4]:

1. A comprehensive master plan for physical integration, based on a detailed field survey on transfer facilities;
2. A hub-like transfer facility, based on the master plan, and improvement of facilities;
3. Operation and management center for facilities; and

4. Improvement in law and principles related to development of transfer hubs.

The principles of forming a system of transport interchange hubs can be considered from several positions: on the one hand, when forming a transport hub, it is necessary to ensure maximum passenger comfort, on the other hand, a transport interchange hub is an important infrastructural element of the city's transport system. Transport hubs are formed at metro stations, along the perimeter of the city, in the peripheral zones. They can also be of agglomeration value [5].

III. CREATION OF A TRANSPORT HUB IN A SUBURBAN AREA

Several transport interchange hubs have been created in Baku to ensure the exchange of passengers between modes of transport. Analysis of the transport system of Baku [6] shows that it is necessary to create transport hubs to ensure the transfer of passengers traveling from suburban areas and settlements in the direction of the city, to the city public. Considering that high-speed railway lines serve the suburban population in the direction of Baku, we can see the importance of creating transport hubs in Khirdalan, Sabunchu, Zabrat and other territories.

According to the results of a survey conducted to study the current state of transport services in the settlements of Hokmali, Gobu, Atyali, Absheron region, it was determined that the majority of respondents (about 66%) lose most of their time to get to their destination [6]. The overwhelming majority of the population of the study area makes travel to Baku. The stations on January 20, Memar Ajami and Avtovagzal were indicated as the primary destination. As shown in Fig. 1 time of arrival at the destination located in Baku varies from 32 to 49 minutes. This is a fairly large figure.

As can be seen from the figure, the average arrival time from the Gobu village to Baku is 47 minutes, and the arrival time from the Atyali village is 49 minutes. However, the high-speed train passing through the Khirdalan railway station reaches the 28 metro station in 17 minutes. Taking into account the time of arrival of passengers at the station by buses, we can see how much the time will shorten to the destination.

In order to provide faster, more convenient and safer access to the destination for the population living in the considered territories, the routes of buses running in this area should contact the Khirdalan railway passenger station. To reduce the time of movement of the population by public transport, the route schedule in these settlements should be coordinated with the schedule of the high-speed train passing through the Khirdalan railway station.

The last stop of the bus route near the Khirdalan railway station is 100-150 meters from the station entrance. Although safe waiting areas for passengers - attics and seats - have been installed on the station platform, the condition of the overpass for entering the station platform is unsatisfactory. The passage here is open, the stairs are wooden. The transition is not able to be used by passengers with reduced mobility. The current state of the Khirdalan passenger railway station is shown in Fig. 2.

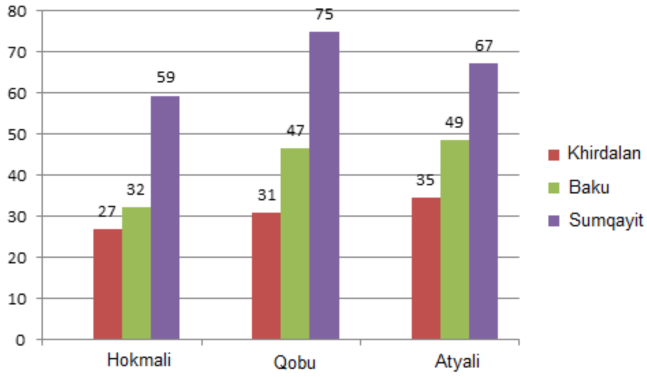

Fig. 1. Time of arrival from the settlements of Hokmali, Gobu and Atyali to Khirdalan, Baku and Sumgayit.

Fig. 2. Current state of the crossing at the Khirdalan passenger station.

To improve passenger exchange, the final stop of the bus route should be close to the train station. To improve the exchange of passengers between these types of public transport, the passage from all directions should be provided with escalators. The passage must be completely covered by a canopy. It is also desirable to install pedestrian lifts for passengers with reduced mobility and hand luggage.

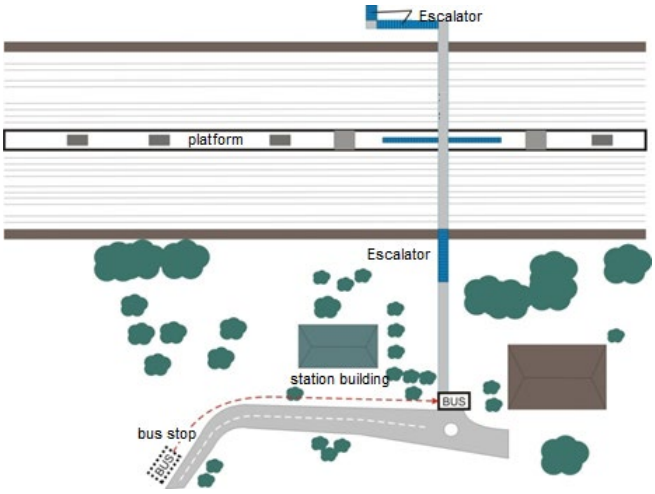

Fig. 3. Scheme for improving the exchange of passengers in front of the Khirdalan railway passenger station.

IV. AGENT BASED SIMULATION OF A TRANSPORT HUB

In recent years, some transport problems have been solved with the help of computer simulation. Three main types of simulation are widely used (system dynamics; discrete event simulation; agent-based simulation) [7]. Of these, the most suitable for modeling a public transport network is agent-based modeling, in which vehicles and passengers act as an agent [8].

It is proposed to build an agent-based simulation model in order to visualize the operation of the transport interchange hub and describe the exchange process between the bus stop and the Khirdalan railway passenger station. Anylogic 8.7.4 software was used to create the model.

Anylogis is an object-oriented program designed specifically for simulation, supported by user interfaces. The simple yet complex animation features of Anylogic allow you to create visually rich designs and interactive modeling environments.

A simulation model of the movement of passengers in a transport interchange hub was created in the Anylogis 8.7.4 program. using the tools of the Pedestrian Library library (PedGoTo, TargetLine, PedEscalator, PedWait, PedExit, PedSink, etc.). The boarding of passengers waiting at a stop is simulated using a queue model.

The logical model of the traffic pattern in the transport interchange hub is shown in Fig. 4.

To simulate the movement of buses, the tools of the Road Traffic Librare panel (Road, BusStop, CarSurce, CarMoveTo, Delau, etc.) are used. The tools RailWau Trakk, TrainSourse, TrainMoveTo are used to simulate the movement of trains. The logical diagram of passenger boarding is shown in Fig. 5.

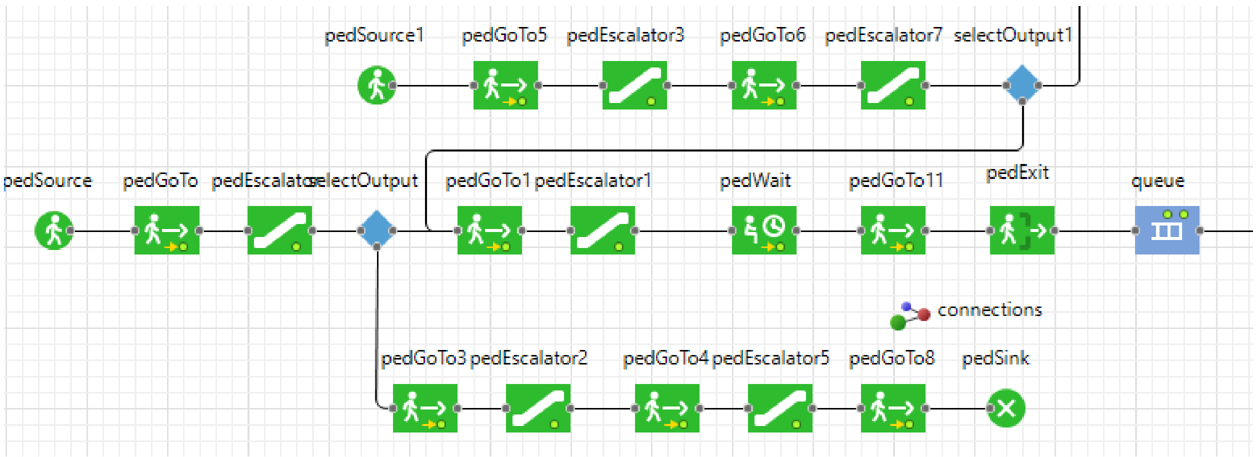

Fig. 4. Logical model for constructing a passenger traffic pattern

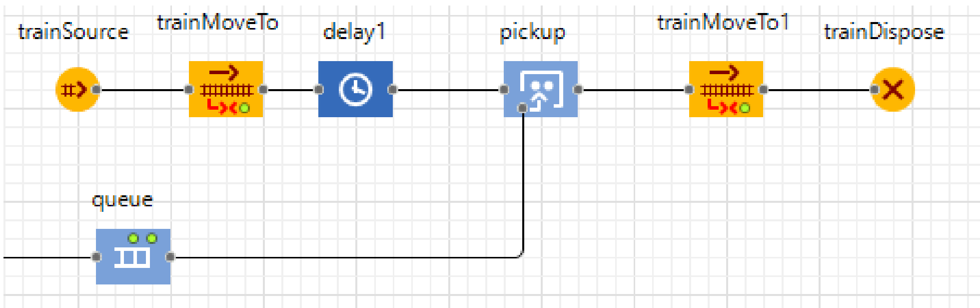

Fig. 5. Logic diagram of passenger boarding on the train

The 3D Window tool from the Presentation section is used to view the generated model in 3D. This tool is selected and placed on the analogy work area.

Figure 6 shows a three-dimensional image of a simulation model of a transport interchange hub proposed to be created around the Khirdalan railway station.

Fig. 6. 3D image of a simulation model of a transport interchange hub in front of the Khirdalan railway station.

CONCLUSION

The creation of public transport interchange hubs serving passengers living in suburban areas significantly affects the reduction of passengers' time losses. To organize the operation of such stations, it is advisable to use modern computer modeling. Such models make it possible to accurately predict the operation of a transport hub in changing situations (for example, a decrease in passenger traffic as a result of a pandemic).

REFERENCES

[1] Azarenkova Z. V. Planning organization of transport hubs // Academia. Architecture and construction. - 2011. - Issue. 1. - S. 76-80.
Азаренкова З.В. Планировочная организация транспортно-пересадочных узлов//Academia. Архитектура и строительство. – 2011. – Вып. 1. – С. 76-80.

[2] NapreenkoLidiya. Three-dimensional structure of transport hub in urban environment. INTERNATIONAL SCIENTIFIC JOURNAL "TRANS & MOTAUTO WORLD". Year VI, ISSUE 1, P.P. 11-12 (2021)

[3] Leticia Pinheiro RizerioCarmo. Multimodal Transport Hubs. AFD 2020. Paris, France. p. 180.

[4] Youngjong Kwon.Enhancing Urban–Rural Connectivity through Transport Hubs. 2020. https://development.asia/printpdf/insight/enhancing-urban%E2%80%93rural-connectivity-through-transport-hubs.

[5] Bulgakova E.A. Modern trends in the design of transport hubs in the infrastructure of a metropolis. Bulgakov, A.A. Savicheva // Eurasian Union of Scientists. - 2015. - No. 4 (13).
Булгакова Е.А. Современные тенденции проектирования транспортно-пересадочныхузлов в инфраструктуре мегаполиса / Е.А. Булгакова, А.А. Савичева // Евразийский союз ученых. – 2015. – № 4(13).

[6] The project "Development of decision-making mechanisms to increase the coverage and quality of public services (as a pilot in the transport sector of Absheron and Gobustan regions)." AzTU. January-April. 2021
"İctimai xidmətlərin əhatəliliyinin və keyfiyyətinin artırılması üçün qərarqəbuletmə mexanizmlərinin işlənməsi (pilot olaraq Abşeron və Qobustan rayonlarının nəqliyyat sektoru timsalında)" layihəsi. AzTU. Yanvar-aprel. 2021.

[7] GizemGunesh. Agent-based simulation and an example in anylogic. Yildiz technical university, industrial engineering department, İstanbul, 2014.

[8] Dashdamirov F.S. CREATION OF A SIMULATION MODEL OF BUS TRAFFIC IN URBAN ROUTES. ВІСНИК ПРИАЗОВСЬКОГО ДЕРЖАВНОГО ТЕХНІЧНОГО УНІВЕРСИТЕТУ. 2020р. Серія: Технічні науки Вип. 41. P.p.205-211

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Key Aspects of Formation of Transportation Planning Framework and Selection of Accounting Parameters of City Street-Road Network

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***Abstract*—The street-road network, which plays the role of the main transport-planning axes in the planning structure of the city, is of great importance. The street-road network is a part of the road system of a settlement, between the separate functional zones of the settlement, within these zones and (or) in other areas of the city, providing passenger and freight traffic. This study aims to determine the main aspects of the formation of the planning framework and selection of calculation parameters of the street-road network system, which provides a comfortable, uninterrupted, fast and safe transport connection with all functional zones, other settlements of the settlement system, suburban facilities during the design of settlements.**

Keywords—street-road network, transport-planning framework, general plan, satisfaction rate, average distance between settlements, calculated parameters, main characteristics of traffic, highways, city-wide avenue, middle line

I. FORMATION OF URBAN TRANSPORTATION PLANNING FRAMEWORK

The transport planning structure of the settlement is the main element of the functional planning structure of the city, settlement. When planning the development of settlements, balanced development of the area and transport networks should be ensured, the structure of the planned street-road network should provide the possibility of alternative routes of movement in the same directions.

Urban highways include streets and avenues within the administrative-territorial boundaries of cities, including public roads. The road network (urban highways) forms part of the urban area, the boundaries are defined by a red line (demarcated by urban planning documents and separating the territories of neighborhoods, neighborhoods, as well as other planning structures from streets and squares) and for the placement of traffic, pedestrians and greenery. It is intended.

The transport planning framework should be developed in conjunction with the transport system of the adjacent areas. The framework of transport and planning, the functional purpose of streets and roads, taking into account the architecture and planning, the organization and perspective development of areas, taking into account the perspective intensity of transport, pedestrians, bicycles, should be designed as a hierarchically integrated system.

It is necessary to approach the solution of transport problems in each city individually. The practice of one city may not be effective in another. In this case, local conditions and the already established planning structure must be taken into account. The planning structure determined by the configuration of the street-road network of each city is individual and depends on the historical development features of the city, the location of the main attractions in the plan, the terrain, the presence of water barriers in the city, etc. depends.

Transport issues should be prepared on the basis of strategic or precise design, future urban transport scenarios should be taken into account in detail during the preparation of the city's Master Plan, and a comprehensive approach to the city's future transport system should be formed. The solution to the problem of transport planning will determine the appearance of the city in the next 100 years and the basis for solving transport problems. If proper transport planning is carried out today, each of these projects will play a key role in the future, even if they are not implemented in the coming years.

When designing a street and road network in cities, the level of automation (current and projected), as well as the distribution of displacements by private and public vehicles (existing and projected) should be taken into account. Adequate traffic capacity of the road network and transport junctions should be provided based on the projected level of automation for the approximate period.

The number of cars coming to the city from other settlements and transit traffic flows should be determined by calculations based on the number of permanent and temporary residents, the number of jobs, the number of expanding and suburban settlements towards the city and the expected level of automation.

When designing a street network of a settlement, priority conditions should be created for the development of public passenger transport and conditions should be created for safe cycling or walking. Bicycle traffic must be provided in residential, public and commercial, industrial and recreational areas.

The network of streets and roads in the settlements should be formed taking into account the following expectations for the estimated period [1]:

- ☑ estimated (project) number of permanent residents and temporary travelers;

- ☑ the number of jobs created by individuals and legal entities, taking into account transport requirements;
- ☑ taking into account the volume of daily movements in compliance with safety requirements;
- ☑ Ensuring accessibility of facilities and areas for various functional purposes in accordance with the norms.

The assessment of transport-planning factors takes into account the overall assessment of the degree to which the nearest area of the city is provided with transport communications. This includes a feature of the transport element, such as "provision of the area" and its following indicators: the availability of one or another type of transport, its class, the width of the road impact zone and the time spent on one way.

In planning, the transport availability of the center and sub-centers has a significant impact on the surrounding areas and characterizes these areas by the degree of satisfaction. The degree of satisfaction depends on the time of arrival at the district centers.

Our observations have identified the possibility of efficient and accessible use of the road network by people if satisfactory zones are distributed over the following optimal distances [1,2]:

- ➢ Up to 10 km from I-II class highways;
- ➢ Up to 5 km from III class roads;
- ➢ Areas located up to 2 km from IV class roads.

Limited-satisfactory zones:

- ✓ Up to 25 km from I-II class highways;
- ✓ Areas located up to 12.5 km from III class roads.

Areas outside these zones are considered unsatisfactory.

It is suggested to use formula (1) to determine the average distance between settlements.

$$\mathbf{P=\sqrt{S/N}} \quad (1)$$

Here: P - average distance (km); S - area (km²); N - number of settlements.

In typical conditions, the area of a conventional settlement is 2000 km², and when the number of settlements is 50, $P = \sqrt{2500/100}=5$ km. Thus, the average distance between settlements in the administrative district will be 5 km. At the same time, it should be noted that the calculated average distance does not fully take into account the complex relief of the region, so the real distance will be slightly different.

However, this is one of the indicators of the compactness of the settlement and can be considered as a relatively positive factor in the deepening of economic, labor and cultural ties between the settlements.

The average distance between settlements characterizes these areas in terms of the degree of satisfaction of people's efficient and accessible use of the road network. The analysis revealed that over the past 20 years, there has been a significant increase in population in all areas of the local settlement system in major developed cities around the world and the development of satisfactory use of the road network in the context of intensive urbanization.

In addition to these and other factors, mathematical modeling should be used to determine the average radius of impact of a city on its surrounding settlements.

As a result of comprehensive analysis, it was determined that the degree of satisfaction with the efficient and accessible use of the street-road network (their radius of influence) can be assessed as an indicator of its relatively important role in the district settlement system and socio-economic development. The said radius of impact should be in line with the urban impact zone, which has been identified through the analysis of local labor and cultural migration. Limited and unsatisfactory zones will occur due to relatively weak traffic activity in the region and the existence of underdeveloped connections between settlements. At the same time, the limited and unsatisfactory level of efficient and accessible use of the road network will lead to relatively poor traffic activity and the development of underdeveloped connections between urban settlements.

In the context of intensive urbanization, it is necessary to calculate and take into account the prospective population of cities in order to determine the optimal displacement distances according to the degree of satisfaction of the efficient and accessible use of the street network.

The calculation of the prospective population of cities should be carried out by the component (cohort) method and the results obtained should be analyzed.

The component (cohort) method allows to obtain a more accurate forecast based on* the shift of sex-age groups. The method uses the demographic balance equation (2):

$$\mathbf{P_1 = P_0 + B - D + M_i - M_0} \quad (2)$$

Here: P_0 and P_1 - the number of population at the beginning and end of the year (period); B - number of births during the period; D - number of deaths during the period; M_i - arrival of migrants; M_0 is the departure of migrants. B, D, M_i and M_0 are called the components of population change [3].

In calculating the population of the city for the first time and for the reporting period, the author proposed to consider 3 options:

- high natural growth rate, very weak mechanical growth and perspective number in the conditions of negative mechanical growth - continuation of existing trends - inertia (extrapolation) scenario;

- a pessimistic (depressive) scenario with a relatively high natural growth rate and a perspective number of adverse mechanical action conditions;

- high natural growth rate and number of perspectives in conditions of positive mechanical growth - favorable dynamic scenario.

As a result of comparing all the options (scenarios) analyzed above, the project should select a dynamic (2-4%) scenario that is more suitable for the economic, social and demographic development of the city and its territories, and summarize its results. should be predicted.

The calculations for the above scenarios should be reflected in the determination of the optimal displacement distances in terms of the degree of satisfaction with the efficient and accessible use of the street-road network.

As a result of complex analysis, it was determined that the main characteristics of the demographic situation of cities for the forecast years are as follows:

- increase in the share of able-bodied population;

- faster population growth over the working age population;

*P.K. Whelpton, 1893-1964. bax: Bogoue D.J.Techniques for Making Population Projections: Age-Sex Projections. Chicago, 1980. P. 8. Reprinted in: Readings in Population Research Methodology. Volume 5. Population Models, Projections and Estimates. Chicago, 1993.

- reduction of the share of the population under working age;

- against the background of indicators of natural population growth, increase in longevity of the population and, as a result, increase in the average age of the population (observed);

- higher middle age of women.

These trends are mainly in line with changes observed around the world.

A comprehensive assessment of the urban area and urban planning analysis, as well as the optimal planning of the city's street network and the framing of the appropriate framework should be provided to identify the population potential for the future development of the city and identify problem planning situations that require optimal urbanization measures [4,7].

The general architectural-planning composition of the city should be determined by the historical features of planning and construction, the nature of the development of transport communications, the natural conditions of the area (climate, rivers and ravines) and other development features of the city.

II. REQUIREMENTS FOR THE CITY TRANSPORT NETWORK

The street-road network of settlements should be designed as a continuous, uninterrupted and integrated system, taking into account the functional purpose of streets and roads, the intensity of traffic, bicycle and pedestrian traffic, the nature of the architectural-planning organization and construction of the area, as well as their development characteristics.

The urban transport system depends on the city they serve, the location of its population and buildings, the terrain, social conditions, etc. should form a unity. The whole complex of planning, socio-economic, demographic, climatic and other characteristics of the city must be taken into account when forming the urban transport network [5].

The design of the street and road network of the settlement should be carried out as follows [5]:

- as part of general plans prepared within the general territorial planning of the territory of the country or territorial parts (regions, district territorial units) (administrative centers of the district);
- as part of the transport part of the general plan of the settlement;
- as part of programs for integrated development of transport infrastructure of settlements and urban areas;
- as part of spatial planning projects, including general and detailed spatial planning projects that provide for the location of the road transport system or several transport infrastructure facilities;
- while developing project documents.

At the same time, the solution of transport issues is based on the principle that different modes of transport should be developed not in isolation from each other, but in parallel and interconnected, and serve to ensure the movement of the population. No transport route should be limited to a single point without performing a logical function and should not transfer traffic to a small street network in the city. A transport route should not be completed without establishing a logical and physical connection. Failure to address this issue leads to transport chaos in these areas and, as a result, necessitates the creation of road junctions at various levels, as a result of which tens of hectares of this valuable urban area are occupied by transport facilities, and transport problems remain.

Roads connecting cities and individual district centers, national and local roads (roads directly connecting villages and settlements with cities and district centers) and measures for their development in the territory of the country and (or) territorial parts (regions and) district territorial units) should be taken into account and defined in the general plans prepared at the level.

Highways of cities, settlements and individual district centers, city-wide avenues, streets and roads, district avenues, streets and roads, inter-settlement and village roads and measures for their development should be taken into account and defined in the master plans of these settlements.

Streets and roads of settlements, villages, as well as roads in the neighborhood (except for roads owned by the municipality) and measures for their development should be taken into account and defined in the detailed plans of these settlements. Measures for the development of district and local importance, as well as municipal roads opened for public use and their development should be included in spatial planning schemes.

Motorways within the territory of municipal highways or municipalities (except for international, republican and local highways, city, branch and private highways), as well as local roads of cities and regional centers, as well as in the territory of villages and settlements and owned by municipalities Streets, crossings, other roads and road facilities and measures for their development should be included in the spatial planning documents ordered by municipalities

All streets and roads of the road network determined by the detailed plans of settlements shall be determined by general plans and general plans, and all streets and roads belonging to the road network determined by general plans shall be determined by general plans of those settlements (regions, administrative and district territorial units). It should be taken into account, coordinated and planned in accordance with all measures and development directions related to the planned and defined road transport network [7].

The following requirements are set for the city's transport network:

- ❖ coordination of passenger and cargo flows with the capacity of the transport network;
- ❖ Optimality of the movement of the rolling stock between the regions with mutual transport connection and the minimum amount of time spent by the population on transport;
- ❖ minimum construction costs;
- ❖ Minimum traffic accidents and related costs.

Depending on these requirements, transport planning solutions based on tangential-circular and rectangular (rectangular-diagonal) urban transport planning schemes should be considered in the design of cities, except for historically formed, previously formed and formed transport schemes. During the design of settlements, traffic must be bypassed from the center, sharp angles and complex transport junctions must not be allowed to complicate urban construction and limit the capacity of the transport network.

Table 1.

STREETS AND ROADS

CLASSIFICA-TION OF STREETS AND ROADS	Rate and distribution of streets and roads	The main characte-ristics of street and road traffic	Functional purpose of streets and roads
MAIN HIGHWAYS	I	high speed and continu-ous move-ment	- provides high-speed and uninterrupted transport links between public and business and residential areas located far from large and very large cities; - connects suburban public roads, urban areas, as well as airports and seaports, railway stations, reserves and recreation areas, as well as provides access to large recreation areas (recreation areas) and settlements in the settlement system; traffic is high-speed, unobstructed and uninterrupted, provides high-speed traffic and high traffic capacity; it is prohibited to stop or stop vehicles on the carriageway; - Entrances of vehicles are provided through road junctions of different levels built at streets and road crossings, as well as there are no crossings at the same level as pedestrian lanes. Pedestrian crossings are organized at different levels, outside the carriageway. Intersections are provided at different levels on different levels of streets and roads; with the exception of separate locations or where temporary rules are established, there are separate lanes for traffic in opposite directions, and between these parts there is a demarcation line or other means, except in exceptional cases.
	II	Adjust-able move-ment	- provides transport connections between the districts of the city, access to the surrounding highways; - pass outside the living space. Movement is regulated; - access roads for vehicles through intersections and road junctions are organized not more than 300-400 m; movement is allowed for all modes of transport; - Intersections with roads and streets of different degrees are organized at the same or different levels; - provides services to surrounding and adjacent buildings through side or local crossings; - pedestrian crossings are organized at the same and different levels with the carriageway.
URBAN CITY SIGNIFI-CANT AVENUE	I	Continu-ous and sustain-able move-ment	- transport links between residential, public-business and industrial zones and public centers within the boundaries of large, large and very large cities and with them and other main streets, urban and suburban public roads, as well as other avenues with highways in the city and connects roads between streets; - provides uninterrupted and continuous traffic flows in the main direction; organizes the main transport communications providing high-speed communication in the populated areas of cities; provides access to highways, provides services to surrounding and adjacent buildings through side or local crossings; movement is allowed for all modes of transport; pedestrian crossings are organized at different levels along the carriageway; - provides traffic (including entrances) through road junctions of different levels, as well as road junctions of the same level built at the intersections with other streets.
	II	Adjust-able move-ment	- provides transport links between residential areas, industrial (industrial, scientific-production, utility-warehouse) zones and the city center, the centers of planning areas; - provides access to public roads outside the city. Movement is regulated; - movement is allowed for all modes of transport; the organization of a special lane for the unimpeded movement of public ground passenger transport with appropriate justifications is allowed (including for the movement of special purpose, ambulance, emergency and rescue vehicles); - Intersections with roads and streets of different degrees are organized at the same or different levels; - pedestrian crossings are organized at different levels with the carriageway, and at the same level with the carriageway with the application of traffic lights.
URBAN STREETS AND ROADS	-	Adjust-able move-ment	- ensures the connection of roads within the city boundaries between residential areas and public centers, as well as between highways and other avenues and streets in the city, connecting different districts of the city, as well as different residential areas of the city; - traffic is regulated or traffic is organized through unregulated intersections (traffic is self-regulating); - movement is allowed for all modes of transport; - the organization of a special lane for the unimpeded movement of public surface passenger transport with appropriate justifications is allowed (including for the movement of special purpose, ambulance, emergency and rescue vehicles); pedestrian crossings are organized at the same and different levels with the carriageway.
DISTRICT IMPORTANT AVENUE	-	Adjust-able move-ment	- provides transport and pedestrian connections within the settlement areas, access to other main streets, transport connection with avenues and streets of city-wide significance located within the district, as well as access to inter-district and city-wide avenues, streets and roads; - traffic is regulated or traffic is organized through unregulated intersections (traffic is self-regulating); - traffic is allowed for all modes of transport, intersections with other streets are basically at the same level; - pedestrian crossings are organized at the same and different levels with the carriageway.
DISTRICT IMPORTANT STREETS AND ROADS!	-	Adjust-able move-ment	- provides transport and pedestrian connections and access to city-wide streets and roads within the boundaries of the residential area, within the settlements; - traffic is regulated or traffic is organized through unregulated intersections (traffic is self-regulating); - traffic is allowed for all modes of transport, intersections with other streets are at the same level; - pedestrian crossings are organized at the same level as the carriageway.
ROADS BETWEEN SETTLE-MENTS AND VILLAGES	-	-	- provides transport and pedestrian connections and access to city-wide streets and roads within the boundaries of the residential area, within the settlements; - traffic is regulated or traffic is organized through unregulated intersections (traffic is self-regulating); - traffic is allowed for all modes of transport, intersections with other streets are at the same level; - pedestrian crossings are organized at the same level as the carriageway.
	streets and local roads in residential areas	-	- transport and pedestrian connections in the areas of residential areas (micro-districts), access to the main streets of the district (streets and roads) and regulated streets and roads, as well as transport and pedestrian traffic within settlements and villages, micro-districts and other residential areas, direct access to buildings and areas provides.

STREETS AND ROADS OF SETTLEMENTS, VILLAGES, AS WELL AS NEIGHBORHOOD ROADS			- pedestrian crossings are organized at the same level as the carriageway.
	in public-business zones public streets and roads	-	- within settlements and villages, micro-districts and other residential areas, between public centers, departments and enterprises, service enterprises, as well as trade, office and administrative buildings, public service facilities, educational and scientific institutions (organizations), etc. provides transport and pedestrian connections within settlements and villages, micro-districts and other residential areas for access; - pedestrian crossings are organized at the same level as the carriageway.
	streets and roads in production areas	-	- provides transport and pedestrian connections within production zones (industrial, scientific-production, utility-warehouse) and territories, as well as for access to these zones and territories; - pedestrian crossings are organized at the same level as the carriageway.
	pedestrian streets and squares		- Landscaping, which is part of the street-road network, intended for pedestrian traffic and recreation, providing safe and high comfort for pedestrians. - provides pedestrian connections of high pedestrian attraction (collection) points. - traffic of all modes of transport is excluded. - access of special purpose vehicles (ambulance, emergency and rescue vehicles) is provided.
	park roads		Ecologically clean vehicles, bicycles, as well as special purpose vehicles (including cleaning equipment and vehicles, ambulance, emergency recovery, rescue and law enforcement activities to serve the park and forest-park area and users of these areas) for) are roads designed for movement.
	Passageways: -basic -secondary		These are roads that provide access to vehicles for residential and public buildings, offices, enterprises and other facilities of urban buildings within districts, micro-districts and neighborhoods.

Protected natural, historical and cultural monuments (ancient buildings, cemeteries, paleontological, archeological objects, mounds, objects of special interest to the local population, etc.), as well as unique natural phenomena (special geological forms, water sources, protected) are protected in the construction zone of the highway. natural heritage, etc.), the application of special engineering solutions for the protection of these facilities must be ensured.

In order to ensure the rational use of the road-transport system, the possibility of traffic should be provided with a gradual increase (decrease) in the indicators of street classifications used [8]:

- ☑ accesses (entrances) to the local street-road network from the neighborhood areas should be provided;
- ☑ access (entrances) from streets and roads of local importance to avenues of district significance, streets and roads, avenues of district significance, avenues of citywide significance from streets and roads, streets and roads, as well as to highways;
- ☑ accesses (entrances) from the street-road network of the settlement (including city highways) to other public highways and from other public highways to the street-road network of the settlement (including city highways) must be provided. Under the conditions of reconstruction, entrances (exits) to streets and roads of different functional importance (level) should be in accordance with the above hierarchy, and if necessary, additional development of streets and roads with low classification indicators (low level) should be provided.

When designing a street-road network in settlements, parking lots of buildings, engineering and technical facilities, as well as relevant structural elements (carriageway, sidewalks, bicycle lanes, public transport) necessary for the construction, operation, repair, maintenance and protection of the road structure itself , taxi parking lots, parking lots, water supply and protection facilities, bathtub and road shoulder, decorative greenery).

When designing a street-road network of a settlement, based on the requirements of the current normative acts, streets and roads with all classification indicators and objects located along the streets and roads must be accessible for people with limited mobility, pedestrian safety and unimpeded movement of pedestrians.

(*)- The classification of urban highways in the Republic of Azerbaijan is determined on the basis of "Classification indicators of highways in the Republic of Azerbaijan" approved by the Resolution of the Cabinet of Ministers of the Republic of Azerbaijan No. 91 dated July 1, 2004.

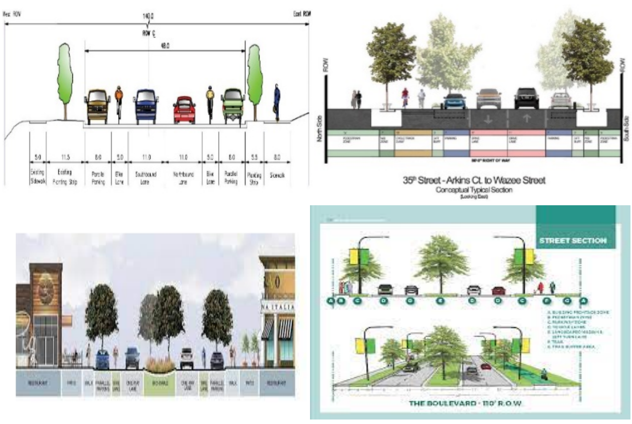
III. CLASSIFICATION OF CITY STREETS AND ROADS. PLANNING AND ACCOUNTING PARAMETERS

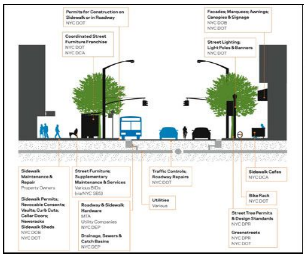
Urban highways are classified as follows for the importance of traffic and accessibility (*):

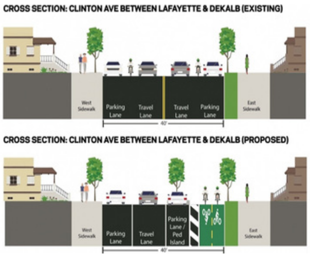
1. highways;
2. avenues, streets and roads of citywide importance;
3. avenues, streets and roads of regional significance;
4. roads between settlements and villages;
5. Streets and roads of settlements, villages, as well as roads within the neighborhood (except for roads owned by the municipality).

When preparing spatial planning documents and planning settlements, highways, city-wide and district avenues, streets and roads, inter-settlement and inter-village roads, as well as streets and roads of settlements, villages, as well as neighborhood roads should be identified as part of the street-road network. The main planning indicators of streets and roads are determined depending on the calculated speed. When designing streets and roads of different importance in settlements, the calculated speed should be determined in accordance with Table 2. The determination of the geometric parameters of the street and road should be carried out taking into account the calculated vehicles moving on the street or road in question [9-13]. The calculation of streets and roads of very large, large and large cities should be adopted in accordance with Table 1.

Figure 1.







Depending on the planning structure, accessibility, feasibility and administrative significance, urban highways (streets and roads) are divided into technical grades according to different indicators in Table 2 for very large, large and large cities, and according to different indicators for medium and small cities. The following key indicators related to the street and road network should be identified within the area planning projects: number and width of the carriageway, number and width of lanes, width of sidewalks, locations of public passenger parking lots, vehicles and other elements of the street-road network system , including places for placement of technical means of traffic organization, as well as elements of landscaping and landscaping. When designing streets, it is not recommended to take the carriageway larger than four lanes. If an expensive large number of lanes are required, they should be divided into two free-lanes, for example, the main one for public transport and the additional one for local transport. As the number of lanes increases, the efficiency of the carriageway decreases: in terms of throughput, one lane is lost in the case of a four-lane carriageway, and two lanes in the case of a six-lane carriageway.

Table 2.

Rate and distribution of streets and roads	Calculated speed, km / h	The width of the lane, m	Number of lanes (total in the direction of interaction)	The smallest radius of curves (with / without twist), m	The largest longitudinal slope, ‰	The smallest radius of the vertical convex curve, m	The smallest radius of the vertical depression curve, m	The smallest width of the sidewalk, m	The height of the curb from the carriageway), cm	Width of streets and roads between red lines, m	Width of dividing strips, m				
											Central separator	Between the main moving part and the local or side passages	Between the carriageway and the tramway line	Between the carriageway and the sidewalk	Between the side walk and the tram way line
Highways															
I	130	3,50-3,75	4, 6, 8, 10	1200/1900	40	21500	2600	-	-	50-100	6,0 2,65*	-	-	-	-
	110			760/1100	45	12500	1900								
	90			430/580	55	6700	1300								
II	90	3,50-3,75	4, 6, 8	430/580	55	5700	1300	-	-	50-80	5,0 2,65*	3,0	-	-	-
	80	3,25-3,75		310/420	60	3900	1000								
	70			230/310	65	2600	800								
Citywide avenues															
I	90	3,50-3,75	4, 6, 8, 10	430/580	55	5700	1300	4,5	20-25	40-100	6,0 2,65*	-	3,0	-	-
	80	3,25-3,75		310/420	60	3900	1000								
	70			230/310	65	2600	800								
II	80	3,25-3,75	4, 6, 8, 10	310/420	60	3900	1000	3,0	18-22		4,0 2,65*	3,0	3,0 2,0	3,0	2,0
	70			230/310	65	2600	800								
	60			170/220	70	1700	600		15-20						
Streets and roads of citywide importance															
-	70	3,25-3,75	4, 6, 8	230/310	65	2600	800	3,0			3,5	3,0			1,25
	60			170/220	70	1700	600		12-15	40-80	2,65*	2,0	1,0	3,0	-1,5
	50			110/140	70	1000	400		3-12		1,5-2	1,5-2	-	1,5	-
Avenue of regional importance															
-	70	3,25-3,75	2, 4, 6	230/310	60	2600	800	2,25	12-15	20-60	3,5	-	-	2,0	-
	60		2, 4	170/220	70	1700	600							-	
	50			110/140	70	1000	400		10-15	20-40	1-1,5				
Streets and roads of district importance															
-	60	3,25-3,75	2, 4, 6	170/220	70	1700	600	2,25	3-12	20-40	2-3,5	-	1,0 -	1,5-2 -	1,25 -
	50		2, 4	110/140	70	1000	400	2,0		15-40					
Roads between settlements and villages															
-	70	3,25-3,75	2, 4	230/310	60	2600	800	1,5	15-20	15-40	2 -	-	-	1,5-2 -	-
	60	3,25-3,5		170/220	70	1700	600								
Streets and roads of settlements, villages, as well as roads in the neighborhood															
streets and local roads in	50	3,0-3,5	2, 4	110/140	80	1000	400	2,0	3-12	15-30	0,75-1	-	1,0	0,5-1	1
	40			70/80	80	600	250				-		-	-	-
	30			40/40	80	600	200		3-10		-			-	-

residential areas															
park roads	40	3,0	2	75	80	600	250	-	3-10	Per a project	-	2 -	1,0 -	0,5-1 -	1 -
Passageways: -basic	40	3,0	2	50	70	600	250	1,0	3-10	Per a project	-	-	-	0,25-0,75 -	-
-secondary	30	3,5	1	25	80	600	200	0,75							
pedestrian streets and squares	-	by calculation	by calculation	-	50	-	-	Per a project	-	Per a project	-	-	1,0 -	-	-
in public-business zones public streets and roads	50	3,0-3,5	2, 4	110/140	80	1000	400	2,0	3-12	15-30	1-1,5 -	-	-	0,5-1 -	-
	40			70/80	80	600	250								
	30			40/40	80	600	200		3-10		-			-	
streets and roads in production areas	50	3,5	2, 4	110/140	60	1000	400	2,0	15-25		1-2 -	-	-	1-1,5 -	-

Note:

1. Prices for new construction are given in Table 2, and the denominator is given for dense and reconstruction conditions.

2. It is allowed not to build a central dividing strip or to accept the width of the strip less than the values indicated in the table, provided that the calculated speed of traffic does not exceed 70 km / h on highways and city-wide avenues with regulated traffic in dense and reconstructed conditions.

3. It is allowed to build a left-turn lane on the streets of city-wide and district significance, where traffic is regulated, by reducing the width of the central dividing strip.

4. * - Taking into account the installation of protective devices.

The width of streets and roads is determined by calculation, taking into account the requirements of sanitary-hygienic and civil defense, depending on the intensity of traffic and pedestrian traffic, the composition of the elements located within the transverse profile (roadway, technical lanes for laying underground communications, sidewalks, greenery, etc.). is done. In the conditions of reconstruction of streets and roads of settlements, villages, as well as roads in the neighborhood, as well as when the calculated pedestrian traffic in both directions is less than 50 people / hour, it is allowed to build sidewalks and sidewalks with a width of 1 m [8].

It is recommended that the width of sidewalks on city-wide avenues, streets and roads be at least 3 m, unless other technical solutions are provided for the placement of short-term snow accumulations in climatic zones with frequent icing, in areas with a snow depth of more than 200 m / m [9].

The width of the designed streets and roads should be determined by calculations based on their classification (including rates), including the purpose and urban conditions, traffic and pedestrian flows, composition and number of transverse profile elements (including areas for engineering networks), red lines and s. should be taken into account. The cross-sectional profile of the street network and the number of lanes should be determined based on the expected hourly peak traffic. Typical cross-sectional patterns are shown in Figure 1.

If there are buildings of the same type on both sides of the street, the cross-sections should be designed symmetrically. In the case of one-sided residential or public buildings, it is allowed to arrange an asymmetrical street profile (cross section) in terms of sidewalk design. At the intersections of the designed or reconstructed street-road network, the central axes of the roads in different directions should be placed symmetrically relative to each other. At intersections of the same level, the cross-sections of streets and roads must be symmetrical and of equal size (cross-sections).

It is recommended to make changes in the cross sections of streets and roads at the same or different levels of intersections. Transverse profiles of bridges, overpasses, piers and tunnels must be designed in accordance with the requirements of SNiP 2.05.03 and legislation.

Transverse profile elements of streets and roads of settlements may include the carriageway (including crosswalks, dividing lanes, parking lanes, lanes for stopping and stopping vehicles), sidewalks, bicycle lanes, central and side dividing lanes, boulevards. can.

The cross-sectional profile of the street-road network may include high-speed bus transport (metrobus-BRT) with a special lane, as well as electrified railway transport lines (trams, high-speed trams and surface parts of metro transport). Within the street-road network determined by these norms, separate lanes may be established for the movement of metrobus transport along their dividing lanes [10].

Separation strips should be provided to separate the individual elements of the cross-section of the street-road network, to separate adjacent carriageways, as well as to ensure the safety of road users and the environment. The minimum width of the dividing strips shall be taken in accordance with Table 2. Fences, landscaping and boulevards (taking into account the requirements of applicable building codes and relevant legislation) should be placed within the side and central dividing strips or a hard flat surface should be arranged.

Boulevards may be arranged on regulated highways (including city-wide and district-wide avenues) and on city-wide and district-wide streets and roads with a dividing strip of 6 m or more.

On main highways and avenues of city-wide importance, external safety lanes shall be provided on both sides of the carriageway between the carriageway and the curbstone (or fencing). The width of the outer safety lanes shall be determined depending on the type of fences adopted and the conditions of visibility, but shall not be less than 0.75 m [11].

IV. SPIRITUAL LINE PRINCIPLE WHEN LOCATIONS ARE ORGANIZED IN SPACE

Taking into account the existing (defined concrete) dimensions of traffic and pedestrian traffic, it is necessary to reserve underground space and area for perspective construction by gradually achieving the calculated dimensions of highways, city-wide and district avenues, streets and roads, road junctions.

The street network of settlements should be designed as a sustainable integrated system, and service areas should be interconnected with each other and with the city center. The reliability of the transport framework is ensured by the creation of recurring (alternative) routes for city-wide avenues, streets and roads.

The distances (distances) between the network of streets and roads of settlements, which determine the size of micro-districts and neighborhoods, should be taken as follows:

o 300-500 m for main streets in the areas where apartment buildings are located;

o 150-250 m for streets of local importance (depending on the specific urban situation).

Grade I-III highways should, as a rule, pass through residential areas with access roads built.

To ensure the future reconstruction of these roads, the distance from the edge of the landfill to the construction line of settlements should be not less than 200 m in accordance with the General Plan of settlements and General Plans and the width of the road to protect buildings from noise and harmful gases 10 m of green space should be provided [11].

If, on the basis of technical and economic calculations, it is considered expedient for roads of I-III classes to pass through settlements, their design should be carried out in accordance with the requirements of the normative documents in force. In cases where it is not possible to provide this condition, the degree and calculation indicators of roads within the settlements shall be determined in accordance with the requirements of these norms. If, on the basis of technical and economic calculations, it is considered expedient for roads of I-III classes to pass through settlements, their design should be carried out in accordance with the requirements of the normative documents in force.

I and II classes roads designed at a distance of about 50 meters from the settlements should have sound protection boards along the residential part of the settlement [11-12].

In case of impossibility to pass the existing and designed I-III classes roads outside the settlements, unimpeded operation of the street-road network of the settlement, connection of its territories, transport service, safety of the adjacent area and construction and ecological protection must be provided.

Based on feasibility studies, when different levels of roads pass through the territory of settlements, depending on the development prospects of the adjacent areas, these roads should be designed as urban highways or streets.

Figure 2.

Figure 3.

During the design of highways and city-wide avenues, their perspective expansion, management, repair, maintenance, protection and protection of the surrounding areas from various impacts of vehicles (environmental, noise pollution, etc.), from the edge of the main road to the border of buildings. the size of this area should be determined depending on the nature of the structures and the design speed, taking into account the presence of obstacles in the area and the limited territorial conditions.

The distance from the edge of the main carriageway of the highway to the line of regulation of residential buildings should be not less than 50 m, and in the case of the use of sound protection devices - not less than 25 m [13].

The distance from the edge of the main carriageway of the first-class city-wide avenues to the line of regulation of residential buildings shall be not less than 30 m, and in the case of application of sound protection devices - not less than 15 m.

The distance from the edge of the main carriageway of the avenues of city-wide importance of II class to the line of regulation of residential buildings shall be not less than 15 m, and in the case of application of sound protection devices - not less than 7.5 m.

The distance from the edge of the main carriageway, local or side crossings to the construction regulation line should not exceed 25 m. If the specified distance is increased, a 6 m wide strip suitable for the passage of fire engines, not closer than 5 m to the construction line, shall be provided [14].

When designing a settlement system (territory) consisting of low-rise residential buildings of new development areas in existing settlements or existing settlements, to provide opportunities for construction or repair, reconstruction, rehabilitation and perspective development of transport and engineering-communication systems, as well as healthy and safe people During the spatial organization of cities and other settlements for the purpose of ensuring the living environment, protection and restoration of the environment, residential buildings (including construction sites) shall not be located within the direct boundaries of the red lines of public roads and buildings. In this case, the yard areas of residential buildings (including construction sites) should form a border with public roads, and they should be located within the boundaries of adjacent land plots (along the boundaries of adjacent walls, diagonally or adjacent).

Figure 2 shows a typical urban planning option in the United States. Under this scheme, the houses are located in the center of the rectangular planning scheme, and the protection strips of the highways are provided by maintaining the appropriate distances from the street-road network.

Figure 3 shows the planning scheme of a new planned settlement in Azerbaijan. This architectural-planning solution is a traditional method and has a number of serious shortcomings. It is currently used in most developing countries. Under this scheme, the houses are located directly on the side of the highway along the boundaries of the red lines, which leads to the non-observance of environmental and sanitary norms, as well as completely limiting the possibility of possible expansion of the road in the future. Currently, there are serious difficulties in this regard.

In the new approach proposed by us, during the spatial organization of cities and other settlements, residential buildings (including construction sites) are located along the middle neighborhood line, directly beyond the red lines of public roads and buildings. From this point of view, this architectural-planning solution can be called the middle line principle. During the design of the settlement system with the application of this system, the construction or repair, reconstruction, rehabilitation and perspective development of transport and engineering-communication systems, as well as the provision of healthy and safe living environment, protection and restoration of the environment Adequate protection strip will be maintained between.

At the same time, as a result of the application of this architectural-planning solution, a green and wooded area is placed between the buildings (mainly residential buildings), which, unlike the traditional method, provides protection of human health and ecologically clean environment.

The proposed mid-line principle can be effective if the architectural-planning solution is applied in completely redeveloped settlements in the liberated areas.

REFERENCES

[1] Turnquist M.A., Bowman L.A. (1980), The effects of network structure on reliability of transit service. Transportation Research, Cilt 14(B), s. 79-86. Urban Transport Group (Pteg). (2014), “Bus Punctuality”, London, UK.

[2] ÇALIŞKANELLİ S.P., ÖZUYSAL M. (2019). Kentiçi otobüs sisteminin güvenilirliğini etkileyen faktörlerin incelenmesi. DEUFMD, 21(61), pp. 259-269.

[3] Trepanier M, Morency C, Agard B. (2009), "Calculation of transit performance measures using smartcard data". Journal of Public Transportation, 12(1), pp. 79–96.

[4] Tanyel S, Çalışkanelli S.P, Aydın M.M, Utku S.B. (2013), "Yuvarlak ada kavşaklardaki ağır araç etkisinin incelenmesi". Teknik Dergi, 24(4), pp. 6479-6504.

[5] Aimsun. (2017), Aimsun new features. https://www.aimsun.com/aimsun.

[6] Luhua S, Yin H, Xinkai J. (2011), “Study on method of bus service frequency optimal model based on genetic algorithm”. Procedia Environmental Sciences,10, pp. 869-874.

[7] Scottish Government. (2009), “Bus Punctuality Improvement Partnerships (BPIPs) Guidance”. Scottish Government, Edinburgh, Scotland, RR Donnelley.

[8] Lu X., Lee J., Chen D., Bared J., Dailey D., Shladover S.E. (2014), Freeway micro-simulation calibration: Case study using Aimsun and Vissim with detailed field data. 93rd TRB Annual Meeting, Jan. 12-16. Washington D.C.

[9] Liu, R., Sinha, S. (2007), Modelling urban bus service and passenger reliability. The Third International Symposium on Transportation Network Reliability (INSTR), Hague, Netherlands.

[10] Sterman B.P, Schofer J.L. (1976), Factors affecting reliability of urban bus services. Transport Engineering Journal, pp.147-159.

[11] Chingiz Rahimov, Azerbaijan Technical University, Candidate's dissertation - "Working out of scientific bases of systematic management of the quality of organization of passenger transportation in big cities".

[12] Chingiz Rahimov. (2017), Azerbaijan Technical University, “Logistical Solution of Passanger Transportation”, Scientific works, №4, İSSN 1815-1779.

[13] SP 42.13330.2011, Urban development. Urban and rural planning and development.

[14] SP 35.13330.2010. Database manufacturer's note. BUILDING REGULATIONS BRIDGES AND PIPES.

Investigation of the Protection System According to the Main Working Parameters of Electric Motors

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***Abstract*—The research work is devoted to the creation of a protection system for electric motors used in industry and transport, based on modern and traditional sensors. In the course of operation, the malfunctions of electric motors were investigated and it was found that the emergency modes occur mainly as a result of exceeding the permissible values of the current, voltage and temperature parameters. Modern sensors of current, voltage, and temperature were compared and the most effective ones were selected for use in electric motors. On the basis of these sensors, a protection system for a low-power electric motor was built in the laboratory. Also in the Multisim application software package, a simulation of the operation of the protection system at different voltage and current values is performed, a circuit of the sensor control unit and the power source for powering the protection system is constructed. It is proposed to apply such a multi-parametric complex protection system for electric motors specially in transport.**

***Keywords*—electric motor, short circuit, overload, current sensors, relay control, protection system**

I. INTRODUCTION

In industry, transport and various fields of technique asynchronous, synchronous and collector alternating current machines are widely used. Currently, it is used more than asynchronous machines that work in motor mode.

In connection with the development of static converters, the capabilities of induction motors have significantly increased. In this regard, the possibilities of using these motor in electric transport are considered more effective. Modern vehicles mainly use a short-circuit rotor asynchronous motor as an electric motor.

As in all electrical machines, there is always a high probability of occurrence of abnormal and accidental regimes, injuries on induction motors. Therefore, the working process and operating parameters of induction motors especially in railway transport, operating in difficult working conditions should be constantly monitored.

One of the most important issues to increase the efficiency and durability of vehicles, power supply system is to provide reliable and accurate control of its electrical parameters, optimal protection against voltage, current and other parameters in case of emergency operation.

Thus, as a result of the research, it was determined that the application of modern electronic sensors to control the technical condition of electric motors can provide a more reliable mode of operation.

It is known that the increase in load for one reason or another during the use of electrical equipment leads to the failure of the device, and at best, to the damage to the elements of the electrical circuit of the device. Faults of electrical origin occur as a result of the effects of short-circuit currents, electric arcs and sparks, reduced insulation resistance and other causes. This shortcoming requires more funding and worker from operating companies.

In recent years, significant research has been conducted to develop new methods to monitor the technical condition of electric motors, to overcome the shortcomings of traditional methods. The incidence of motor failures or abnormal modes increases with the complexity of its operating mode, and therefore there is a need to create more sensitive and modern protection systems based on the results of additional failures and the results obtained.

Only the temperature parameter is used to conduct diagnostic monitoring of traction electric motors operating in railway transport, produced by a number of leading companies in the world. The results of the research show that the temperature parameter alone does not provide complete and perfect information about the technical condition of the motors and a number of parametrs need to be added to these parameters in row in order to obtain more accurate results. For this reason, complex diagnostic monitoring of electric motor and the creation of multi-parameter proection systems based on it is actual [1].

II. STATEMENT OF THE PROBLEM AND SELECTION SUBSTANTIATE OF SENSORS FOR MULTI-PARAMETER PROTECTION SYSTEM

The technical condition of electrical equipment is carried out primarily by checking the level of reliability and parameters. It is possible to create more reliable and sensitive protection systems due to the information obtained as a result of diagnostic monitoring of the technical condition.

In order to ensure more stable working conditions, it is necessary to take into account the characteristics of the effect of caution and reliability indicators in the motors on the uninterrupted operation of the power supply system associated with this unit.

Suppose two identical motors are used as a backup in a system. If one of them fails, the other motor will run at full system load. The breakdown intensities of the motors are the same and constant, $\lambda = \lambda_1 = \lambda_2 =$ 0,0005 1/s. In this case, it is necessary to determine the exponential law of the probability of proper operation of the motor at t = 400 hours.

Since the motors are of the same type, the probability of a malfunction is as follows:

$$P_{sis}(t) = 2e^{-\lambda_1 \cdot t} - e^{-2\cdot\lambda_2 \cdot t} = 2 \cdot e^{-0{,}0005\cdot 400} - e^{-0.0005\cdot 400} = 0{,}9671 \quad (1)$$

According to the data, the average operating time of the system is calculated as follows:

$$T_O = \frac{1}{\lambda}\left(1+\frac{1}{2}\right) = \frac{3}{2}\cdot\frac{1}{0{,}0005} = 3000 saat \quad (2)$$

In order to increase the probability of proper operation of the electric motor, it is necessary to ensure that it is switched on and off and that the operating modes are protected from leaps in transition process and possible accidents.

Acute voltage fluctuations, current overloads, short circuits, temperature changes, etc. in such cases, the establishment and application of a multi-parameter protection system to prevent equipment, source and loads failures is of particular importance.

During operation of electric motors, non-standard and possible emergency cases can be divided into the following groups:

- Abnormal and accident modes occurring in the network (voltage above and below the nominal value, frequency change, etc.)

- Non-standard and accident situations related to the current (interphase short circuits in three-phase motors; breaks in the stator or rotor windings; overload or short-circuit currents etc. perforation of insulation due to temperature rise caused by)

Special protection devices are developed and applied to protect motors from damage in unacceptable and emergency modes. As it is known, a short-term decrease in voltage leads to a decrease in the torque of electric motors used in transport. After the voltage is restored, the motor restores its torque and returns to the nominal operating mode. In this case, the value of the current required by the motor increases sharply, which, in turn, can lead to the activation of the protection. The setting parameters of the protection installed in the electric motor should be selected so that the protection does not start and turn on the motor circuit when the short-term voltage drops. For this, special attention should be paid to the selectivity of the security system.

In addition to the current and voltage parameters, one of the other main parameters that must be protected is the operating temperature of the windings. It is unacceptable to increase the temperature in the windings. If the operating temperature of the motor windings exceeds the +10°C heat limit for any period of time, the insulation of the stator and rotor windings is reduced by half the service life.

It is known that, there are plenty of sensors based on various physical effects to control the values of current and voltage: resistive, inductive and capacitive sensors based on Ohm's law; transformer sensors based on Faraday's electromagnetic induction law; voltage and current sensors based on the Holl's effect, and traditional voltage and current sensors based on other effects [2-5].

At the same time, there are modern sensors based on the application of Rogovsky winding, electro-optical and magnetic-optical effects for non-contact measurement of high voltages and currents.

Resistors, transformers and Holl-effect sensors are mainly used to measure the electrical parameters of modern locomotives used in railway transport.

Resistive sensors are simpl and economical, the principle of operation is based on the direct proportion of the voltage across the reference resistor connected in series with the load in the current circuit (Ohm's law), can be used to measure direct and alternating currents.

The external appearance and connection diagram of the widely used different types of current sensors are shown in Fig.1, and the constructive and principle diagram of the voltage sensors are shown in Fig. 2.

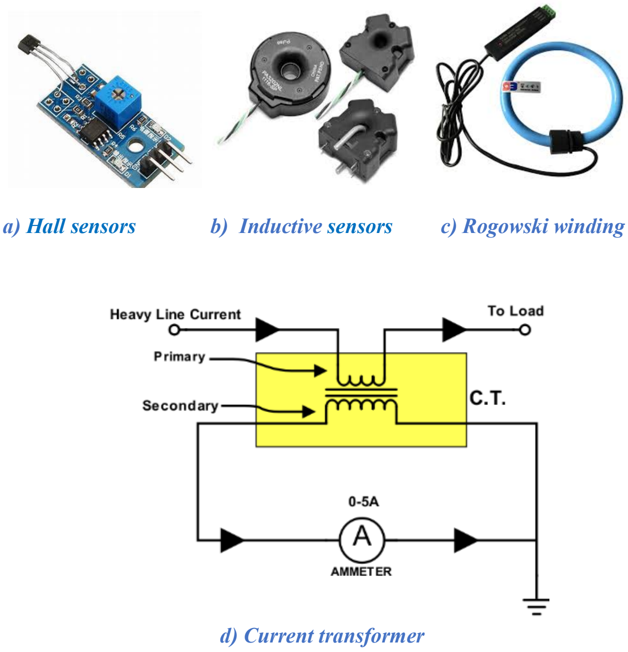


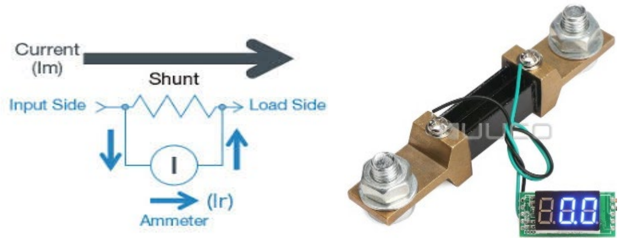
Fig. 1. Constructive and principle scheme of current sensors

In the laboratory, a current transformer was used to control the current value in protection system designed for a low-power asynchronous motor. In high-power motors, the introduction of the Ragowsky windings is considered to be more promising than the current sensors [6].

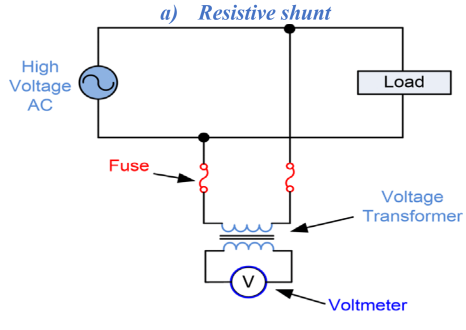
Voltage sensors based on electrical, electro-magnetic, electromechanical, electro-thermal, electro-optical and other similar physical effects are widely used in theoretical and practical researches.

The measurement procedure, the selection of the appropriate type of sensors is determined by the type and level of voltage. It is important to amplify the signals in order to record low voltages in the measurement circuit, and to reduce the received signals to an acceptable level at high voltages [7-9].

Voltage dividers (resistive, capacitive and inductive), voltage transformers, electronic voltage sensors, etc. are more widely used as voltage sensors (Figure 2).



a) Resistive shunt



b) Voltage transformer

Fig. 2. Constructive and principle scheme of voltage sensors

The use of voltage transformers for measuring high voltages is considered more expedient.

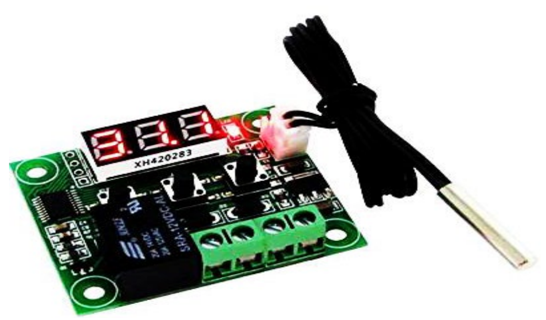
A resistive divider was used to control the voltage value in the protection system designed for the low-power electric motor. The resistive divider is considered simpler and technically more economical.

Voltage transformers are often used as voltage sensors in high power motors. Due to the large dimensions of voltage transformers, it is more expedient to use a resistive shunt and a resistive divider as a voltage sensors, where possible [10, 11].

Several methods are used to measure temperature. These include fiber-optic temperature sensors, electrical resistance thermometers, thermographic methods, thermocouple-based temperature sensors, etc. (Fig. 3).

As a contact temperature sensor for determining the temperature value in high-powered motors, the thermocouple is considered more suitable.

The main advantage of a thermocouple-based module sensor is the transmission of a signal with a direct relay output. Based on the signal received from the sensor, it is possible to both protect the motor and perform diagnostic analysis of the recorded data, as well as set up special alarm systems by displaying the data on special displays. Thanks to this, it is possible to ensure more reliable and stable operation of the motor.



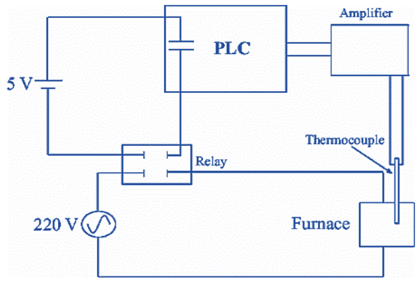


Fig. 3. Constructive and principle scheme of temperature sensors

Experiments were carried out on the electric motor according the three important parameters mentioned above and a protection system based on automatic control with relay output was installed. The operation of the relay is determined by the electrical signal received from the sensors. Based on the electrical signals, in any abnormal and emergency situation the relay motor which is controlled by the protection system is disconnected from the mains. MLE00137 of type relay was used to protect the motor (Fig. 4).

This type of relay is distinguished by its compactness, large process switching capabilities, start-up speed, etc. This relay is able to provide normal operation when the supply voltage of the working winding is in the range of 6-15V.

III. MAGNETIC FIELD MEASUREMENT AND OUTPUT SIGNAL ANALYSIS

In laboratory conditions, an experimental stand on the basis of a low powerful motor has been developed to simulate malfunctions that may occur in motors and control the changes that occur in electrical parameters.

One of the most modern and promising methods for diagnosing motor malfunctions and building a protection-warning system based on this, is the measurement and spectral analysis of the magnetic field.

The results of the analysis show that the defects and malfunctions in the electric motor have a significant effect on the spectrum of the electromagnetic field generated outside it. By continuously monitoring the magnetic aura of the motor in working condition, it is possible to determine the change of a number of parameters and create special protection and warning systems based on the results obtained. For example: overload, increase and decrease of voltage, change of current frequency, etc.

In researchs, the use of a Hall sensor as a sensor that allows non-contact diagnostics without interfering with motor design has been preferred. Thus, this sensor can be considered one of the most informative sensors that allows you to assess the condition of the motor by monitoring the electromagnetic spectrum.

In experimental research, the use of KY-024 Hall sensor, which is less sensitive to external influences, was preferred. The connection scheme and design structure of these types of sensors are given in Figure 4.

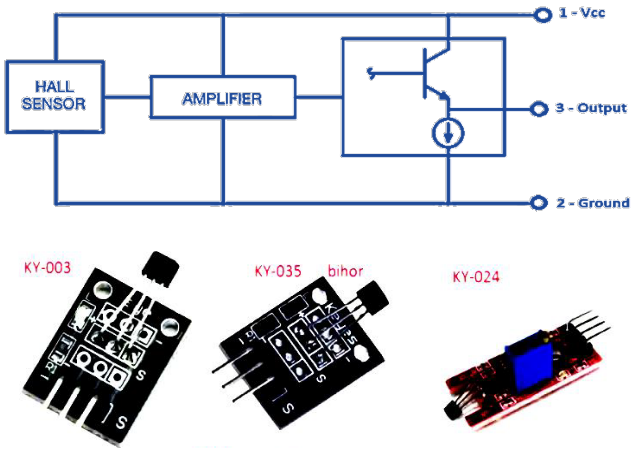


Fig. 4. Traditional connection scheme and constructive descriptions of Hall sensors

The recorded oscillograms of the magnetic field change in different modes of the electric motor studied using the KY-024 sensors are given in Figure 5.

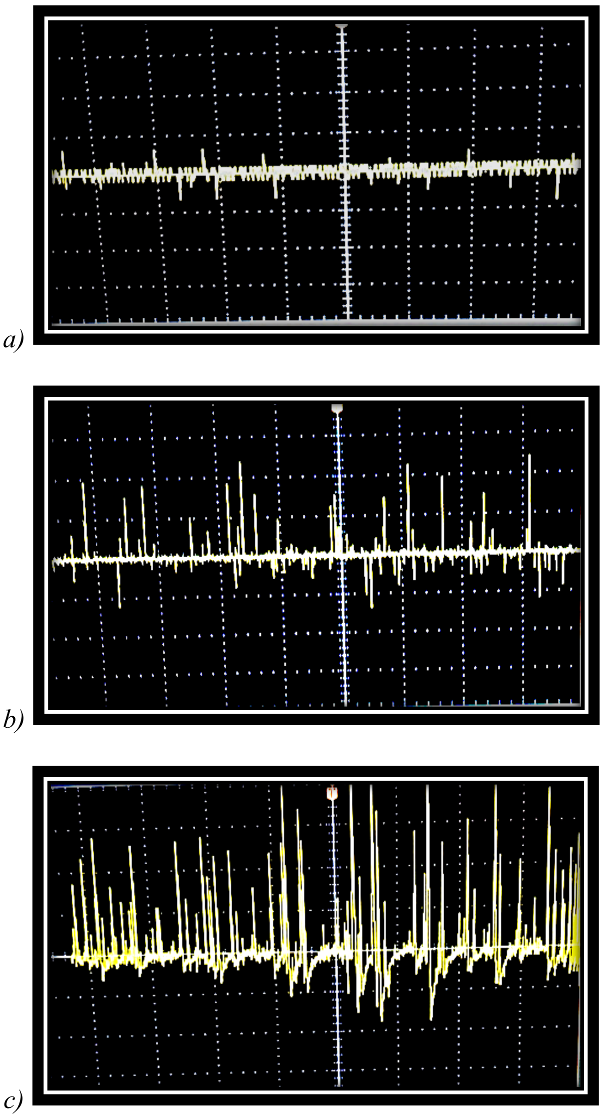


Fig. 5. Oscillograms of the motor magnetic field: a) at standstill; b) in normal operation; c) in overload

As can be seen from the analysis of oscillograms, in normal, failures or defects, overload and etc. conditions, the magnetic field around the electric motor changes with big difference. Thus, on the basis of the recorded data, it is possible to create a modern protection-warning system by diagnosing the motor and at the same time analyzing the signals at the output of the sensor [1].

IV. MODELING OF MULTI-PARAMETER PROTECTION SYSTEM

In reality, the development and implementation of a working version of the system that can perform the above functions is accompanied by many technical problems. Therefore, since modern applications are more accessible for individual and complex simulation of functions, it is more expedient to develop an imitation model of the system through these programs. This, in turn, allows the creation of a working model based on an imitation model of the system in research and production facilities, which allows you to design a real prototype of the system. In our research, based on the Multisim program, an imitation model of the device was developed, which provides protection against short circuits, overloads, as well as drop of voltage and overvoltage in the phase of the motor powered by an electric power source.

Relay control is applied at both high and low voltage limits at specified values. In the Multisim program, the protection circuits are built and modeled according to the voltage limit. Schematics of protection activation at normal, high and low voltage values are shown in Figure 6, Figure 7 and Figure 8. When the green LED is turning on indicates that the voltage is within the normal range. In abnormal modes, red LED in turning on and indicates that the mains voltage has exceeded the allowable limit.

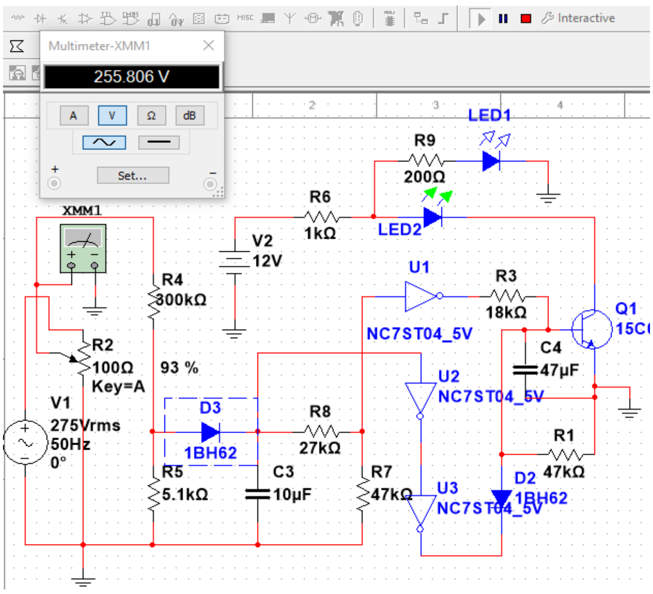


Fig. 6. Electrical circuit of the protection device at the range of normal operating voltages (168-260V)

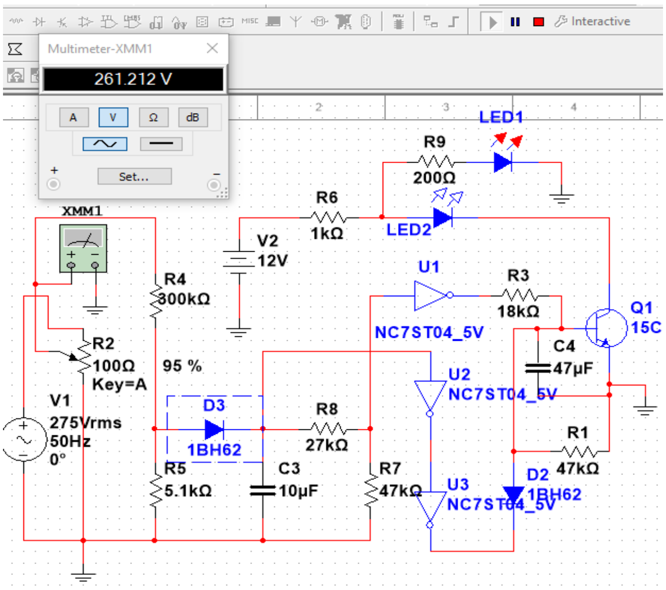


Fig. 7. Electrical circuit of the protection device at the value of the voltage above the nominal (U_{in} > 260V)

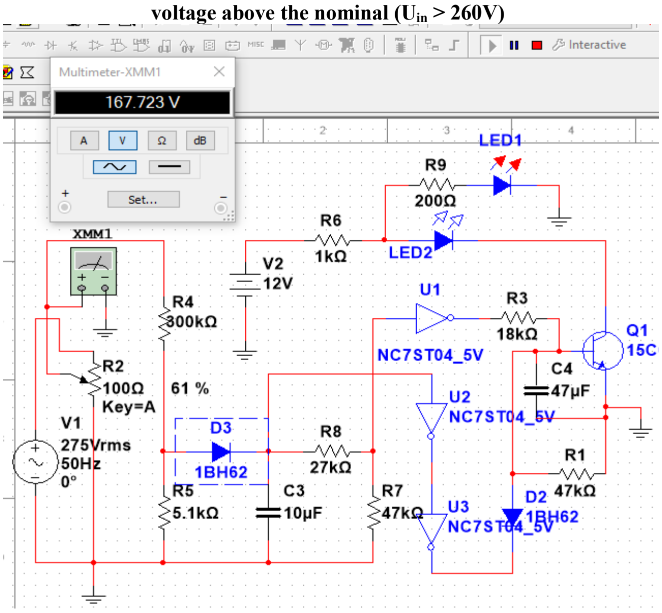


Fig. 8. Electrical circuit of the protection device at a voltage low the nominal value (U_{in}<168V)

The current protection ensures the opening of the motor from the food source by activating the relay at the limits of the current above the specified values. To simulate the current protection in Multisim, a resistive shunt-based protection scheme was used and the change of the current in the intended range was immobilized, giving an adjustable voltage to the input of the scheme.The simulation results for the current performed in Multisim are given in Fig 9 and Fig 10.

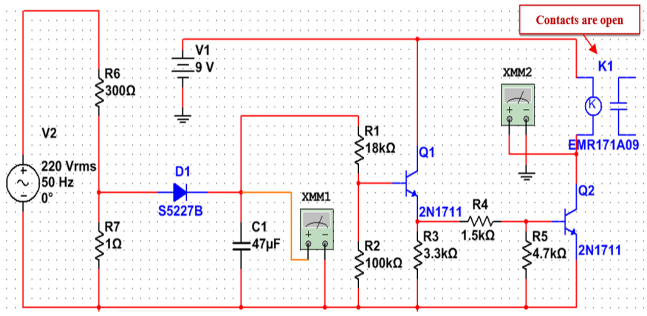


Fig. 9. Electrical circuit of the protection device at the nominal value of current

The rated motor current is 0.55A at 220V. In our case, the critical value of overloading, the minimum value of the current required for the protection of operation, is 0.9A.

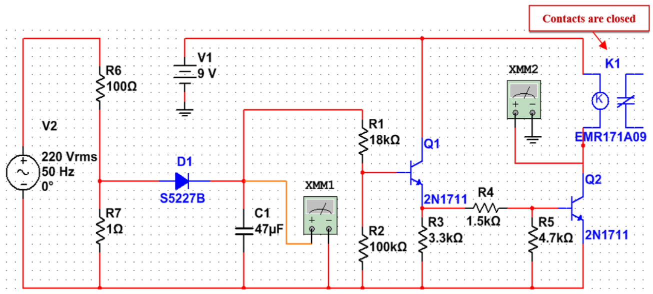


Fig. 10. Electrical circuit of the protection device during emergency operation (short circuit or allowable price overload)

Built on the logic elements of the protection system, a second transformless unit was developed to provide the nominal 5V and 9V supply voltages required to power the electronic control unit for voltage limits, transistor control unit for current limits, temperature protection unit and output relay unit.

An autotransformer was used to obtain a controlled voltage value in laboratory conditions.

As mentioned, the second power supply of the unit is for power supply of voltage and current, as well as the control unit of temperature control sensors and the protection system according to these parameters. On the basis of the transformerless power supply circuit for power supply of the protection system, the input voltage is 170 - 275V, the output voltage is 5.1V, the relay circuit is 7.5 - 12V, the total current required by the parametric stabilized power supply is 40-65mA. Since there is no autotransformer in the MultiSim software base, the regulated voltage is supplied to the circuit via a potentiometer.

For sufficient load capacity of the power supply, it is possible to use a transistor in the output circuit of the stabilizer as an amplifier. Since the base-emitter junction of the transistor has a voltage drop of 0.7 - 0.8V, a stabilitron with a stabilization voltage of 5.6 - 5.7V should be selected to provide 5V at the output. For the selected stabilitron to operate in stabilization mode, its current in the range Ist = 3 - 50mA, as well as the current of the base circuit and stabilitron together can be selected 10 - 15 mA, taking into account that the rated voltage of the transistor is higher than 50 and the current at the output of the transistor is less than 100 - 200mA.

The type of relay, designed to replace the power chains of the selected relays and powerful analog motors, can normally operate at wide voltages (in this case 7 - 15V), the stabilization is not required for the relay power circuit. If necessary, the same stabilization scheme can be applied.

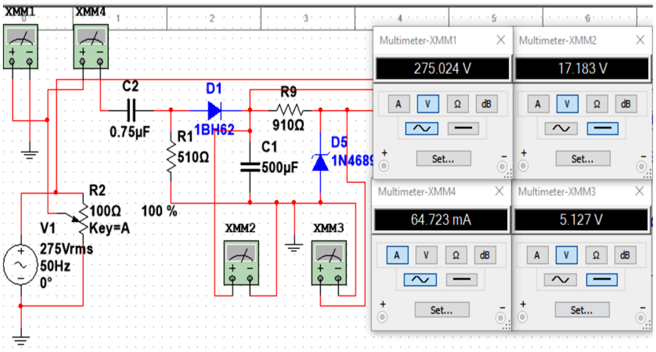


Fig. 11. Electrical circuit of the second power supply of the protection device

A protection system based on relay control was installed and experiments were performed on the motor to control the temperature parameter. The normal temperature of the motor windings is determined by the insulation class. Traction electric motors operated in the most modern locomotives used in railway transport are equipped with C-class insulation (200°C and above).

$$T_{open} \geq +38{,}5°C \;;$$
$$T_{norm} = 0 \div 38.4°C;$$
$$T_{rec.t} = 35.7°C \qquad (1)$$

- T_{open} – operating temperature of the protection system;
- T_{norm} – normal motor operating temperature;
- $T_{rec.t}$ – reconnection temperature;

In order to connect the protection system (opening the motor) in motor, which is the object of study, the temperature of the windings should reach T_{open}. These temperature values were conditionally taken for the experiments. To restore the operation mode of the motor started by means of protection, the temperature of the windings must be conditionally lowered to the reconnection temperature value $T_{rec.t}$. When the winding temperature cools down to normal operating temperature (that is, reconnection temperature), the relay restarts the motor.

A modular thermocouple based on a was used to determine the temperature of the motor windings. The input of the module is supplied with a constant supply voltage of 9V. The output terminals are similarly connected to the motor and relay. The thermocouple transmits the signal to the module, where it compares the opening temperature with the normal temperature and sends a pulse to the relay. The relay turns on the motor according to the received impulse or restarts the motor with protection.

A model of the complex protection system for voltage, current and temperature, developed in laboratory conditions, is shown in Fig. 12.

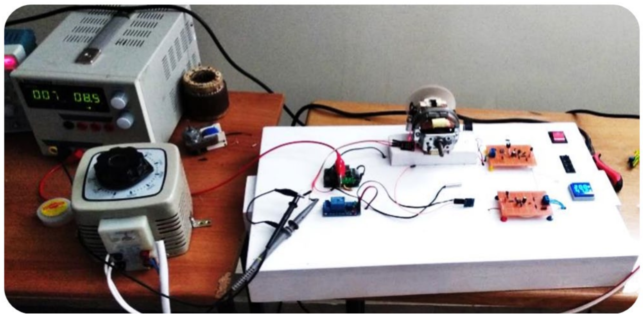


Fig. 12. Multi-parameter protection device developed in the laboratory

V. CONCLUSION

Thus, in the research, the faults of the electric motor were investigated and it was determined that the emergency modes occur mainly as a result of exceeding the permissible values of current, voltage and temperature parameters. Also, modern current, voltage, temperature sensors were compared and those with the best performance for use in electric motors were selected. According to the mentioned main parameters, the main control and power supply blocks of the protection system were analyzed in the Multisim application program and a model of the system providing complex protection in the laboratory was practically established.

At the same time, the use of LEDs as a signaling element, as well as limit elements in the control circuits of the lower and upper current limits, or as a component of the logic "OR" element in the proposed device has been found to have different advantages over other such devices.

Thus, based on theoretical and practical research, it can be said that it is possible to show the warning signals on the appropriate display by protecting the temperature, voltage and current of electric motors used in transportation and industry and transmitting also the results send to the relay control circuit and the central control station.

Using the modern sensors we offer, it is possible to ensure a stable operating mode of electric motors with the help of a complete multi-parameter protection system.

REFERENCES

[1] İsgəndərov İ.Ə, Manafov E.K, Hüseynov F.H. “Elektrik mühərrikinin elektrik parametrlərinə kompleks nəzarət üçün üsul və vasitələr”. *Azərbaycan Texniki Univerisiteti*, “Azərbaycan və Türkiyə univerisitetləri: təhsil, elm, texnologiya” I Beynəlxalq elmi-praktiki konfransın materialları, Bakı-2019, səh. 252-255. [In Azerbaijan: Isgandarov IA, Manafov EK, Huseynov F.H. "Methods and tools for complex monitoring of electrical parameters of the electric motor." Azerbaijan Technical University, Materials of the I International scientific-practical conference “Universities of Azerbaijan and Turkey: education, science, technology”, Baku-2019, p. 252-255].

[2] İsgəndərov.İ.Ə., Manafov.E.K, Hüseynov.F.H. “Müasir gərginlik və cərəyan vericilərinin elektrik təchizat sistemində tətbiqi perspektivləri”. Respublikanın 100 illiyinə həsr olunmuş “Fizika və Energetikanın aktual məsələləri” konfrans materiallar toplusu. Bakı-2018, səh.248-250. [In Azerbaijan: Isgandarov.I.A, Manafov.E.K, Huseynov.F.H. "Prospects for the application of modern voltage and current sensors in the power supply system." Collection of conference materials "Actual issues of Physics and Energy" dedicated to the 100th anniversary of the Republic. Baku-2018, p. 248-250].

[3] Fernando J. T. E. Ferreira. Single-Phasing Protection of Line-Operated Motors of Different Efficiency Classes. Ieee transactions on industry applications, 2018.

[4] R.Dickinson, S.Milano. Izolated Open Loop Current Sensing Using Hall Effect Techn. in Optimized Magnetic Circuit. Allegro MicroSystems, Inc.C.NH, USA, 2002, p. 1-12.

[5] Jianghua Feng , Junfeng Xu, Wu Liao and Yong Liu. Review on the Traction System Sensor Technology of a Rail Transit Train. Sensors 2017, p. 13-26.

[6] Данилов А.Б. Современные промышленные датчики тока. Современная электроника. М., 2004, №10, с.26-28. [In Russian: Danilov A.B. Modern industrial current sensors. Modern electronics. M., 2004, №10, p. 26-28.

[7] Bayrak, M. A New Digital Relay for Generator Protection Against Asymmetrical Faults, IEEE Trans. On Power Delivery, 2002, p. 54-59

[8] Jose, E.D., Roy, T.B., Chai, C., Yu, L. Stall Protection of Large Induction Motors, IEEE Transactions on Industry Applications, 1995, p. 1159-1166.

[9] Novak, T., Morley, A.L., Frederick, C.T., Sensitive Ground-Fault Relaying, IEEE Transactions on Industry Applications, 1988, p. 853-861.

[10] Paoletti, G.J., Rose, A., Improving Existing Motor Protection for Medium Voltage Motors, IEEE Transactions on Industry Applications, 1989, p. 456-464.

[11] Zocholl, S.E., Integrated and Protective Relay Systems, IEEE Transactions on Industry Applications, 1989, p. 889-893.

Digital Solutions for Digitalization of Non-Oil Exports

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Keywords—EU4Digital, Shipping, Cargo, e-commerce, digitalization, post service, creative industry, digital transformation, Azexport, Amazon, ebay, non-oil export

I. Introduction

At present, multidimensional reforms are being carried out in Azerbaijan. One of the important aspects of the Reforms is to support the production of export-oriented products and to provide easier access to new export markets. As a result of planned and wide-ranging reforms, Azerbaijan's export geography has expanded, and opportunities have been created for the delivery of manufactured products and services to traditional and new markets. At the same time, one of the priorities of the country's economy is the digital transformation of the economy. For this purpose, serious steps have been taken in digitalization by applying modern technologies in various fields. The broadband Internet network has been further developed to ensure the efficiency of the economy and public administration and information security. Widespread use of digital solutions such as G-Cloud, Smart City and Smart Village has begun. In order to systematize the digitalization process, President of the Republic of Azerbaijan Ilham Aliyev signed the "Decree on Improving Governance in the Field of Digital Transformation" on April 27, 2021. According to the decree, it is important to effectively coordinate the management of modern telecommunications and digital architecture in the country, as well as to develop a platform for digital services and solutions in various fields [1]. The export of products produced in Azerbaijan for the food, agriculture and creative industry (CI) to foreign markets is also supported through e-commerce platforms. Various state programs are being adopted and new projects are being implemented in this direction. In projects carried out by influential international organizations in the field is closely concerned. One of these projects is the EU4Digital project [2]. A digital warehouse was established within the scope of the EU4digital project to facilitate the export of products produced in the Republic of Azerbaijan to the European Union and Eastern Partnership countries via e-commerce platforms. This article examines the working principle of the automatic information exchange process created within the EU4Digital project for easier export of Azerbaijani products to the European Union and Eastern Partnership countries and offers suggestions for solving the problems.

II. Electronic solutions available for non-oil export in Azerbaijan

Today, 27.2% of the 7.8 billion people in the world, or 2.1 billion people, use e-commerce. Traditional commerce is rapidly replacing e-commerce. In some areas, e-commerce has completely surpassed traditional commerce. The interest in the field has had a positive impact on the development of e-commerce in our country. Strengthening Azerbaijan's position as a digital trading center, increasing access to new markets through e-commerce platforms and diversifying digital infrastructure are among the priorities of the state's economic policy. Many projects are being implemented to support e-commerce. One of the steps taken in this direction is the adoption of the Electronic Commerce Law in 2005. Then, the website Azexport.az was created according to Order by Mr. Ilham Aliyev, the President of the Republic of Azerbaijan about "Creation of a unified database of goods produced in the Republic of Azerbaijan" on September 21, 2016 [3]. As a result of the successful operation of the portal, the representation of entrepreneurs in international e-commerce platforms has increased more than 100 times and the representation of local products more than 500 times. During the operation of the portal, it received more than $ 2 billion worth of export orders from about 150 countries and provided them to entrepreneurs free of charge.

As a continuation of the reforms carried out for the development of the e-commerce sector, the Digital Commerce Center was established by the Decree of the President of the Republic of Azerbaijan dated February 23, 2017. The Digital Trade Center allows entrepreneurs to obtain all necessary permits by applying online for a single export application. Interest in e-commerce is growing in many countries around the world. E-commerce platforms account for 18% of global retail sales in 2020. In 2019, this figure was 13.6%. By the end of this year, 19.5% of retail sales are expected to be made through e-commerce. Azerbaijan is also experiencing growth in this field. Thus, 1.8 billion manats were paid in e-commerce in the first five months of 2021. This figure is 34.3% higher than the same period of the previous year. Also, in the first five months of 2020, e-commerce accounted for the largest share of non-cash payments at 52.9%. The statistics presented give us reason to say that the interest of the population in e-commerce is increasing. The increasing interest of consumers in the use of e-commerce platforms also directs manufacturers to this area. At the same time, the fact that most shopping centers and stores will be closed for some time from 2020 due to the coronavirus pandemic has had a positive impact on the faster development of e-commerce in Azerbaijan.

III. AUTOMATION OF INFORMATION EXCHANGE IN POSTAL SERVICES.

One of the fastest growing sectors of the world economy is the creative industry (CI). In developed countries, CI products make up 6 percent of the economy. This figure is expected to rise to 10-15 percent in the coming years. Approximately 50 percent of CI employees are women [4]. This has a positive effect on maintaining the gender balance in employment. Today, about 30 million people around the world work in the creative industry. Most of the people working in the field of CI are young people aged 15-29 [5]. In recent years, various studies have been conducted to study the impact of CI on the world economy, employment and social welfare in the categories of theater, fine arts, music, design, film, video and photography, advertising, games and creative technologies. According to the research, the UN document "UNCTAD Review of Creative Economy for 2002-2015" was published [6]. According to the document, the CI sector has grown at an annual average rate of 7.3 percent worldwide over the years. At the same time, exports of CI products and services have tripled. hus, this figure, which was 208 billion dollars in 2002, increased to 509 billion dollars in 2015. According to research in Germany, France, the United Kingdom and other advanced countries, CIs require less investment than other sectors of the economy and grow twice as fast. According to a report released by BMWI in 2019, 1.8 million people in Germany work in the field of CI [7]. Music, books and handicrafts stand out here as CI's most developed fields. Most countries adopt various strategic documents for the development of the sector. n Azerbaijan, concrete work has been done in this area, various support mechanisms have been established. The Azerbaijan Culture Development Indicators Report, prepared in 2017, is one of the key documents determining the share of CIs in the Azerbaijani economy [8]. According to the document, the share of CIs in GDP is 1% ($ 374 million for 2016).

As the people of Azerbaijan are a creative people, CIs are constantly evolving. Arts, music, handicrafts, literature, film, painting and other fields are widespread among the population. Taking into account the existing potential of Azerbaijan in this area, we can say that in the future CI participants have the opportunity to attract an additional $ 1-1.5 billion to the country. One of the mechanisms provided by the state for the development of CI products is the introduction of their products to foreign markets using modern digital infrastructure. For this purpose, CI products are posted on the Azexport.az internet portal. One of the main goals in the creation of the portal is the creation of a single database of products and services produced in Azerbaijan and their delivery to potential customers in foreign markets. CI products posted on the Azexport.az internet portal are integrated into platforms such as etsy.com, kickstarter.com, amazon kindle and sotheby's. Sales of CI products are mainly between B2C and C2C segments. This makes it necessary to transport these products by mail. One of the directions of the project implemented with the support of EU4Digital is the creation of a virtual warehouse between the European Union and the Eastern Partnership countries and the automation of information exchange in postal services. The project envisages long-term cooperation between the EU and the EU in the fields of communications, postal services, digital infrastructure, trade, security and the economy. The created digital market meets the most modern standards and works on the principle of one-time data entry only. When the order is received, the information entered by the seller is automatically transmitted by the system to the customs and postal authorities of both countries (buyer and seller). This allows orders to be processed more conveniently and faster. 44% of worldwide mail costs less than 25 euros and 86% weigh less than 2 kilograms [9]. Such transactions generally occur between buyers and sellers from the B2C and C2C segments**.** Such transactions generally occur between buyers and sellers from the B2C and C2C segments. The virtual warehouse project implemented by EU4Digital also aims to support buyers and sellers in this segment. There are many SMBs in Azerbaijan in this segment. The virtual warehouse project also plays an important role in the fast and safe delivery of food, industrial and creative cultural products. The virtual warehouse project also plays an important role in the fast and safe delivery of food, industrial and creative industry products.

IV. THE PROBLEM OF INTEGRATION INTO INTERNATIONAL PAYMENT SYSTEMS.

According to the State Program "Expansion of Digital Payments in the Republic of Azerbaijan in 2018-2020" approved by the Decree of the President of the Republic of Azerbaijan Ilham Aliyev dated September 26, 2018 and numbered 508, the application of new digital payment technologies was established in the country. But there are some factors that hinder the development of the sector. Thus, in the world practice, B2C and C2C products are mainly made to small individual orders and sold through platforms such as Etsy, Kickstarter, Sotheby's and Amazon, Amazon Kindle, Ebay, Alibaba. Payments for sales made through these platforms are made through payment systems such as Paypal, Payline, Google Pay, Apple Pay, 2Checkout. Payment systems listed in Azerbaijan work unilaterally (only for external payments). This makes it difficult to sell B2C and C2C products on European and American portals. Thus, in order to purchase a handmade souvenir, the customer must conclude a purchase agreement, draw up an invoice and pay by bank transfer to the account specified in the agreement. Some vendors use various methods to solve the problem indirectly. One of them is that the seller goes to one of the neighbouring countries and opens a bank account there, or opens a bank account in the name of a relative living abroad and connects Paypal, Apple Pay or other payment systems to this account. In this case, the value of the product produced in Azerbaijan is transferred to a foreign bank account.

V. RESULTS AND SUGGESTIONS:

B2C and C2C segments creates products that are more intelligent. In addition, this area is the most rapidly developing area in the world and has more immunity to digitalization. In Azerbaijan, the state and society pay special attention to CI. Throughout history, the people of Azerbaijan have been known as a nation distinguished by their creativity. The country's geographical location and the preservation of multicultural values have also had a positive impact on the development of the CI sector in various directions. Currently, the main problem hindering the development of the industry in the country is the one-sided operation of various high-speed payment channels such as Paypal, Payline, Google Pay, Apple Pay, 2Checkout. By solving this problem, it is easier to export Azerbaijani-made CI products to foreign markets through e-commerce platforms.

REFERENCES

[1] Decree of the President of the Republic of Azerbaijan on "Improving Governance in the Field of Digital Transformation", Baku, April 27, 2021, https://president.az/articles/51299

[2] https:// www.eufordigital.eu/countries/azerbaijan/;

[3] "Creation of a single database of goods produced in the Republic of Azerbaijan, Baku, September 21, 2016, https://president.az/articles/21139;

[4] https://www.britishcouncil.org/sites/default/files/gender_equality_and_empowerment_cci_eastern_partnership_2018_en-compressed.pdf;

[5] https://en.unesco.org/creativity/sites/creativity/files/info-kit_brochure-final-en-web.pdf

[6] https://unctad.org/system/files/official-document/ditcted2018d3_en.pdf;

[7] https://www.bmwi.de/Redaktion/EN/Publikationen/Wirtschaft/2020-cultural-and-creative-industries-monitoring-report.pdf?__blob=publicationFile&v=5;

[8] http://mct.gov.az/medias/media/other/285/hesabat-2016.pdf;

[9] https://index1520.com/en/analytics/elektronnaya-kommertsiya-i-ee-vliyanie-na-transevraziyskie-zh-d-gruzoperevozki/

Research and Development of a Mathematical Model to Assess the Characteristics of the Noise Immunity of the Information Exchange System

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***Abstract*—A mathematical model is proposed for evaluating the noise immunity characteristics of a coherent modem reception in a message transmission system that functions under the influence of unintended interference sources. The developed mathematical model takes into account the demodulator synthesis algorithm, decoding methods, effective M-ary Phase Shift Keying modulations and Reed-Solomon codes in the modem. Integrated expressions are obtained that evaluate the noise immunity characteristics of a modem receive, taking into account the energy performance of the receiver.**

Keywords—communication networks, corporate networks, multiservice communication networks, communication channel, data transmission rate, coherent modem, telecommunication networks, mathematical model

I. INTRODUCTION

Currently, the development of corporate multiservice communication networks, provided that the volume of the transmitted useful and service flows of traffic packets is intensively growing, requires the creation of a noise-resistant message transmission system using a coherent modem that ensures high reliability of transmission. The most important task in the development of modern messaging systems in multiservice telecommunication networks is to constantly increase their noise immunity under the harmful effects of various sources of interference and linear distortions in the communication channel [1]. It is known [2, 3] that with an increase in the data transmission rate via an noise-tolerant coherent modem, intersymbol interference, which leads to a deterioration in the quality of communication, plays an increasingly important role in the quality of their reception. Based on the study [3, 4], it was found that the main obstacles to solving this problem are the lack of adequate mathematical models of digital signal processing in these systems, as well as effective numerical methods for analyzing and optimizing the reception noise immunity characteristics.

Thus, the urgency of the reception noise immunity problem lies in the need to increase the reliability of traffic packet message transmission and develop algorithms for calculating communication quality indicators, as well as optimize these message transmission systems.

II. PROBLEM STATEMENT

A messaging system using a coherent modem has the means to control the transmission and quality of communication in order to evaluate them in an interference environment. As a consequence, this helps the coherent modem adaptively take noise protection measures in real time to transmit documentary and voice traffic in order to minimize the effect of interference sources. As a result, the time delay of the transmitted packet streams of useful and service traffic is minimized, which increases the efficiency of multiservice telecommunication networks in the provision of multimedia services. Further, it should be noted that intentional interference is organized, and the sources of various interference are random [5]. Taking into account the components of the receive noise immunity vector $R_{ny}(t, k_{nm})$ at time t and taking into account the modem transmission coefficient k_{nm} when exposed, intentional interference is functionally described by the following dependence:

$$R_{ny}(t, k_{nm}) = W[P_{BER}, SNR(E_b, k_{nm}), V_b, N_{nn}(t)], \quad (1)$$

where, $N_{nn}(t)-$ is a function that takes into account intentional sources of interference at a time t; $SNR(E_b, N_0)-$ S signal-to-noise ratio (SNR, Signal Noise to Rate) taking into account the energy of the bit signal E_b and the spectral density of the interference power N_0, which characterizes the complex indicators of the communication quality when using a coherent modem. Expression (1) describes the essence of the new approach under consideration, taking into account complex indicators of communication quality in the messaging system, on the basis of which a mathematical model (MM) for estimating the noise immunity of a coherent modem reception is proposed [5].

Describes and implements the proposed mathematical model for evaluating the noise immunity characteristics of the reception of a coherent modem of a communication channel working with discrete binary signals. In this reception model, we assume that in the information signal $u(t,b_i)$, some parameter $b_i, 1 \le i \le n$ carries information, and therefore, is a random process. In the proposed scheme, it is required to efficiently distinguish this parameter from $S(t,b_i)$ in the time interval $[0,T_c]$:

$$S(t,b_i) = b_i \cdot u_0(t) + (1-b_i) \cdot u_1(t) + N_{nn}(t),\ 0 \le t \le T_c \quad (2)$$

Expression (2) allows us to analyze the implementation of binary signals in the time interval $[0,T_c]$optimal [6], in the sense to reliably make decisions in favor of receiving $u_0(t)$ or $u_1(t)$. Thus, this scheme is an integral part of the task associated with noise-tolerant reception and processing of binary signals in a messaging system using a coherent modem.

III. PROBLEM SOLUTION

Now consider the description and construction of a mathematical model for evaluating the reception noise immunity. To solve this problem, an MM of reception noise immunity assessment has been proposed, which takes into account discrete signal reception methods, effective correction codes, and quadrature amplitude modulations in a message transmission system using a coherent modem. System-technical analysis showed [7, 8] that if the noise immunity depends on a number of random characteristics of the modem, then its quantitative measure may be the probability of disruption of the messaging systems. This probability is estimated by the average probability of erroneous reception of a discrete signal $E[P_{ош}]$ and is always a monotonic function of the signal-to-noise ratio at the receiver input:

$$E[P_{ош}] = F[SNR(E_b,k_{nm}),\ V_b], \quad (3)$$

where V_b − is the message bit rate.

The maximum value of the bandwidth of a coherent modem in a messaging system is determined as follows:

$$C_{\max}(E_b,V_b) = \Delta F_c \cdot \ell og_m[1 + SNR(E_b,k_{nm})], \quad (4)$$

where E_b- is the energy spent transmitting one bit of a discrete signal and is equal to

$$E_b = E_c / [R_k \cdot \ell og\, m],\ R_k = (k/n), \quad (5)$$

where R_k − is the speed of the Reed-Solomon code used and; ΔF_c − is the bandwidth occupied by the signal. From the expression (4) and (5) it can be seen that the main parameter that determines the maximum throughput and communication quality in the message transmission system are complex indicators of the signal-to-noise ratio and is found by the expression:

$$SNR(E_b,k_{nm}) = E_b \cdot V_b \cdot [\Delta F_c \cdot N_o]^{-1}, \quad (6)$$

Formula (6) characterizes the communication quality of a coherent modem and determines the ratio of signal power to interference power in a message transmission system. In addition, expression (6) is an energy indicator of the noise immunity of a reception and characterizes the use of a coherent modem in power. The condition in order to prevent a violation of the quality of communication in the message transmission system, taking into account the threshold signal / noise ratio $q_{пор}$, can be determined by the following inequality:

$$SNR(E_b,k_{nm}) \le q_{пор.} \le \min_{E_b}\{\alpha_{кр}[SNR(E_b,k_{nm})]\}, \quad (7)$$

where $q_{пор.}$ − is the threshold value of the signal-to-noise ratio and is the critical SIR with the help of the specified quality of the messaging system using a coherent modem:

$$q_{пор.} = \min_{E_b}\{\alpha_{кр}[SNR(E_b,k_{nm})]\}, \quad (8)$$

where α_{kp} − is a certain modem resource coefficient taking into account energy losses during processing of the received signal in a real transmission system compared to ideal reception conditions and is equal to $\alpha_{kp} \ge 1$.

To solve this problem, a MM has been developed for evaluating reception noise immunity in a messaging system using a coherent modem, a mathematical formulation that describes the following objective functions:

$$Q_P = W\{Arg \max_{E_b,k_{nm}} R_{ny}[SNR(E_b,k_{nm})]\}, \quad (9)$$

under the following restrictions

$$C_{\max}(E_b,V_b) \ge C_{\max}^{треб.}(E_b,V_b),\ P_{BER} \le P_{BER}^{треб.},$$
$$SNR(E_b,k_{nm}) \ge SNR(E_b,k_{nm}), \quad (10)$$

Expressions (9) and (10) determine the essence of the proposed new approach, with the help of which the MM of reception noise immunity estimates is constructed, taking into account indicators of communication quality, energy efficiency, modulation and coding methods. In addition, (9) and (10) are a simple analytical record of the noise immunity function of a message transmission system using a modem in assessing their quality of operation. Considering the above stated tasks, we consider the study and estimation of the probability of bit errors in the reception of discrete signals. Based on the model for evaluating the noise immunity of a reception and in accordance with the Neumann-Pearson criterion, the probability of receiving a discrete signal at the output of the DM and the indicators of the total power of intentional noise at the input of the receiver are taken as a characteristic of the noise immunity of the modem.

As a result of research [3], a formula was proposed for estimating the probability of receiving a discrete signal at the output of the demodulator:

$$P_n = 1 - \sum_{i=1}^{t} C_N^{N-i} \cdot (1 - P_{un})^{N-i} P_{un}^i , \qquad (11)$$

where P_{un} − is the probability of distortion of the message packet traffic when it is transmitted through the transmission system;

C_N^{N-i} – is a binomial coefficient from N to $N-i$, $t-$ the correcting ability of the Reed-Solomon code and taking into account the length of the code sequence N and the code speed is expressed as

$$t = 0{,}5N \cdot (1 - R_k) = 0{,}5(k + r)(1 - R_k) \qquad (12)$$

where R_k − is the speed of the Reed-Solomon code and is equal to $R_k = (k / N) < 1$ Here the polynomial $GF(N, k, d) = GF(32,\ 24, 4)$ was used, where $d_{\min} \geq (2t + \sigma + 1)$ called the minimum code distance, $\sigma = \sigma_{ou}$ – is the number of errors in the packet.

The total interference power p_{mn} at the receiver input is determined by the bandwidth occupied by the signal ΔF_c, the interference ΔF_n and the spectral density of the average external interference power N_n as follows [6]:

$$p_{mn} = \eta_{cn}(F) \cdot N_n \cdot \Delta F_n , \qquad (13)$$

where $\eta_{cn}(F)$ – is the coefficient of matching the interference and signal in frequency and is equal to

$$\eta_{cn}(F) = [(\Delta F_n) + (\Delta F_c)] / \Delta F_c , \qquad (14)$$

Given (13) and (14), and also taking into account that

$$[E_b / N_{mn}] = [P_c / P_{mn}] , \qquad (15)$$

then it is possible to determine the probability of a bit error for a coherent modem:

$$P_{BER} = \frac{1}{2} erfc\left[\frac{k}{N} \cdot \frac{E_b}{N_{mn}} \cdot k_{nm}\right]^{0,5}, \text{ at M=2}, \qquad (16)$$

where $erfc(x)$ – is an additional integral of the error function and is equal to: $erfc(x) = (2/\sqrt{\pi})\int_x^{\infty} \exp(-t^2)dt$, where k and N – are the characteristics of the Reed-Solomon error-correcting code (k – is the number of information bits in the packet).

The essence of using this method is that the graphical dependence is built according to the analytical formulas (14) using the BERTool environment.

As a result, the following numerical values were obtained: $SNR(E_b, k_{nm}) = [2,...,24]dB$, $V_b \leq (155,...,135)Mbs$, 2-PSK modulation scheme, $N = 32,\ d = 4,\ k = 24$, $R_k = 0{,}75$ reed-Solomon coding, and dependency P curves were plotted. As a result of the study, an approach to constructing an MM estimate of the noise immunity level of a coherent modem reception under the influence of unintended interference sources was proposed, taking into account the modem's energy performance, type of modulation manipulation, coding coefficient and bit rates. In the system of transmitting and receiving messages at the physical and channel level, a modulation scheme of the M-ary phase modulation M-PSK (M-ary Phase Shift Keying) type and Reed – Solomon code (RS) with polynomial $GF(N, k, d)$, $N, k, d-$ RS code parameters are used. In the system, the reed-Solomon codes used are among the cyclic codes with direct correction of error packets, described by a polynomial

$$GF(p^m) = GF(N, k, d),\ d = N - k + 1 \qquad (17)$$

System-technical analysis showed [3] that if the noise immunity depends on a number of random characteristics of the receiver, then its quantitative measure may be the probability of system malfunction. This probability is estimated by the average probability of erroneous reception of $E[P_{ou}]$:

$$E[P_{ou}] = F\{R_k, SNR[(E_b, k_E(V_b)],\ M, V_b\}, \qquad (18)$$

where R_k − is the speed of the Reed-Solomon code;

$SNR(E_b, k_{nm})$ – signal-to-noise ratio taking into account the energy of the bit signal E_b and the energy transfer coefficient k and is equal to

$$k_E(V_b) = (E_b / E_{in}) \leq 1, \qquad (19)$$

where E_{in} – is the energy of the bit signal at the input of the SF.

Considering the above, as well as (17) and (19), the mathematical formulation of the problem of the proposed MM assessment of noise immunity indicators in the telecommunication system is described by the following objective functions:

$$K_n(E) = W\{\underset{h_c}{Arg \min} E[P_{ou}(h_c^2)]\}, \qquad (20)$$

under the following restrictions

$$C_{\max} \geq C_{\max.\partial on.},\ P_{BER} \leq P_{BER},$$
$$\eta_{S\Im}(\Delta F_c) \geq \eta_{C\Im.\partial on.}(\Delta F_c), \qquad (21)$$

where $C_{\max}$ – is the maximum bandwidth of telecommunication systems in the provision of multimedia services; Probability of bit errors (BER, Bit Error Rate);

$\eta_{S\Im}(\Delta F_c)$ – is the spectral efficiency of telecommunication systems with incoherent reception, which characterizes the efficiency of using the bandwidth ΔF_c occupied by a binary signal; $C_{\max.don.}$, $P_{BER.don.}$, $\eta_{CЭ.don.}(\Delta F_c)$ –, respectively, the permissible value of the maximum throughput, the probability of bit errors and the spectral efficiency of telecommunication systems. In the structure, the demodulator (DM), the matched filter (SF), the amplitude detector (HELL) and the threshold device (PU) act as the optimal receiver. In the receiver, the receiver solves the problems of coordinated filtering and controls the number of correctly received bit elements. In addition, the circuit consists of a low-pass filter (LPF) block that cuts off high-frequency components, an electronic key that closes at time $t = T_c$. Further, after comparing the threshold value $\Pi(u_{1,0})$ of the PU, a decision is made in favor of hypotheses H_0, and H_1. Using the likelihood criterion, the threshold level is determined as follows:

$$\Pi(u_{1,0}) \underset{H_0}{\overset{H_1}{\gtrless}} \Pi(S) = \frac{p(u_1)}{p(u_0)}, \qquad (22)$$

In the case of equally probable signals, we have $\Pi_0 = 1$, and then the expressions for the relationship likelihood will take the form:

$$\ell n I_0(2S_1 / N_0) - \ell n I_0(2S_0 / N_0) \underset{H_0}{\overset{H_1}{\gtrless}} \frac{E_1 - E_0}{N_0}, \qquad (23)$$

Expressions (22) and (23) determine the structure of the optimal binary signal receiver with an unknown initial phase for incoherent reception. The binary signal at the output of the PF and SS represents, in fact, the energy of the discrete signal: {see P (0, 1)}

$$E_{0,1} = \int_0^{T_c} u_{0,1}^2(t)\, dt = E \qquad (24)$$

At time T_c, we give a comparison with the threshold $S(\Pi_0)$. Usually, in such cases, a threshold close to $(E/2) = S(\Pi_0)$. As a result of the study of MM, we consider the estimates of the average probability of an error in the reception of discrete signals. On the basis of the reception noise immunity estimation model with the likelihood criterion (23) and (24), a formula is proposed for estimating the probability of receiving a code packet at the output of a matched filter:

$$P_n(N, t_k) = 1 - \sum_{i=1}^{t_k} C_N^{N-i} \cdot (1 - P_{un})^{N-i} P_{un}^i, \qquad (25)$$

where P_{un} – is the probability of distortion of the packet message when it is transmitted through the system; C_N^{N-i} – is a binomial coefficient from N to $N - i$;

t_k – is the correcting ability of the R-S code and taking into account the length of the code sequence N and the code rate is expressed as

$$t_k = 0{,}5N \cdot (1 - R_k) = 0{,}5(k + r)(1 - R_k), \qquad (26)$$

where R_k – is the P-C code rate and is equal to $R_k = (k / N) < 1$. Here the polynomial $GF(N, k, d) = GF(127, 64, 7)$ was used, where $d_{\min} \geq (2t + \sigma + 1)$ – is called the minimum code distance, $\sigma = \sigma_{ou}$ – is the number of errors in the packet, k – is the number of information bits in the packet. Expressions (26) allows you to calculate the probability of packet loss on the recipient side, caused by various data distortions due to insufficient corrective ability of the code:

$$P_{nn}(t_k < t_{k.mp.}) = (k / N) \cdot P_{un} \cdot P_n(N, t_k), \qquad (27)$$

When using the modulation scheme $M - PSK$, the total power of intentional interference at the input of the receiver is adopted as a characteristic of noise immunity. The total interference power P_{cmn} at the input of the DM is determined by the bandwidth occupied by the signal ΔF_c and the interference ΔF_n and the spectral density of the average external interference power N_{cn} as follows:

$$P_{cmn} = \eta_{cn}(F) \cdot N_{cn} \cdot \Delta F_n + P_{ш}, \qquad (28)$$

where $\eta_{cn}(F)$ – is the coefficient of matching noise and signal in frequency and is equal to

$$\eta_{cn}(F) = [(\Delta F_n) + (\Delta F_c)] / \Delta F_c, \qquad (29)$$

Taking into account (28) and (29), the signal-to-noise ratio will have a complex form:

$$SNR(P_c / P_{cmn}) = E[B_c, P_{cmn}, \eta_{cn}(F), N_{cn}], \qquad (30)$$

where B_c – is the base of the complex receiving signal and taking into account the duration of the T_b bit is

$$B_c = T_b \cdot \Delta F_c = (1 / V_b) \cdot \Delta F_c, \qquad (31)$$

Given (27), ..., (31) and taking into account that

$$[E_b / N_{cmn}] = [P_c / P_{cmn}],$$

we determine the probability of a bit error for the system $M - PSK$ with $M = 2$ from the relation:

$$P_{BER} = \frac{1}{2} erfc\left(\frac{h_c}{\sqrt{2}}\right) = \frac{1}{2} erfc\left[R_k \cdot \frac{E_{in}}{N_{cmn}} \cdot k_E(V_b)\right], \qquad (32)$$

where $erfc(x) = 1 - erf(x)$ – is the residual error function and is equal to

$$erfc(x) = 2(\pi)^{-0,5}\int_x^{\infty}\exp(-\delta^2)\,d\delta \cdot$$

Using a graphical environment, BERTool calculates and builds BER graphs for a given range of $SNR(E_b, N_0)$. Based on the model, summarized in the form of noise immunity characteristics P_{BER}, taking into account the modulation scheme M-PSK and code R-S will take the following form:

$$P_{BER} = (\frac{2}{\ell og_2 M})\cdot Q\left[2\ell og_2\frac{k_E(V_b)}{(k+r)}\cdot k\cdot\frac{E_{in}}{N_{cmn}}\cdot\sin^2(\pi/M)\right]^{0,5}, \quad (33)$$

where $Q(x)-$ is the Gaussian error integral and is equal to $Q(x) = 0{,}5[1 - erf(x/\sqrt{2})]$.

For the modulation scheme $M-PSK$ and the R-S code with correction of error packets, the average error probability can be expressed as follows:

$$E[P_{ou}] = \frac{1}{N}\sum_{\sigma_{ou}=t+1}^{N}\sigma_{ou}\cdot C_N^{\sigma_{ou}}\cdot(P_{BER})^{\sigma_{ou}}\cdot(1-P_{BER})^{N-\sigma_{ou}}, \quad (34)$$

Expressions (33) and (34) determine the noise immunity for incoherent reception, taking into account the indicators P_{BER}, the parameters of the P-C code, and the modulation $M-PSK$ under the influence of interference. Thus, the analysis and development of a model and methods for calculating the noise immunity indicators of transmission system paths, processing and receiving traffic packet messages based on the development of the architectural concepts of NGN and FN requires the study of individual and complex indicators of the reliability of the system in corporate communication networks.

CONCLUSION

The proposed MM takes into account indicators of communication quality, spectral efficiency, a modulation and coding scheme when providing multimedia services to users. Based on the study, it was found that the use of an M-PSK type modulation scheme and a Reed - Solomon code optimizes the process of transmitting packet messages, minimizes the bit error rate for a given signal / noise ratio, and restores lost packets without additional re-requests using lengths of code and information sequences. Based on the study of the model, the results obtained allow us to achieve improved accuracy in evaluating the noise immunity characteristics of the reception and improve the quality of the receiver with incoherent reception.

REFERENCES

[1] Bollinger J.G., Duffie N.A. Computer Control of Machines and Processes.-Addison-Wesley, 2005.

[2] Roslyakov A.V., Vanyashin S.V. Future Networks. Samara: PSUTI, 2015. 274 p.

[3] Ibrahimov B.G., Ismaylova S.R. The Effectiveness NGN / IMS Networks in the Establishment of a Multimedia Session // American Journal of Networks and Communications. Vol. 7, No. 1.2018. pp. 1-5

[4] Tikhvinsky V.O., Koval V.A., Bocechka G.S., Babin A.I. IoT / M2M Networks: Technology, Architecture, and Applications. M. 2017. 320 p.

[5] Sergienko A.B. Digital signal processing. SPb.: Peter, 2015, 604 p.

[6] Ryndin A.A., Khaustovich A.V. Design of corporate information systems / publishing house "Quart" 2013. Voronezh.

[7] Goncharov O.N. Guide for senior management personnel. M. MP "Souvenir", 2007. 207c.

[8] Kulgin M. "Technologies of corporate networks", 2009.

[9] İbrahimov B.G. The Effectiveness NGN/IMS Networks in the Establishment of a Multimedia Session / B.G.İbrahimov, S.R. İsmaylova // American Journal of Networks and Communications. - 2018. Vol. 7, № 1, - p.1-5 (View Record in Scopus, Google Scholar).

[10] Ibrahimov B.G. Analysis performance multiservice telecommunication networks with using architectural concept future networks. / B.G. Ibrahimov, R.T. Humbatov, R.F. Ibrahimov // T- Comm, – Moskow: - 2018.vol.12, no.12. p. 84-88.

[11] Michael P.F. Fundamentals of Communications Systems. Communications Engineering. / P.F. Michael. - New-York: McGraw-Hill Companies, - 2007. 436 p.

[12] Morozov E. Weak regeneration in modelling of queueing processes // Queueing Systems, - 2004. № 46, p. 295–315.

[13] Schlegel C.B. Trellis and turbo coding. / C.B. Schlegel, L.C. Perez, - Chichester: John Wiley & Sons, - 2004. 393 p.

[14] Zadorozhniy V. N. Optimizing Uniform Non-Markov Queueing Networks/ V.N. Zadorozhniy // Automation and Remote Control, - 2010, Vol. 71, No. 6, p. 1158–1169.

[15] Zhang-Shen R., McKeown N. Designing a fault-tolerant network using valiant load-balancing/ R.Zhang-Shen, N. McKeown // Conf. publ. the 27-th conf. on computer communications, - IEEE INFOCOM, 2008, p. 2360–2368.

Localization of Leak Locations in a Complex Pipeline Network of Fluid Transportation

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***Abstract*—An inverse problem for a pipeline network of complex loopback structure is solved numerically. The problem is to determine the locations and amounts of leaks from unsteady f low characteristics measured at some pipeline points.**

Keywords—pipeline network, leak, optimization, inverse problem, unsteady f low.

I. Introduction

The features of the problem include impulse functions involved in a system of hyperbolic differential equations, the absence of classical initial conditions, and boundary conditions specified as nonseparated relations between the states at the endpoints of adjacent pipeline segments. The problem is reduced to a parametric optimal control problem without initial conditions, but with nonseparated boundary conditions. The latter problem is solved by applying first-order optimization methods [1]. Results of numerical experiments are presented.

This paper differs from many other studies [2] in which leak locations and amounts were determined either in a steady f low regime in a pipeline of complex structure or in a transient f low regime in a pipeline consisting of a single linear segment [3-5]. In this study, we numerically solve an inverse problem [6] of determining leak locations and amounts in an unsteady f low in a pipeline network of complex (loopback) structure[7-9]. The problem is described by a system made up of numerous subsystems of two hyperbolic partial differential equations with impulse actions specified at possible leakage points on pipeline network segments.

Another feature of the problem is the assumption that, due to the long duration of the process under study, exact information on its initial state is not available at the time of monitoring and that the states of the process (which is distributed in space) cannot be quickly measured at all points [10]. Instead, there is information on a variety of possible initial states of the process and some state (regime) characteristics are measured at certain pipeline points starting at this time. One more feature of the problem is that its boundary conditions are specified as nonseparated relations (determined by physical laws) between the states at the endpoints of adjacent pipeline segments..

II. Statement of the Problem

To simplify presentation of numerical schemes and to be specific, let us consider the pipe network, containing 8 segments as shown in figure 1. Numbers in brackets identify the nodes (or junctions). The set of nodes we denote by I : $I = \{k_1,...,k_N\}$; where $k_i, i=\overline{1,N}$ are the nodes; $N = |I|$ is the numbers of nodes in the network. Two numbers in parentheses identify two-index numbers of segments. The flow in these segments goes from the first index to the second (for example, the flow in the segment (1,2)

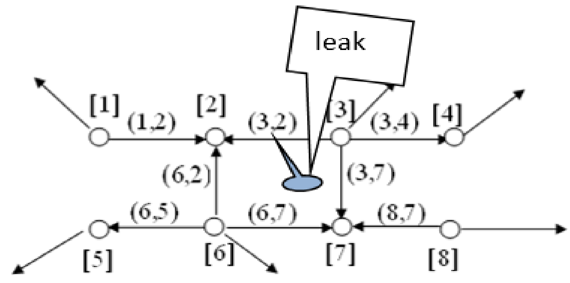

Fig.1 The scheme of pipe network with 8 nodes

is obviously from the node 1 to node 2.

Let J : $J = \{(k_i,k_j): k_i,k_j \in I\}$ is the set of segments and $M = |J|$ is it's quantity; $l_{k_ik_j}$, $d_{k_ik_j}$, $k_i,k_j \in I$ is a length and diameter of the segment (k_i,k_j) respectively; I_k^+ is the set of nodes connected with node k by segments where flow goes into the node, I_k^- is the set of nodes connected with node k by segments where flow goes out of the node; $I_k = I_k^+ \cup I_k^-$ is the set of total nodes connected with node k and $N_k = |I_k|, N_{k^+} = |I_k^+|, N_{k^-} = |I_k^-|$, $N_k = N_{k^-} + N_{k^+}$.

Beside of inflows and outflows in the segments of the network there can be external inflows (sources) and outflows (sinks) with the rate $\tilde{q}_i(t)$ at some nodes $i \in I$ of the network. Positive and negative values of $\tilde{q}_i(t)$ indicate the existence of external inflow or outflow at the node i. However, in general case, assuming that the case $\tilde{q}_i(t) \equiv 0$ for the sources is admissible one can consider all nodes of the network as the nodes with external inflows or outflows. Let $I^f \subset I$ denote the set of nodes $i \in I$, where i is such that the set $I_i^+ \cup I_i^-$ consists of only one segment. It means that the node i is a node of external inflow or outflow for the whole pipe network (for example $I^f = \{1,4,5,8\}$ in fig.1). Let $N_f = |I^f|$ is the number of such nodes, it is obviously that $N_f \le N$; I^{int} is the set of nodes not belonging to I^f , so $N_{\text{int}} = |I^{\text{int}}|$, i.e., $I^{\text{int}} = I / I^f$, $N_{\text{int}} = N - N_f$. In actual conditions, the pumping stations are placed, the measuring equipment is installed and the quantitative accounting is conducted at the nodes from the set I^f .

We assume that at some instants of time $t \ge t_0$ at some points $\xi_{ks} \in (0,l)$, of any (k,s) -th section of the pipeline network, fluid leakage with the flow rates $q_{ks}^{loss}(t)$ began. Using the generalized Dirac function δ(x), we can describe the motion of the liquid by the following linearized system of differential equations for unsteady flow of dripping liquid with constant density ρ in a linear pipe (k,s) of length l_{ks} and diameter d_{ks} of oil pipeline network can be written in the following form [4-8]:

$$\begin{cases} -\dfrac{\partial P^{ks}(x,t)}{\partial x} = \dfrac{\rho}{S^{ks}} \dfrac{\partial Q^{ks}(x,t)}{\partial t} + 2a^{ks} \dfrac{\rho}{S^{ks}} Q^{ks}(x,t), x \in (0,l^{ks}), \\ -\dfrac{\partial P^{ks}(x,t)}{\partial t} = c^2 \dfrac{\rho}{S^{ks}} \dfrac{\partial Q^{ks}(x,t)}{\partial x} + c^2 \dfrac{\rho}{S^{ks}} q_{ks}^{loss}(t)\delta(x-\xi_{ks}), \\ \qquad t \in (0,T],\ s \in I_k^+, k \in I. \end{cases} \quad (1)$$

here c is the sound velocity in the fluid; S^{ks} is the area of an internal cross-section of the segment (k,s) ; a^{ks} is the coefficient of dissipation (we may consider that the kinematic coefficient of viscosity γ is independent of pressure and the condition $2a^{ks} = \dfrac{32\gamma}{(d^{ks})^2} = const$ is quite accurate for a laminar flow). $Q^{k_i k_j}(x,t)$, $P^{k_i,k_j}(x,t)$ are the flow rate and pressure of flow, respectively, at the time instance t in the point $x \in (0,l^{k_i,k_j})$ of the segment (k_i,k_j) of the pipe network. $P^k(t), Q^k(t)$ are the pressure and flow rate at the node $k \in I$, respectively.

The conditions of Kirchhoff's first law (total flow into the node must be equal to total flow out of the node) are satisfied at the nodes of the network at $t \in [0,T]$:

$$\sum_{s \in I_k^+} Q^{ks}(l^{ks},t) - \sum_{s \in I_k^-} Q^{ks}(0,t) = \tilde{q}^k(t),\ k \in I \quad (3)$$

Also, the following conditions of flow continuity for the nodes of the net (the equality of the values of pressures on all adjacent ends of the segments of the network) hold:

$$P^k(t) = P^{k_i k}(l^{k_i k},t) = P^{kk_j}(0,t),\ k_i \in I_k^+, k_j \in I_k^-, k \in I ,(4)$$

where $\tilde{q}^k(t)$ is the external inflow $(\tilde{q}^k(t) > 0)$ or outflow $(\tilde{q}^k(t) < 0)$ for the node k , $P^k(t)$ is the value of the pressure in the node k . We must note that they have significant specific features, consisting in the fact that the conditions (3) and (4) are non-separated (nonlocal) boundary conditions unlike classical cases of boundary conditions for partial differential equations.

The total number of conditions for all nodes from I^f is N_f . So, the total number of conditions in (3) and (4) is $[N_f + N_{\text{int}}] + [(2M - N_f) - N_{\text{int}}] = 2M$. As it was noted above the number of conditions in (3) is N , but in view of the condition of material balance ($\sum_{k \in I} \tilde{q}^k(t) = 0$) for the whole pipeline network, we conclude that the number of linearly independent conditions is $N-1$. So, it is necessary to add any one independent condition. As a rule the value of pressure at one of the nodes $s \in I^f$ is given for this purpose, in place of the flow rate $q^s(t)$:

$$P^s(t) = \tilde{P}^s(t) . \quad (5)$$

In the case of unknown points of leakages and their rates $\xi_{ks}, q_{ks}^{loss}(t)$ we will assume that at the ends of the pipeline sections a constant and rather long observation on pressure is made, i.e., the values of $P_{mes}^n(t),\ n \in I_p^f$ or $Q_{mes}^m(t), m \in I_q^f$ are known. It is quite natural to suppose that the sought leak spots do not coincide with the points of observation of regimes. In more general case, for every node from $I^f = I_q^f \cup I_p^f$, it is necessary to give the values of pressure ($I_p^f \subset I^f$ denotes the set of such nodes) or the values of flow rate (the set $I_q^f \subset I^f$) and I_p^f must not be an empty: $I_p^f \ne \varnothing$. So, we will add the following conditions to the condition (3):

$$\begin{cases} P^n(t) = P^{ns}(0,t) = P_{mes}^n(t), \quad s \in I_n^+,\ if\ I_n^- = \varnothing, \\ P^n(t) = P^{sn}(l^{sn},t) = P_{mes}^n(t),\ s \in I_n^-,\ if\ I_n^+ = \varnothing, \end{cases} \quad n \in I_p^f, (6)$$

$$\begin{cases} Q^m(t) = Q^{ms}(0,t) = Q_{mes}^m(t), \quad s \in I_m^+,\ if\ I_m^- = \varnothing, \\ Q^m(t) = Q^{sm}(l^{sm},t) = Q_{mes}^m(t),\ s \in I_m^-,\ if\ I_m^+ = \varnothing, \end{cases} \quad m \in I_q^f, (7)$$

When the spots of oil leakages from a pipeline and the rates of these leakages are known $\xi_{ks}, q_{ks}^{loss}(t)$, $(k,s) \in J$, it is sufficient to use one of the boundary-value conditions (6) or (7) to calculate the regime of liquid motion in the pipeline from (1) on the time interval $[t_0,T]$. One of them we will use in the functional, the form which will be given below.

The problem consists in the detection of the points of leakage $\xi = \{\xi_{ks},(k,s) \in J\}$ and corresponding losses of raw material $q^{loss}(t) = \{q_{ks}^{loss}(t),(ks) \in J\}$ at $t \in [t_0,T]$ with the use of the given mathematical model and obtained information.

It is important to note that if process (1) is rather long, then, due to the presence of friction typical of any real physical system, the influence of the initial state of the pipeline on the regimes of oil motion in it becomes weaker with time. Therefore, when the process is observed for a long time, i.e., within a large time interval $[t_0,T]$, the influence of the initial regime of oil flow in a pipeline (at $t=t_0$) on the current state of the process decreases, and there exists such τ $(\tau<T)$ that at $t>\tau$ the regime of oil motion experiences only the influence of the boundary-value conditions on the time interval $[t_0,T]$, where the quantity τ is determined by the parameters of the process and the characteristics of the pipeline [9].

Therefore, we will assume that at the initial moment of time t_0 the initial conditions for the process (36) are not exactly known, and some sets of possible values of the initial modes are specified, which are defined in this case by a parametric set $D\subset R^{M+n}$ of possible values of flow rates in the sections under steady-state flow modes:

$$\begin{aligned}&\hat{Q}^{ks}_{\gamma}(x)=Q^{ks}(x,t_0;\gamma)=\gamma^{ks}_q=const,\\&\hat{P}^{ks}_{\gamma}(x)=P^{ks}(x,t_0;\gamma)=\gamma^{ks}_p-2ax\gamma^{ks}_q,\\&x\in(0,l^{ks}),\ (k,s)\in J,\\&\gamma=(\gamma_p,\gamma_q)=(\gamma^{ks}_p,\gamma^{ks}_q)_{\substack{ks\in J\\k\in I}}\in D\subset R^{M+n}.\end{aligned}\tag{8}$$

Here γ^{ks}_q – possible value of flow rates in the (k,s)–th section $ks\in J$, γ^{ks}_p – possible value of pressures at the nodes $k\in I$ under steady-state flow modes, the corresponding density functions are given, which are written in vector form as $\mu_D(\gamma)$.

Possible set of initial states can also be determined as by finite set of their values, as well as by the set of parametrically given functions:

$$\{\hat{Q}^{ks}_{\gamma_1}(x),\hat{Q}^{ks}_{\gamma_2}(x),...,\hat{Q}^{ks}_{\gamma_N}(x)\},\ \{\hat{P}^{ks}_{\gamma_1}(x),\hat{P}^{ks}_{\gamma_2}(x),...,\hat{P}^{ks}_{\gamma_N}(x)\},$$

In order to solve the problem posed, we will consider the functional that determines the derivation of regimes of oil flow at the given points of the oil pipeline section from those predicted:

$$\Im(\xi,q^{loss})=\int_D\left[\Phi(\xi,q^{loss};\gamma)+\Re(\xi,q)\right]\mu_D(\gamma)d\gamma\to\min,\tag{9}$$

$$\Phi(\xi,q^{loss};\gamma)=\sum_{m\in\tilde{I}^f_q}\int_{\tau}^{T}[Q^m(t;\xi,q(t),\gamma)-Q^m_{mes}(t)]^2dt,\tag{10}$$

$$\Re(\xi,q)=\varepsilon_1\left\|q(t)-\hat{q}\right\|^2_{L^Z_2[t_0,T]}+\varepsilon_2\left\|\xi-\hat{\xi}\right\|^2_{R^Z},\tag{11}$$

where $Q^m(t;\xi,q(t),\gamma),m\in\tilde{I}^f_q$ – is the solution of the problem (1)–(5),(7),(8),(10) at the given values of $(\xi,q^{loss}(t))$, $[\tau,T]$ is the time interval of monitoring the process whose regimes already do not depend on the initial conditions; $\tilde{\xi},\tilde{q}\in R^m,\varepsilon_1,\varepsilon_2$ – are the regularization parameters. Since the initial conditions at time t_0 do not influence the process in the interval $[\tau,T]$, exact knowledge of the initial value of t_0 is not of primary importance.

Proceeding from the meaning of the problem considered, technological conditions, and technical requirements, we will assume that are restrictions on the identified functions and parameters:

$$0<\xi_{ks}\le l^{ks},\quad \underline{q}\le q^{loss}(t)\le\overline{q},\quad t\in[t_0,T],$$

where $\underline{q},\overline{q}$ are the given quantities.

As is seen, as to the determination of the points and rates of leakages the posed problem is the problem of parametric optimal control of an object described by a hyperbolic system. For its solution we use numerical methods (projections of the conjugated gradient) based on iteration procedures of first order optimization. To carry out this procedure, it is necessary to obtain formulas for the gradient of functional. If as a result of the solution of posed problem we obtain that $\left|q^{loss}(t)\right|\le\varepsilon,\ t\in[\tau,T]$, this will mean that in this section of the pipeline network there is no leakage of raw material.

III. Numerical solution to the problem

Theorem. In problem (1) - (11), the components of the gradient of functional (9) with respect to admissible places and volumes of leakages $(\xi^{\bar{k}\bar{s}},q^{\bar{k}\bar{s}}(t)),\ (\bar{k},\bar{s})\in J^{loss}$ are determined by the formulas:

$$grad_{q^{\bar{k}\bar{s}}}\Im(\xi,q)=\int_D\left\{grad_{q^{\bar{k}\bar{s}}}\Phi(\xi,q;\gamma)+2\varepsilon(q^{\bar{k}\bar{s}}(t)-\tilde{q}^{\bar{k}\bar{s}}(t))\right\}\mu_D(\gamma)d\gamma,$$

$$grad_{\xi^{\bar{k}\bar{s}}}\Im(\xi,q)=\int_D\left\{grad_{\xi^{\bar{k}\bar{s}}}\Phi(\xi,q;\gamma)+2\varepsilon(\xi^{\bar{k}\bar{s}}-\hat{\xi}^{\bar{k}\bar{s}})\right\}\mu_D(\gamma)d\gamma,$$

$$grad_{q^{\bar{k}\bar{s}}}\Im(\xi,q)=$$

$$=\int_D\left\{c^2\frac{\rho}{S^{\bar{k}\bar{s}}}\psi^{\bar{k}\bar{s}}(\xi^{\bar{k}\bar{s}},t;\gamma)+2\varepsilon(q^{\bar{k}\bar{s}}(t)-\tilde{q}^{\bar{k}\bar{s}}(t))\right\}\mu_D(\gamma)d\gamma,$$

$$t\in[t_0,T],$$

$$grad_{\xi^{\bar{k}\bar{s}}}\Im(\xi,q(t))=$$

$$\int_D\left\{c^2\frac{\rho}{S^{\bar{k}\bar{s}}}\int_{t_0}^{T}q^{\bar{k}\bar{s}}(t)(\psi^{\bar{k}\bar{s}}(x,t))'_x\big|_{x=\xi^{\bar{k}\bar{s}}}dt+2\varepsilon_2(\xi^{\bar{k}\bar{s}}-\hat{\xi}^{\bar{k}\bar{s}})\right\}\mu_D(\gamma)d\gamma$$

Here the functions $\psi^{ks}(x,t)=\psi^{ks}(x,t;\gamma),\ (k,s)\in J$ are the solutions of the conjugate initial-boundary value problem with nonlocal boundary conditions, corresponding to the direct problem.

Let the functions $\phi^{ks}(x,t)$, $\psi^{ks}(x,t)$, $s\in I^+_k,k\in I$ are the solutions to the next adjoint boundary value problem:

$$\begin{aligned}&-\frac{\partial\phi^{ks}(x,t)}{\partial x}=\frac{\partial\psi^{ks}(x,t)}{\partial t},\\&-\frac{\partial\phi^{ks}(x,t)}{\partial t}=c^2\frac{\partial\psi^{ks}(x,t)}{\partial x}-2a^{ks}\phi^{ks}(x,t),\\&\qquad t\in(0,T],\ x\in(0,l^{ks}),s\in I^+_k,k\in I.\end{aligned}\tag{12}$$

$$\phi^{ks}(x,T)=0,\ \psi^{ks}(x,T)=0,\ x\in[0,l^{ks}],\ \ s\in I^+_k,k\in I,$$

$$\psi(l^m,t)=-2\frac{S^{ks}}{\rho}[Q^m(t;\xi,q^{loss})-Q^m_{mes}(t)],$$

$$s\in I^-_m,\ if\ I^+_m=\varnothing,\ m\in I^f_q,$$

$$\psi(0,t) = -2\frac{S^{ks}}{\rho}[Q^m(t;\xi,q^{loss}) - Q^m_{mes}(t)],\ s \in I^+_m,\ if\ I^-_m = \varnothing,$$

$$m \in I^f_q,\quad \sum_{s\in I^+_k} \phi^{ks}(l^{ks},t) - \sum_{s\in I^-_k} \phi^{ks}(0,t) = 0,\ k \in I$$

$$\psi^{k_i k}(l^{k_i k},t) = \psi^{kk_j}(0,t),\ k_i \in I^+_k, k_j \in I^-_k, k \in I.$$

IV. The results of numerical experiments

We will consider the following specially constructed test problem for oil pipeline network consisting of 5 nodes, as shown in figure 3. Here

$N = 6$, $M = 5, I^f\{1,3,4,6\}, N_f = 4, N_{\text{int}} = 2$.

There are no external inflows and outflows inside the network.

We assume that in the course of 30 min we observe the process (mode of operation of pumping plants at the ends of the sections) of oil transportation with the kinematic viscosity $\nu = 1.5\cdot 10^{-4}\,(m^2/s)$ and density $\rho = 920\,(kg/m^3)$ ($2a = 0.017$ for case being considered; the sound velocity in oil is $1200\,(m/s)$) in the sections of pipeline of diameter 530 (mm), of the lengths of the segments:

$l^{(1,2)} = 100$ (км), $l^{(5,2)} = 30$ (км), $l^{(3,2)} = 70$ (км), $l^{(5,4)} = 100$ (км), $l^{(5,6)} = 60$ (км).

Let there was regime in the pipes at initial time instance $t = 0$ with the following values of pressure and flow rate in the pipes:

$\hat{P}^{1,2}(x) = 2300000\text{-}5.8955x$ (Pa),

$\hat{P}^{5,2}(x) = 1745669\text{-}1.17393x$ (Pa),

$\hat{P}^{3,2}(x) = 1827844\text{-}1.677043x$ (Pa),

$\hat{P}^{5,4}(x) = 1827844\text{-}2.35786x$ (Pa),

$\hat{P}^{5,6}(x) = 1827844\text{-}0.94415x$ (Pa). (17)

$\hat{Q}^{1,2}(x) = 300\ (m^3/hour)$,

$\hat{Q}^{5,2}(x) = 200\ (m^3/hour)$ $\hat{Q}^{3,2}(x) = 100\ (m^3/hour)$,

$\hat{Q}^{5,4}(x) = 120\ (m^3/hour)$, $\hat{Q}^{5,6}(x) = 80\ (m^3/hour)$, (18)

Let the oil flow rate at the ends of this pipeline section be defined by the functions:

$\tilde{P}^1_0(t) = 2000000\text{+}300000\,e^{-0.0003t}$ (Pa),

$\tilde{P}^3_0(t) = 1900000\text{-}72156\,e^{-0.0004t}$ (Pa), (19)

$\tilde{P}^4_l(t) = 1800000\text{-}66571\,e^{-0.0007t}$ (Pa),

$\tilde{P}^6_l(t) = 1600000\text{+}86372\,e^{-0.0002t}$ (Pa). (20)

On the assumption that the point of leakage is located at the point $\xi = 30\ (km)$ of the first section of pipeline network and the rate of leakage is determined by the function $q^{loss}(t) = 50 - 10e^{-0.0003t}\ (m^3/h)$, we solved the boundary-value problem (1)-(6) numerically and determined the numerical values of pressure at the ends of the section $P^n(t), n \in I^f_p$. Thereafter, with the aid of the probe of uniformly distributed random numbers these values were changed within _2% (to simulate the error of measurements) and used as the observed regimes of the process. The point and rate of leakage $\xi,\ q^{loss}(t)$ "forgotten" in this case.

It is required to determine $\xi,\ q^{loss}(t)$ with the aid of the above-suggested method of solving problem (1)–(5),(7),(8),(10). For this purpose, we used the method of the projection of conjugate gradients. The numerical solution of the boundary-value problem (1)–(5),(7) was made using the scheme of the sweep method [7], on the grids with the pitches $h_x = 10м$ and $h_t = 100\,(сек)$.

Table 1 presents the obtained results of the minimization of functional (10) for different initial values of the identified parameters $(\xi,\ q^{loss}(t))^0$, as well as the required number of iterations (one-dimensional minimizations) of the method of projection of conjugate gradients.

Table1. The results of experiments ($\alpha = e^{-0.0003t}$)

ξ_0 (km)	$q_0^{loss}(t)$ $(m^3/hour)$	ξ_* (km)	$\Im_0$	$\Im_*$	Number of iter.
60,00	$90-10\alpha$	30,00	76,10	$5{,}73\cdot 10^{-7}$	6
20,00	$20-10\alpha$	29,99	16,70	$1{,}26\cdot 10^{-7}$	5
90,00	$30-10\alpha$	30,00	11,66	$3{,}19\cdot 10^{-6}$	16
10,00	$66+20\alpha$	29,99	42,48	$1{,}85\cdot 10^{-6}$	14
45,68	$66+20\alpha$	29,99	57,63	$7{,}43\cdot 10^{-7}$	8

V. Conclusion

A numerical approach to determining leak locations and amounts in an unsteady fluid flow in a pipeline network of complex structure was proposed. The mathematical formulation of the considered problem was reduced to the class of parametric optimal control problems for a system of a large number of hyperbolic partial differential equations. A feature that causes special difficulties in the numerical solution is that the problem involves nonseparated boundary conditions at network nodes, which appear due to an analogue of Kirchhoff's law concerning material balance conservation and the continuity of the pressure value. Another specific feature is that no initial conditions are specified, since the process is too long; additionally, impulse functions are involved in the differential equations. Formulas for the gradient of the cost functional with respect to the identification parameters were obtained, which make it possible to use efficient numerical optimization methods of the first order.

References

[1] Yu. G. Evtushenko, Methods for Solving Optimization Problems and Their Applications in Optimization Systems (Nauka, Moscow, 1982) [in Russian].

[2] Oyedeko K.F.K. Balogun H.A Modeling and Simulation of a Leak Detection for Oil and Gas Pipelines via Transient Model: A Case Study of the Niger Delta //Journal of Energy Technologies and Policy, 2015, – Vol.5, No.1

[3] I.A. Charnyi, Unsteady Flows of Real Fluids in Pipelines (Nedra, Moscow, 1975) [in Russian].

[4] Chaudhry H.M. Applied Hydraulic Transients. Van Nostrand Reinhold, New York ,1988.

[5] R. Wichowski, "Hydraulic transients analysis in pipe networks by the method of characteristics (MOC)," Arch. Hydro-Eng. Environ. Mech. 53 (3), 267–291 (2006).

[6] A.A. Samarskii and P. N. Vabishchevich, Numerical Methods for Solving Inverse Problems in Mathematical Physics (LKI, Moscow, 2009) [in Russian].

[7] Aida-zade K.R. and Ashrafova E. R. Localization of the points of leakage in an oil main pipeline under non-stationary conditions // J. of Eng. Phys. and Therm. 2012, V. 85. No.5. pp. 1148–1156.

[8] Aida-zade K.R. Ashrafova Y.R. Numerical Leak Detection in a Pipeline Network of Complex Structure with Unsteady Flow //Computational Mathematics and Mathematical Physics, 2017, Vol. 57, No. 12, pp. 1919–1934.

[9] Aida-zade K.R. Ashrafova Y.R. Numerical solution to an inverse problem on a determination of places and capacities of sources in the hyperbolic systems //Journal of industrial and management optimization American Institute mathematical sciences-AIMS, 2020, V.16, No.6, p.3011-3033.

[10] Ashrafova Y.R. Numerical investigation of the duration of the effect exerted by initial regimes on the process of liquid motion in a pipeline //J. of Eng. Physics and Therm. 2015. – V. 88. No.5, – P.1–9.

On the Problem of Identification of the Hydraulic Resistance Coefficient of a Pipeline

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***Abstract*—We consider a problem of identification of the hydraulic resistance coefficient of a main pipeline's section when transporting hydrocarbon raw materials. The considered identification problem is reduced to a class of finite-dimensional optimization problems, for the solution of which we propose to use numerical finite-dimensional first-order optimization methods. For this purpose, we derive formulas for the components of the gradient of the objective functional in the space of identifiable parameters. The obtained values of the optimizable vector can then be used to construct the identifiable function from any class of basis functions using interpolation and approximation techniques. We also carried out some numerical experiments, the results of which are presented.**

Keywords—distributed system, hydraulic resistance coefficient, inverse problem, identification problem, adjoint problem, gradient of functional.

I. Introduction

In recent years, pipeline transportation systems have become the main and most significant means of transporting hydrocarbon raw materials. When a fluid moves through a pipeline, two sources of energy loss occur: losses along the length of the pipeline and losses in local resistances. Local resistances are due to the presence of all kinds of devices that have short length in comparison with the length of the pipe, in which there takes place a sharp change of velocity in magnitude and/or direction, as well as various locking devices, turns, valves, etc. Losses in local resistances result from increased fluid mixing, followed by vortex formation, and large velocity gradients. Losses along the length of the pipe or friction losses arise due to friction in the flow and depend on the length of the pipeline and on the hydraulic resistance coefficient (see [1,2]). Resistance values of pipeline sections have a significant impact on the movement of oil (gas) in the pipeline. It is known (see [3]) that the resistance of a pipeline section depends not only on the geometric dimensions of the pipe, such as the length of the section and the diameter of the pipe, but also on the roughness of the inner surface of the pipe, which affects the value of the hydraulic resistance coefficient. In the course of long-term operation of pipelines, the hydraulic resistance coefficients of the sections change, namely, they increase as a result of the formation of hydrates on the inner surface of the pipelines. These processes occur most intensively as a result of disruption of technological operation modes of pipelines at installations for the preparation of hydrocarbon raw materials transportation. The development of main pipeline networks for hydrocarbon raw materials transportation is accompanied by the wide and intensive use of modern measuring and computer equipment, as well as remote control systems. Therefore, it is of great practical importance to use mathematical methods for identifying hydraulic resistance coefficients for operational monitoring of the state of pipeline network sections that makes it possible to identify suspicious areas where hydrate formation processes have begun actively, which significantly affects the loss of oil (gas) energy, as a result of which it is necessary to use more intensively artificial increase in the energy of oil (gas) on pumping (compressor) stations. Accidents are also possible at pipeline sections due to hydration and formation of hydraulic jams in them. Currently, to determine the hydraulic resistance coefficient in a pipeline, there are a large number of empirical and semi-empirical formulas derived from experimental studies (see [4,5]). These formulas involve parameters, in particular, the roughness coefficient, the determination of the value of which poses certain difficulties. In this regard, it is important to conduct research to determine the hydraulic resistance coefficient individually for each section of a particular pipeline system. The problem of identification of the hydraulic resistance coefficient of a pipeline section considered in the paper belongs to the class of coefficient-inverse problems for systems with distributed parameters. Here we take into account the dependence of the identifiable function on the current state of the process, namely, on the fluid velocity, $\omega(x,t)$, and on the pipeline point, $x \in (0,\ell)$. The initial data for solving the identification problem are the known values of fluid pressure and/or fluid motion velocity, observed continuously or at discrete times at different points of the pipeline section. For numerical solution of the problem, we employ a projection approach, based on finding optimal zonal values of the parameters of the identifiable coefficient on a given class of functions, which is defined by means of known basis functions. To do this, the entire section is divided into a given number of subsections, for each of which the set of possible feasible values of the process operating modes is divided into a given number of phase subsets (zones). For each such subset and subsection, the hydraulic resistance coefficient is sought in the form of a representation (depending on the operating mode) using basis functions. With respect to the ends of the subsections and representation parameters for each subsection, we have obtained formulas for the gradient of the objective functional, which make it possible to use efficient first-order optimization methods. The results of the carried out numerical experiments are presented using a few test problems.

II. Problem Statement

Consider non-stationary motion of an incompressible fluid with constant density, ρ, and viscosity, υ, along a linear horizontal pipeline section of length ℓ and diameter d. This process can be adequately described by the Charny-linearized system of hyperbolic type differential equations (see [6]):

$$-\frac{\partial p}{\partial x} = \rho\left[\frac{\partial \omega}{\partial t} + \alpha\,\lambda\,\omega\right], -\frac{\partial p}{\partial t} = c^2\rho\frac{\partial \omega}{\partial x}, \qquad (1)$$
$$x \in (0,\ell), \qquad t > t_0.$$

Here $p = p(x,t)$ and $\omega = \omega(x,t)$ define the fluid flow regime, namely the pressure and velocity of flow at a point $x \in (0,\ell)$ of the pipeline at point of time $t > t_0$; c is the speed of sound in the fluid; α is the linearization coefficient defined, generally speaking, by the average velocity of the fluid in the pipeline. It is known (see [7]) that the hydraulic resistance coefficient, λ, participating in (1) depends on the fluid motion regime (laminar or turbulent), i.e. on the Reynolds number, $\mathrm{Re} = \omega d/\upsilon$. The coefficient λ also depends on the relative roughness of the inner surface of the pipeline section, $\varepsilon = k/d$. Here k is the value of absolute roughness characterizing the state of the inner surface of the pipeline. The range of possible values of the roughness coefficient, k, is quite large; its values for new pipes depend on the manufacturing quality and material, and for old pipes they mainly depend on the period, operating conditions, and properties of the transported fluid. In all known formulas for the hydraulic resistance coefficient (see [3]), an essential role is played by the absolute roughness coefficient, k, of the pipe surface, direct measurement of the value of which is not possible in practice. On the other hand, studies related to the determination of the hydraulic resistance coefficient are important, given the significant influence of their values on the consumption of energy resources spent on the transportation of hydrocarbon raw materials. Knowing the value of the friction coefficient, on the one hand, allows monitoring the current state of pipelines, planning and carrying out appropriate preventive maintenance work to clean the inner surface of the pipeline in time. On the other hand, control of the fluid pumping-over process under non-stationary flow regimes arising from planned and unplanned transient processes, as well as the calculation of optimal operating modes of technological equipment is carried out using a mathematical model of the process (see [8]). Equation (1) and the hydraulic resistance coefficient of the pipeline section participating in (1) play an important role in calculations. Taking all of the above into account, the paper proposes a formulation and numerical solution of the problem of determining the hydraulic resistance coefficient of a pipeline section under specific operating conditions and the current state of its inner surface. Considering that the roughness is different for different sections of the pipeline, we conclude that λ is a function of the velocity, ω, and the point of the pipe, x, i.e., $\lambda = \lambda(\omega, x)$. At that, the value of the roughness coefficient of the inner surface for a given section is taken into account by the dependence $\lambda(\omega, x)$ itself.

Let there be the results of any two of the following three types of pairs of observations of pumping-over modes at pumping stations located at the ends of the section, carried out in N different time intervals $[\underline{T}_i, \overline{T}_i]$, $i = 1,2,\dots,N$:

$$p_i(0,t) = \varphi_{0i}(t), \qquad p_i(\ell,t) = \varphi_{\ell i}(t), \qquad (2)$$
$$p_i(0,t) = \varphi_{0i}(t), \qquad \omega_i(\ell,t) = \psi_{\ell i}(t), \qquad (3)$$
$$\omega_i(0,t) = \psi_{0i}(t), \qquad p_i(\ell,t) = \varphi_{\ell i}(t), \qquad (4)$$

assuming a sufficiently long duration of each of the time intervals $[\underline{T}_i, \overline{T}_i]$. The observable functions $\varphi_{0i}(t)$, $\varphi_{\ell i}(t)$, $\psi_{0i}(t)$, $\psi_{\ell i}(t)$ are assumed to be continuous on $[\underline{T}_i, \overline{T}_i]$, $i = 1,2,\dots,N$. For practical reasons, if it is impossible to measure the operating mode simultaneously at all points of the pipeline, we will assume that only the operating modes at the ends of the pipeline are observable, and the state of the initial operating modes for each of the observable processes at $t \in [\underline{T}_i, \overline{T}_i]$ is not specified. Therefore, we will consider the processes described by (1) without initial conditions. The research of such problems was initiated by A.N. Tikhonov (see [9]). In [10], they carried on studies of the duration of the influence of initial conditions on evolutionary processes and it was discovered that this duration is finite within practical accuracy and mainly determined by the viscosity of the fluid and the geometric dimensions of the pipeline section, but does not depend on the initial and boundary conditions themselves. Note that to determine the duration of the influence of the initial conditions for each specific section, taking the properties of the pumped fluid into account, it is necessary to carry out special calculations recommended in [10] only once. Let's denote the duration of this influence by ΔT; we assume that the duration of the observation intervals $[\underline{T}_i, \overline{T}_i]$, $i = 1,2,\dots,N$, much exceed the duration ΔT. The solution of differential equations with unspecified initial conditions and given boundary conditions is usually called the boundary mode. To calculate the boundary mode for (1) in the case of a given hydraulic resistance coefficient, some boundary conditions must be specified. In the case of specifying one of the types of conditions (2) – (4), the problem of calculating boundary modes is correct. For a direct numerical solution of the problem and obtaining the boundary mode on the time interval $[\underline{T}_i + \Delta T, \overline{T}_i]$, for example, using the grid method for each i-th observation experiment, it is necessary to set some initial conditions at $t = \underline{T}_i$. For this purpose, considering the process steady up to the moment of time $\underline{T}_i$, $i = 1,2,..,N$, i.e. $\omega(x,t) = \mathrm{const}$, $x \in [0,\ell]$, $t \le \underline{T}_i$, integrating the first equation in (1) over x and using, for example, the available values of the boundary conditions for pressure and velocity at the left or right ends at $t = \underline{T}_i$, the following values can be taken as initial conditions:

$$p_i(x,\underline{T}_i) = [\varphi_{\ell i}(\underline{T}_i) - \varphi_{0i}(\underline{T}_i)]\frac{x}{\ell} + \varphi_{0i}(\underline{T}_i),$$
$$\omega_i(x,\underline{T}_i) = \frac{[\varphi_{0i}(\underline{T}_i) - \varphi_{\ell i}(\underline{T}_i)]}{\beta \cdot \ell}, x \in [0,\ell], \qquad (5)$$

in the case of specifying the boundary conditions as (2) (here β is some approximate value for the product $\alpha \cdot \lambda$);

$$p_i(x,\underline{T}_i) = \varphi_{0i}(\underline{T}_i) - \beta \cdot \psi_{\ell i}(\underline{T}_i) \cdot x,$$

$$\omega_i(x,\underline{T_i}) = \psi_{\ell i}(\underline{T_i}), \qquad x \in [0,\ell], \qquad (6)$$

in the case of specifying the boundary conditions as (3);

$$p_i(x,\underline{T_i}) = \varphi_{\ell i}(\underline{T_i}) + \beta \cdot \psi_{0i}(\underline{T_i}) \cdot (\ell - x),$$
$$\omega_i(x,\underline{T_i}) = \psi_{0i}(\underline{T_i}), \qquad x \in [0,\ell], \qquad (7)$$

in the case of specifying the boundary conditions as (4).

The unknown hydraulic resistance coefficient, $\lambda(\omega, x)$, can be defined by distinct formulas at different speed ranges and have discontinuities of the first kind. Therefore, the solution of the considered boundary-value problems, i.e., the pair $(p(x,t), \omega(x,t))$ will be assumed to be continuous in $x \in (0,\ell)$ and differentiable in $t \in [\underline{T_i}, \overline{T}_i]$.

In order to determine the required hydraulic resistance coefficient, $\lambda(\omega, x)$, for possible types of observation (2) – (4), we introduce the following functionals of standard deviation of

1) the observable boundary conditions

$$\omega_i(0,t) = \psi_{0i}(t), \qquad \omega_i(\ell,t) = \psi_{\ell i}(t) \qquad (8)$$

from those calculated as a result of solving the problem (1), (2), and (5):

$$\mathrm{F}(\lambda) = \frac{1}{N}\sum_{i=1}^{N} \mathrm{F}_i(\lambda; \varphi_{0i}, \varphi_{\ell i}) + \varepsilon\|\lambda - \hat{\lambda}\|^2, \qquad (9)$$

$$\mathrm{F}_i(\lambda; \varphi_{0i}, \varphi_{\ell i}) = \int_{\underline{T_i}+\Delta T}^{\overline{T}_i} \{[\omega(0,t;\lambda;\varphi_{0i},\varphi_{\ell i}) - \psi_{0i}(t)]^2 +$$
$$+[\omega(\ell,t;\lambda;\varphi_{0i},\varphi_{\ell i}) - \psi_{\ell i}(t)]^2\}dt,$$

where $\omega(x,t;\lambda;\varphi_{0i},\varphi_{\ell i})$, $x \in (0,\ell)$, $t \in [\underline{T_i} + \Delta T, \overline{T}_i]$, $i = 1,2,\dots,N$, is the solution of problem (1), (2), and (5);

2) the observable boundary conditions (4) from those calculated as a result of solving the problem (1), (3), and (6):

$$\mathrm{F}(\lambda) = \frac{1}{N}\sum_{i=1}^{N} \mathrm{F}_i(\lambda; \varphi_{0i}, \psi_{\ell i}) + \varepsilon\|\lambda - \hat{\lambda}\|^2, \qquad (10)$$

$$\mathrm{F}_i(\lambda; \varphi_{0i}, \psi_{\ell i}) = \int_{\underline{T_i}+\Delta T}^{\overline{T}_i} \{[\omega(0,t;\lambda;\varphi_{0i},\psi_{\ell i}) - \psi_{0i}(t)]^2 +$$
$$+[p(\ell,t;\lambda;\varphi_{0i},\psi_{\ell i}) - \varphi_{\ell i}(t)]^2\}dt,$$

where $p(x,t;\lambda;\varphi_{0i},\psi_{\ell i})$ and $\omega(x,t;\lambda;\varphi_{0i},\psi_{\ell i})$, $x \in (0,\ell)$, $t \in [\underline{T_i} + \Delta T, \overline{T}_i]$, $i = 1,2,\dots,N$, is the solution of problem (1), (2), and (6);

3) the observable boundary conditions (3) from those calculated as a result of solving the problem (1), (4), and (7):

$$\mathrm{F}(\lambda) = \frac{1}{N}\sum_{i=1}^{N} \mathrm{F}_i(\lambda; \psi_{0i}, \varphi_{\ell i}) + \varepsilon\|\lambda - \hat{\lambda}\|^2, \qquad (11)$$

$$\mathrm{F}_i(\lambda; \psi_{0i}, \varphi_{\ell i}) = \int_{\underline{T_i}+\Delta T}^{\overline{T}_i} \{[p(0,t;\lambda;\psi_{0i},\varphi_{\ell i}) - \varphi_{0i}(t)]^2 +$$
$$+[\omega(\ell,t;\lambda;\psi_{0i},\varphi_{\ell i}) - \psi_{\ell i}(t)]^2\}dt,$$

where $p(x,t;\lambda;\psi_{0i},\varphi_{\ell i})$ and $\omega(x,t;\lambda;\psi_{0i},\varphi_{\ell i})$, $x \in (0,\ell)$, $t \in [\underline{T_i} + \Delta T, \overline{T}_i]$, $i = 1,2,\dots,N$, is the solution of problem (1), (2), and (7). The second terms in the considered functionals (9) – (11) are for regularization purposes, where ε and $\hat{\lambda}$ are regularization parameters (see [11]).

Thus, the considered problem of determining the hydraulic resistance coefficient of a pipeline section has been reduced to the problem of minimizing one of the functionals (9), (10), or (11) taking into account the mathematical model of the process, (1), and one of the boundary conditions, (2), (3), or (4). In this case, the initial conditions can be chosen from (5) – (7) rather arbitrarily, since they do not affect the value of the functional. The present problem is to be called the inverse problem or the parametric identification problem with unspecified initial conditions.

In the general case, it is possible that observations of pumping-over modes are carried out not only at the ends of the section, but also at some intermediate points $x_j \in (0,\ell)$, $j = 1,2,\dots,M$. Most often, in practice, it is technically possible to measure the current pressure values at intermediate points of the pipeline section, i.e.

$$p(x_j,t) = \varphi_{ji}(t), t \in [\underline{T_i}, \overline{T}_i], j = 1,2,\dots,M, i = 1,2,\dots,N.$$

In this case, instead of functionals (9) – (11), one should consider the functional

$$\hat{\mathrm{F}}(\lambda) = \mathrm{F}(\lambda) + \frac{1}{N \cdot M}\sum_{i=1}^{N}\sum_{j=1}^{M}\int_{\underline{T_i}+\Delta T}^{\overline{T}_i} [p(x_j,t) - \varphi_{ji}(t)]^2 dt.$$

It is clear that when solving the inverse problem, an increase in the number of pipeline points at which measurements are made and in the duration of measurements leads to an increase in the accuracy of the results, taking into account the inevitable errors and interference in measurements.

III. Numerical Solution of the Problem

The considered problem of determining the hydraulic resistance coefficient function is formulated within the framework of the optimal control problem for a system with distributed parameters, and more precisely, the feedback control problem, since the current value of the function to be identified for all $x \in (0,\ell)$ and $t \in [\underline{T_i}, \overline{T}_i]$, $i = 1,2,\dots,N$, depends on the current state of the process $\omega(x,t)$ and the point of the pipeline $x \in (0,\ell)$. For numerical solution of the problem, we propose to use an approach based on the idea outlined in [12, 13]. We split the entire segment $X = [0,\ell]$ by intermediate ordered (subsequently optimized) $(L_x - 1)$ points ξ_k, $k = 0,1,\dots,L_x$, such that $0 = \xi_0 < \xi_1 < \dots < \xi_{L_x-1} < \xi_{L_x} = \ell$, into L_x subsections $X_k = [\xi_{k-1}, \xi_k)$. Suppose that, based on a priori information on the process, the range of actually possible values of the fluid motion velocity in the pipeline is known, i.e.

$$\omega(x,t) \in \Omega = [\underline{\omega}, \overline{\omega}], \qquad x \in (0,\ell), \qquad t > t_0,$$

where $\underline{\omega}$ and $\overline{\omega}$ are known limit values of the function $\omega(x,t)$. We quantize the set Ω with predetermined ordered values ω_j, $j = 0,1,\dots,L_\omega$, such that $\underline{\omega} = \omega_0 < \omega_1 < \dots < \omega_{L_\omega} = \overline{\omega}$, and introduce subsets (zones) $\Omega_j = [\omega_{j-1}, \omega_j) \subset \Omega$, $j = 1,2,\dots,L_\omega$. In particular, quantization can be uniform or dependent on a priori information on the process.

The function to be identified, which determines the hydraulic resistance coefficient $\lambda(\omega, x)$, will be determined for each zone Ω_j and for each subsection X_k by means of predetermined L basis functions, namely, the function $\lambda(\omega, x)$ is sought in the form

$$\lambda(\omega, x) = \sum_{s=1}^{L} \lambda_s^{kj} \cdot \gamma_s(\omega), \qquad \omega \in \Omega_j, \qquad x \in X_k \quad (12)$$

Here λ_s^{kj} are unknown coefficients to be identified, and $\gamma_s(\omega)$, $s = 1, 2, \dots, L$, is a set of known linearly independent basis functions. Thus, the problem of finding the function $\lambda(\omega, x)$ has been reduced to the problem of finding finite-dimensional vectors $\Lambda = (\lambda_s^{kj})$, $j = 1,2, \dots, L_\omega$, $k = 1,2, \dots, L_x$, $s = 1,2, \dots, L$, and $\xi = (\xi_1, \xi_2, \dots, \xi_{L_x})$. We denote by $z = (\Lambda, \xi)$ a vector of dimension $L \cdot L_x \cdot (L_\omega + 1) + L_x - 1$. The original optimal control problem has been reduced to the parametric optimal control problem to find a finite-dimensional vector z. To solve it, one can use numerical methods based on the construction of a minimizing sequence $\{z^k\}$ using iterative first-order optimization procedures, for example, the conjugate gradients method (see [14]). To construct a procedure for first-order numerical optimization, we need formulas for the components of the gradient of the objective functional; to obtain them, we use the well-known technique of variation of the optimizable parameters of the functional (see [13,15,16]) (the derivation of these formulas is omitted). The components of the gradient of the objective functional of the considered problems on the class of functions (12) with respect to unknown parameters λ_s^{kj} are determined by the formulas

$$\frac{\partial F(z)}{\partial \lambda_s^{kj}} = \frac{1}{N} \sum_{i=1}^{N} \int_{\underline{T}_i + \Delta T}^{\overline{T}_i} \int_{\Pi_{kj}^i(t;z)} \alpha \rho q(x,t) \gamma_s(\omega) \omega(x,t,z)\, dx\, dt$$

$$s = 1,2, \dots, L; \;\; j = 1,2, \dots, L_\omega; \;\; k = 1,2, \dots, L_x,$$

and with respect to the unknown parameters $\xi_1, \xi_2, \dots, \xi_{L_x}$ by the formulas

$$\frac{\partial F}{\partial \xi_k} = \frac{1}{N} \sum_{i=1}^{N} \sum_{s=1}^{L} \int_{\underline{T}_i + \Delta T}^{\overline{T}_i} \alpha \rho \left[\lambda_s^{k-1,j} - \lambda_s^{k,j}\right] \gamma_s(\omega) q(x,t)$$

$$\omega(x,t;z) dt, \;\; k = 1,2, \dots, L_x - 1.$$

Here the set $\Pi_{kj}^i(t;z)$ for each moment in time $t \in [\underline{T}_i + \Delta T, \overline{T}_i]$ is defined as the union of those intervals of the sub-segment X_k, in which, under the i-th observation of the process at moment of time t, the velocity $\omega(x,t;z) \in \Omega_j$. The pair $(q(x,t), v(x,t))$ is a solution to the system of equations conjugate to (1):

$$\frac{\partial q(x,t)}{\partial x} + \frac{\partial v(x,t)}{\partial t} = 0,$$

$$\rho \frac{\partial q(x,t)}{\partial t} + c^2 \rho \frac{\partial v(x,t)}{\partial x} - \alpha \rho q(x,t) \left[\lambda + \omega(x,t) \frac{d\lambda}{d\omega}\right] = 0$$

for which the boundary and initial conditions, depending on the problem under consideration, have different forms:

a) for the problem (1), (3), (6), and (10):

$$q(\ell, t) = -2[p(\ell, t) - \varphi_{\ell i}(t)],$$

$$v(0,t) = \frac{2}{c^2 \rho} [\omega(0,t) - \psi_{0i}(t)],$$

$$q(x, \overline{T}_i) = 0, \qquad v(x, \overline{T}_i) = 0,$$

$$x \in (0, \ell), \qquad t \in [\underline{T}_i + \Delta T, \overline{T}_i];$$

b) for the problem (1), (4), (7), and (11):

$$q(0,t) = 2[p(0,t) - \varphi_{0i}(t)],$$

$$v(\ell, t) = -\frac{2}{c^2 \rho} [\omega(\ell, t) - \psi_{\ell i}(t)],$$

$$q(x, \overline{T}_i) = 0, \qquad v(x, \overline{T}_i) = 0,$$

$$x \in (0, \ell), \qquad t \in [\underline{T}_i + \Delta T, \overline{T}_i];$$

c) for the problem (1), (2), (5), and (9):

$$v(0,t) = \frac{2}{c^2 \rho} [\omega(0,t) - \psi_{0i}(t)],$$

$$v(\ell, t) = -\frac{2}{c^2 \rho} [\omega(\ell, t) - \psi_{\ell i}(t)],$$

$$q(x, \overline{T}_i) = 0, \qquad v(x, \overline{T}_i) = 0,$$

$$x \in (0, \ell), \qquad t \in [\underline{T}_i + \Delta T, \overline{T}_i].$$

An important role in identifying the unknown function $\lambda(\omega, x)$ using the described approach is played by the choice of both the zones Ω_j, $j = 1,2, \dots, L_\omega$, and their number, as well as the number of points ξ_k, $k = 1,2, \dots, L_x - 1$. The following approach is recommended. Firstly, the initial values of L_x and L_ω are arbitrarily chosen, the boundaries of the subsections ξ_k, $k = 1,2, \dots, L_x - 1$ are specified, and some zones Ω_j, $j = 1,2, \dots, L_\omega$, are chosen. Having solved the posed identification problem, the obtained values of the identifiable parameters are analyzed for all neighboring subsections and zones. If the identifiable parameters in any two adjacent subsections or zones differ by a sufficiently small amount, then these adjacent subsections or zones can be combined into one, thus decreasing the numbers L_x and/or L_ω. If the identifiable parameters in two adjacent subsections or zones differ significantly, then, on the contrary, each of these adjacent subsections or zones should be divided, for example, into two parts, thus increasing the numbers L_x and/or L_ω, and again solve the posed identification problem. An increase in the number of subsections and zones should be carried out until the value of the objective functional ceases to change (decrease) significantly.

IV. Result of Numerical Experiments

Numerous computational experiments have been carried out on test (model) problems. Here are some of the results of these experiments. Let us assume that we are observing non-stationary oil transportation processes with density $\rho = 860$ kg/m^3 on a straight pipeline section with diameter $d = 0.53$ m and length $\ell = 100$ km. We take the speed of sound in oil equal to $c = 1200$ m/s, the value of the linearization parameter to be $\alpha = 1$. Suppose that we have the following results of $N = 10$ observations of the form (2) over the pumping-over modes (pressure) on pumping stations located at the ends of the segment; observations have been performed over ten different time segments $[\underline{T}_i, \overline{T}_i]$, $i = 1,2, \dots, 10$, each of duration 120 min., i.e., $\overline{T}_i = \underline{T}_i + 120$, and, moreover, $\underline{T}_1 = 0, \underline{T}_i = \underline{T}_{i-1} + 180$, for $i = 2,3,\dots,10$:

$$p_1(0,t) = \left[5\cos\left(0.0009(t-\underline{T}_1)\right) + 20\right] 98066.5 \frac{\text{kg}}{\text{m}^3},$$
$$p_1(\ell,t) = \left[2\sin\left(0.0009(t-\underline{T}_1)\right) + 10\right] 98066.5 \frac{\text{kg}}{\text{m}^3},$$
$$t \in [\underline{T}_1, \overline{T}_1]; \quad (13)$$

$$p_2(0,t) = \left[6\cos\left(0.0009(t-\underline{T}_2)\right) + 30\right] 98066.5 \frac{\text{kg}}{\text{m}^3},$$
$$p_2(\ell,t) = \left[2\sin\left(0.0008(t-\underline{T}_2)\right) + 10\right] 98066.5 \frac{\text{kg}}{\text{m}^3},$$
$$t \in [\underline{T}_2, \overline{T}_2]; \quad (14)$$

$$p_3(0,t) = \left[7\cos\left(0.0009(t-\underline{T}_3)\right) + 40\right] 98066.5 \frac{\text{kg}}{\text{m}^3},$$
$$p_3(\ell,t) = \left[2\sin\left(0.0009(t-\underline{T}_3)\right) + 10\right] 98066.5 \frac{\text{kg}}{\text{m}^3},$$
$$t \in [\underline{T}_3, \overline{T}_3]; \quad (15)$$

$$p_4(0,t) = \left[8\cos\left(0.0009(t-\underline{T}_4)\right) + 50\right] 98066.5 \frac{\text{kg}}{\text{m}^3},$$
$$p_4(\ell,t) = \left[3\sin\left(0.0007(t-\underline{T}_4)\right) + 10\right] 98066.5 \frac{\text{kg}}{\text{m}^3},$$
$$t \in [\underline{T}_4, \overline{T}_4]; \quad (16)$$

$$p_5(0,t) = \left[9\cos\left(0.0009(t-\underline{T}_5)\right) + 60\right] 98066.5 \frac{\text{kg}}{\text{m}^3},$$
$$p_5(\ell,t) = \left[4\sin\left(0.0006(t-\underline{T}_5)\right) + 10\right] 98066.5 \frac{\text{kg}}{\text{m}^3},$$
$$t \in [\underline{T}_5, \overline{T}_5]; \quad (17)$$

$$p_6(0,t) = \left[10\cos\left(0.0009(t-\underline{T}_6)\right) + 70\right] 98066.5 \frac{\text{kg}}{\text{m}^3},$$
$$p_6(\ell,t) = \left[5\cos\left(0.0007(t-\underline{T}_6)\right) + 10\right] 98066.5 \frac{\text{kg}}{\text{m}^3},$$
$$t \in [\underline{T}_6, \overline{T}_6]; \quad (18)$$

$$p_7(0,t) = \left[10\cos\left(0.0009(t-\underline{T}_7)\right) + 80\right] 98066.5 \frac{\text{kg}}{\text{m}^3},$$
$$p_7(\ell,t) = \left[4\cos\left(0.0008(t-\underline{T}_7)\right) + 10\right] 98066.5 \frac{\text{kg}}{\text{m}^3},$$
$$t \in [\underline{T}_7, \overline{T}_7]; \quad (19)$$

$$p_8(0,t) = \left[9\cos\left(0.0009(t-\underline{T}_8)\right) + 90\right] 98066.5 \frac{\text{kg}}{\text{m}^3},$$
$$p_8(\ell,t) = \left[3\sin\left(0.0009(t-\underline{T}_8)\right) + 10\right] 98066.5 \frac{\text{kg}}{\text{m}^3},$$
$$t \in [\underline{T}_8, \overline{T}_8]; \quad (20)$$

$$p_9(0,t) = \left[8\cos\left(0.0009(t-\underline{T}_9)\right) + 100\right] 98066.5 \frac{\text{kg}}{\text{m}^3},$$
$$p_9(\ell,t) = \left[2\sin\left(0.0007(t-\underline{T}_9)\right) + 10\right] 98066.5 \frac{\text{kg}}{\text{m}^3},$$
$$t \in [\underline{T}_9, \overline{T}_9]; \quad (21)$$

$$p_{10}(0,t) = \left[10\cos\left(0.001(t-\underline{T}_{10})\right) + 110\right] 98066.5 \frac{\text{kg}}{\text{m}^3},$$
$$p_{10}(\ell,t) = \left[5\sin\left(0.001(t-\underline{T}_{10})\right) + 10\right] 98066.5 \frac{\text{kg}}{\text{m}^3},$$
$$t \in [\underline{T}_{10}, \overline{T}_{10}]. \quad (22)$$

To obtain some test observable values of raw material consumption at the ends of the pipeline section, the section X is divided by one ($L_x = 1$) point $\xi = 70$ km into 2 subsections, $X_1 = [0, 70]$ and $X_2 = [70, 100]$. From preliminary numerical calculations for various permissible values of hydraulic resistances, the range of possible speeds in the entire section was identified to be $\underline{\omega} = 0.35$ m/s and $\overline{\omega} = 2.65$ m/s. That is why the following 10 zones, Ω_i, $i = 1,2,\dots,10$, were considered for Ω:

$$\{[0.35; 0.5), [0.5; 0.75), [0.75; 1), [1; 1.25), [1.25; 1.5), [1.5; 1.75), [1.75; 2), [2; 2.25), [2.25; 2.5), [2.5; 2.65)\}.$$

For the test problems, we obtained the observable values of raw materials consumption at the ends of the section of the form (8) for ten observations by means of calculation. For this purpose, ten initial-boundary value problems were solved for (1) with the corresponding ten variants of boundary conditions (24) – (33) of the form (2) with the initial conditions calculated according to (5). Here are the results of solving two test problems. In the first test problem, to obtain the observable values of the form (8), the hydraulic resistance coefficients for each zone and for all subsections were taken as linear functions

$$\lambda(\omega, x) = \lambda_1^{k,j} + \lambda_2^{k,j}\omega, \qquad k = 1,2, \qquad i = 1,2,\dots,10$$

i.e. the basis functions in (12) are $\gamma_1(\omega) = 1$, $\gamma_2(\omega) = \omega$, $L = 2$. The used (optimal) values of the parameters $\lambda_s^{k,j}$ are given in Table 1. The same class of functions was used to solve the problem of identifying the hydraulic resistance function. For the second test problem, the observable values (8) were obtained for the class of piecewise constant hydraulic resistance functions:

$$\lambda(\omega, x) = \lambda_1^{k,j}, \qquad k = 1,2, \qquad i = 1,2,\dots,10,$$

i.e. $L = 1$ and $\gamma_1(\omega) = 1$. The used (optimal) values of the parameters $\lambda_1^{k,j}$ are given in Table 3. To analyze the stability of the obtained solutions of the considered parametric identification problem, noises were introduced into data given by (8). Namely, we solved the inverse problems under conditions for which the observed values of the flow rate at the ends of the section (the results of solving the above direct boundary-value problems under the boundary conditions (13) – (22)) are subject to disturbances that have a uniform distribution on the interval $[-\chi, \chi]$. The value of $\chi \geq 0$ in the experiments varied and took the values 0 (i.e., without any noise), 0.05, and 0.1, which corresponded to noise level equal to 0%, 0.5%, and 1%, as if from the measured flow rates $\widehat{\omega}_i(0,t)$ and $\widehat{\omega}_i(\ell,t)$ at the ends of the segment:

$$\widehat{\omega}_i(0,t) = (1+\gamma_1)\omega_i(0,t), \widehat{\omega}_i(\ell,t) = (1+\gamma_2)\omega_i(\ell,t),$$
$$i = 1,2,\dots,N.$$

To generate random variables γ_1 and γ_2 uniformly distributed over the interval $[-\chi, \chi]$, we used a standard program for generating pseudorandom numbers.

To determine the value of ΔT, special calculations were carried out, namely, the boundary-value problem (1) and (13) – (22) was solved for the considered section of the pipeline under various initial conditions. As a result, the duration ΔT was determined to be about 10 minutes.

The numerical solution of the boundary-value problem (1) and (13) – (22) was carried out using the implicit scheme of the grid method with the steps in the variables x and t equal to $h_x = 100$ m and $h_t = 7.2$ s, respectively. To solve the optimization problem, the conjugate gradient method was used with the following optimization parameters: the accuracy of solving the auxiliary one-dimensional minimization problem is 10^{-4},the accuracy of solving the multidimensional minimization problem is 10^{-3}. In all test problems, the zero vector was taken as the initial values of the identifiable parameters, i.e. $\lambda_s^{k,j} = 0$, $\xi_1^0 = 6$. For example, the value of the objective functional in the first test problem at the initial point $z_0 = (\lambda^0, \xi^0)$ under the noise level of 0% was $F^0 \approx 1198267791$.

As can be seen from the results of numerical experiments given in Tables 1 – 4, the influence of a measurement error of up to 1% (for instance, when measuring pressure in practice, the error range of 0.5 – 1% is quite acceptable) on the obtained values of the identifiable parameters is insignificant; therefore, the graphical presentation of the results of the influence of measurement errors is not given due to low information content.

TABLE 1. OPTIMAL AND OBTAINED VALUES OF THE PARAMETERS OF THE HYDRAULIC RESISTANCE FUNCTIONS UNDER 0%, 0.5% AND 1% NOISE LEVELS FOR TEST PROBLEM 1.

Zone index (j)		Segment 1: $(\lambda_1^{1j}; \lambda_2^{1j})$	Segment 2: $(\lambda_1^{2j}; \lambda_2^{2j})$
1	$(\lambda_s^{kj})^*$	(0.0368; –0.0181)	(0.0404; –0.0188)
	0 %	(0.0330; –0.0198)	(0.0383; –0.0171)
	0.5 %	(0.03299; –0.01991)	(0.038173; –0.01721)
	1 %	(0.03254; –0.02074)	(0.03764; –0.01760)
2	$(\lambda_s^{kj})^*$	(0.0328; –0.0101)	(0.0361; –0.0102)
	0 %	(0.0329; –0.0089)	(0.0362; –0.0133)
	0.5 %	(0.03319; –0.00894)	(0.036043; –0.01340)
	1 %	(0.03391; –0.00914)	(0.03772; –0.01363)
3	$(\lambda_s^{kj})^*$	(0.0300; –0.0065)	(0.0332; –0.0063)
	0 %	(0.0307; –0.0062)	(0.0317; –0.0074)
	0.5 %	(0.03093; –0.00624)	(0.03195; –0.00738)
	1 %	(0.03042; –0.00617)	(0.03159; –0.00773)
4	$(\lambda_s^{kj})^*$	(0.0282; –0.0046)	(0.0313; –0.0044)
	0 %	(0.0318; –0.0068)	(0.0331; –0.0037)
	0.5 %	(0.03206; –0.00677)	(0.03296; –0.00369)
	1 %	(0.03138; –0.00711)	(0.03471; –0.00367)
5	$(\lambda_s^{kj})^*$	(0.0268; –0.0035)	(0.0299; –0.0033)
	0 %	(0.0286; –0.0042)	(0.0264; –0.0020)
	0.5 %	(0.02880; –0.00423)	(0.026558; –0.00199)
	1 %	(0.02824; –0.00416)	(0.02636; –0.00195)
6	$(\lambda_s^{kj})^*$	(0.0258; –0.0028)	(0.0288; –0.0026)
	0 %	(0.0298; –0.0050)	(0.0269; –0.0019)
	0.5 %	(0.02973; –0.00499)	(0.026859; –0.00189)
	1 %	(0.02922; –0.00515)	(0.02689; –0.00188)
7	$(\lambda_s^{kj})^*$	(0.0249; –0.0023)	(0.0279; –0.0021)
	0 %	(0.0264; –0.0030)	(0.0257; –0.0021)
	0.5 %	(0.02632; –0.00301)	(0.025650; –0.00211)
	1 %	(0.02738; –0.00299)	(0.02641; –0.00219)
8	$(\lambda_s^{kj})^*$	(0.0242; –0.0020)	(0.0272; –0.0017)
	0 %	(0.0249; –0.0023)	(0.0261; –0.0013)
	0.5 %	(0.02483; –0.00229)	(0.026057; –0.00131)
	1 %	(0.02563; –0.00228)	(0.02688; –0.00127)
9	$(\lambda_s^{kj})^*$	(0.0235; –0.0017)	(0.0266; –0.0014)
	0 %	(0.0259; –0.0027)	(0.0257; –0.0012)
	0.5 %	(0.02587; –0.00269)	(0.025925; –0.00119)
	1 %	(0.02660; –0.00267)	(0.025289; –0.00125)
10	$(\lambda_s^{kj})^*$	(0.0230; –0.0015)	(0.0261; –0.0012)
	0 %	(0.0201; –0.0004)	(0.0253; –0.0008)
	0.5 %	(0.02001; –0.00039)	(0.025495; –0.00079)
	1 %	(0.02110; –0.00039)	(0.026528; –0.00083)

TABLE 2. OBTAINED VALUES OF THE ENDS OF THE SUBSECTIONS AND OF THE FUNCTIONAL UNDER 0%, 0.5% AND 1% NOISE LEVELS FOR TEST PROBLEM 1.

	Noise 0 %	Noise 0.5 %	Noise 1 %
End of segment ξ	69.9999	70.3813	69.5986
Functional $J(z)$	0.011035	0.014134	0.025079

TABLE 3. OPTIMAL AND OBTAINED VALUES OF THE PARAMETERS OF THE HYDRAULIC RESISTANCE FUNCTIONS UNDER 0%, 0.5% AND 1% NOISE LEVELS FOR TEST PROBLEM 2.

Zone index j		Segment 1: λ_1^{1j}	Segment 2: λ_1^{2j}
1	$(\lambda_s^{kj})^*$	0.0295	0.0329
	0 %	0.02848	0.03519
	0.5 %	0.02903	0.03389
	1 %	0.02948	0.03657
2	$(\lambda_s^{kj})^*$	0.0265	0.0297
	0 %	0.02556	0.03186
	0.5 %	0.02519	0.03091
	1 %	0.02630	0.03282
3	$(\lambda_s^{kj})^*$	0.0244	0.0277
	0 %	0.02360	0.02953
	0.5 %	0.02383	0.02890
	1 %	0.02409	0.03043
4	$(\lambda_s^{kj})^*$	0.0230	0.0263
	0 %	0.02233	0.02782
	0.5 %	0.02256	0.02799
	1 %	0.02293	0.02854
5	$(\lambda_s^{kj})^*$	0.0220	0.0254
	0 %	0.02141	0.02675
	0.5 %	0.02162	0.02694
	1 %	0.02198	0.02771
6	$(\lambda_s^{kj})^*$	0.0212	0.0246
	0 %	0.02066	0.02583
	0.5 %	0.02086	0.02609
	1 %	0.02033	0.02644
7	$(\lambda_s^{kj})^*$	0.0206	0.0241
	0 %	0.02009	0.02526
	0.5 %	0.02029	0.02551
	1 %	0.02003	0.02581
8	$(\lambda_s^{kj})^*$	0.0200	0.0236
	0 %	0.01951	0.02469
	0.5 %	0.01971	0.0249
	1 %	0.01999	0.02563
9	$(\lambda_s^{kj})^*$	0.0196	0.0232
	0 %	0.01913	0.02425
	0.5 %	0.01933	0.02442
	1 %	0.01882	0.02381
10	$(\lambda_s^{kj})^*$	0.0192	0.0229
	0 %	0.01876	0.02389
	0.5 %	0.01895	0.02412
	1 %	0.01845	0.02365

TABLE 4. THE OBTAINED VALUES OF THE ENDS OF THE SUBSECTIONS AND OF THE FUNCTIONAL UNDER 0%, 0.5% AND 1% NOISE LEVELS FOR TEST PROBLEM 2.

	Noise 0 %	Noise 0.5 %	Noise 1 %
End of segment ξ	69.90	69.81	70.63
Functional $J(z)$	0.007674	0.009021	0.010147

V. CONCLUSION

In the paper, we have considered the numerical solution of the parametric identification problem for a mathematical model of a dynamic object with distributed parameters by the example of solving the problem of identifying the hydraulic resistance coefficient under a non-stationary mode of fluid motion through pipelines. It is known that the hydraulic resistance coefficient is a function of the fluid velocity. Empirical formulas proposed by many engineers for estimating the value of the hydraulic resistance coefficient do not always give adequate results on specific pipelines due to the fact that they do not take into account the specific features of these pipelines. The theoretical and practical results obtained in the paper make it possible to use them in automatic control systems on pipelines. We proposed an approach to numerical solution of the considered problem that consists in the fact that the entire pipeline section is divided into a given number of subsections, the ends of which are optimizable, and we introduced the concept of a "zone" for the optimizable parameters of the identifiable function depending on the current state of the object. The set of all phase states of the object is divided into a finite number of subsets (zones), in each of which the function to be identified is assumed to be constant, linear, or having some other form of functional dependence. The results obtained can also be used in mathematical modeling and solving inverse problems for many technological processes and technical objects, the identifiable parameters of which are functions of the state of the process (object).

REFERENCES

[1] I.E. Idelchik, Handbook of Hydraulic Resistance, CRC Begell House, 1994.

[2] M.A. Guseinzade and V.A. Yufin, Neustanovivsheesya dvizhenie nefti i gaza v magistral'nykh truboprovodakh (Non-Established Motion of Oil and Gas in Magistral Pipelines), Moscow: Nedra, 1981.

[3] R.A. Aliev, V.D. Belousov, A.G. Nemudrov, et al., Truboprovodnyi transport nefti i gaza (Pipe Transport of Oil and Gas), Moscow: Nedra, 1988.

[4] V.V. Mikhailov, "A Refined Formula for Computing the Hydraulic Resistance Coefficient for Pipe Transit Systems", Izv. RAN, Mekh. Zhidkosti Gaza, 2001, no.4, pp.159–161.

[5] A.P. Silash, Dobycha i transport nefti i gaza (Extraction and Transportation of Oil and Gas), Moscow: Nedra, 1980.

[6] I.A. Charnyi, Neustanovivsheesya dvizhenie real'noi zhidkosti v trubakh (Non-Established Motion of Real Liquids in Pipes), Moscow: Nedra, 1975.

[7] V.G. Geier, V.S. Dulin, and A.N. Zarya, Gidravlika i gidroprivod (Hydraulics and Hydrodrives), Moscow: Nedra, 1991.

[8] K.R. Aida-zade, D.A. Asadova, "Study of transients in oil pipelines", Autom. Remote Control, 2011, vol. 72, no. 12, pp.2563–2577.

[9] A.N. Tikhonov, A.A. Samarskii, Uravneniya matematicheskoi fiziki (Equations of Mathematical Physics), Moscow: Nauka, 1966.

[10] E.R. Ashrafova, V.M. Mamedov, "A numerical study of the state of evolution processes for unspecified initial conditions", Izv. NAN Azerbaidzhana, ser. Fiz.-Mat. Nauk, 2013, vol. 33, no. 6, pp.30–38.

[11] A.A. Samarskii, P.N. Vabishchevich, Chislennye metody resheniya obratnykh zadach matematicheskoi fiziki (Numerical Methods for Solving Inverse Problems of Mathematical Physics), Moscow: LKI, 2009.

[12] K.R. Aida-zade, S.Z. Guliev, "Numerical solution of nonlinear inverse coefficient problems for ordinary differential equations", J. Comput. Math. Math. Phys., 2011, vol.51, no.5, pp.803–815.

[13] K.R. Aida-zade, S.Z. Guliev, "On numerical solution of one class of inverse problems for discontinuous dynamic systems", Autom. Remote Control, 2012, vol.73, no.5, pp.786–796.

[14] B.T. Polyak, Vvedenie v optimizatsiyu (Introduction to Optimization), Moscow: Nauka, 1983.

[15] R. Gabasov, F. Kirillova, Printsip Maksimuma v Teorii Optimalnogo Upravleniya (The Maximum Principle in Optimal Control Theory), Moscow: Librokom, 2011.

[16] F.P. Vasilyev, Metody Optimizatsii (Methods of Optimization), Moscow: Faktorial Press, 2002.

[17] J.L. Lions, Controle Optimal des Syst`emes Gouvernes par des Equations aux Derivees Partielles, Paris: Dunod Gauthier-Villars, 1968.

Mathematical Modeling of the Planning of Measures to Improve Road Safety

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***Abstract*—In this study, a mathematical model for planning of measures taken to improve road safety by using Qualimetry methods was developed. The problem was modelled as One-Dimensional Integer Bounded Knapsack Problem where the variables are bounded above and bounded below. A greedy algorithm was proposed in order to solve the problem and a software was developed in C# programming language, then computational experiments were performed. The results show the that the proposed algorithm is efficient. The exact solution of the problem was obtained by using WinQSP package program. The prepared mathematical model was applied to road data of Aliaga-Izmir and the results were presented.**

***Keywords*—mathematical modeling, integer programming, knapsack problem, highways, road safety, planning, Qualimetry**

I. Introduction

In today's economic conditions, organizations need to make timely and healthy decisions that may affect their lives in order to survive. For this, the authorities of the establishment need information systematically. Organization officials make use of the information they have in their decision-making processes and apply to mathematical methods and models [1].

Although "analysis of systems" is an important subject in our age, the mathematical tools required for this analysis are limited. Solving a system of equations with several hundred unknowns is very easy with computers. More difficult problems arise in the analysis of large systems. Mathematical modeling techniques, which can be a solution to all these difficulties, have proven to be useful in wide areas in a short time and have become a promising tool for the future [2].

Traffic accidents have taken thousands of lives in the world for years and this problem has not been solved to a significant extent yet [3]. There are three main factors in the formation of traffic accidents: human (driver or pedestrian), environment and road. Although the fault is mostly caused by the human factor in accidents, road and environment are important factors. It is possible to reduce accidents and increase traffic safety by making changes in some geometric features of the road or in the marking [4].

Many measures can be taken to increase road safety, the important thing is to take the measures that can increase traffic safety the most within the possibilities available. Road safety for any road or part of it in road networks is determined by the required safety conditions and the suitability of the road's characteristics [5].

Within the scope of this study, mathematical models of the planning of measures in the form of integer programming models were prepared in order to increase road safety, and the prepared models were solved with discrete optimization methods and computer software. New solution methods and computer software have been developed and implemented on some of the roads in Izmir [6]. In this way, what kind of measures should be taken to increase road safety using the available constraints has been determined and contributed to the literature on traffic safety.

With the obtained data, it has been determined which road features can be improved in order to increase road safety with the budget possibilities available. In this way, traffic safety can be increased and accidents can be reduced.

II. Knapsack Problem

The knapsack problem is a problem in combinatorial optimization: Given a set of items, each with a weight and a value, determine the number of each item to include in a collection so that the total weight is less than or equal to a given limit and the total value is as large as possible [7]:

w_j: the weight of the j.th item,
p_j: the benefit of the j.th item,
c: Total capacity of the knapsack

$$x_i = \begin{cases} 1, & \text{if item } j \text{ is selected} \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

$$\sum_{j=1}^{n} w_j x_j \le c, \quad (2)$$

$$x_j \in \{0,1\}, \qquad j = 1,\ldots\ldots,n \qquad (3)$$

$$Max\ Z^* = \sum_{j=1}^{n} p_j x_j \qquad (4)$$

In addition to the standard knapsack problem defined in the model (2)-(4), the Knapsack Problems have expanded and each of them has become a standard problem on its own, with the addition of many additional constraints to the model in industrial applications [2].

III. Qualimetry

Qualimetry is a science that deals with the measurement methods of the quality of any object with things like relations or processes, natural or man-made objects, natural or inanimate, etc. deals [8]. Qualimeter is the scientific theory of quantification assessment of the 'USSR' formerly written by G.G.Azgaldov and is currently used in the development of Russian standards [9].

IV.Road Safety and Explanation of Road Parameters

Traffic accident occurs when a vehicle collides with another vehicle, pedestrian, animal, road debris, or other stationary obstruction, such as a tree, pole or building. Traffic collisions often result in injury, disability, death, and property damage as well as financial costs to both society and the individuals involved [11].

Many factors with different characteristics can be effective in the occurrence of traffic accidents. In a study conducted in the United States, 289 different factors were found to be effective in 68 accidents. Accident factor, accident-related, accident; can be defined as the condition without which it cannot occur. Essentially, there are many accident factors:

- Factors related to road users,
- Vehicle related factors,
- Road related factors; as 3 main groups [3].

The complex quality assessment of a built and suitable road is described below [11]:

K_t – target,

K_p-process,

K_h- non-hazardous motion,

K_{er}-ergonomics,

K_s-Indicators of road safety

K_{tec}-technology,

K_{es}-aesthetics

Target control indicators (K_t)

P_1 – Road category,

P_2 – Pavement type and Flexibility modulus,

P_3 – Width of the road,

P_4 – Road types in the plan,

P_5 – Profile of the road length ,

P_6 – Equipment of the road

Ergonomics Indicators (K_{er})

This group characterizes the indicators (driver, car, road and environment) criteria.

P_{16} – Psychophysical states,

P_{17} – Polishing properties of the road surface,

P18 – Evaluation of air pollution,

P_{19} – Level of road noise at the time of departure,

P_{20} – Vibration

Technological indicators (K_{tec})

P_{16} - continuity of repair,

P_{17} - content of repair work,

P_{18} - quality of repair work

Indicators of road processing (K_p*)*

P_8 – With level of continuity,

P_7 – Density of movement,

P_9 – Durability of road goods,

P_{10} – Smoothness of pavement,

P_{11} – Coupling coefficient of pavement

Non-hazardous Indicators (K_h)

P_{12} – Non-hazardous indicator of road movement

Indicators of road safety (K_s)

P_{13}– Infallibility (continuous operation without faults on the road),

P_{14}– Long-term operation,

P_{15} – Repairability

Indicator of the aesthetics of the road (K_{es})

P_{21} – Aesthetics

The complex quality assessment of worked roads can be represented by the following expression.

$$K_k = 0.1\ K_t + 0.3K_p + 0.15K_h + 0.25K_s + 0.15K_{er} + 0.05K_{es} \quad (5)$$

When evaluating quality with simple features, the above expression can be shown as the following expression.

$$K_k = 0.01(P_1+P_2+P_3+P_5+P_{18})+0.02(P_4+P_{17}+P_{19})+ 0.03(P_3+P_{20})+ 0.04\ (P_6+P_7)+ 0.08\ P_9+ 0.09(P_{10}+ P_{14})+ 0.06(P_{11}+P_{15})+ 0.15\ P_{13}+ 0.07\ P_{16}+ 0.05\ P_{21} \quad (6)$$

It depends on the conditions of non-hazardousness and whether the characteristics of the road are suitable or not, which measures should be planned in order to increase the non-hazardousness of vehicles moving on the road. Considering the entire budget allocated for the repair and reconstruction of the road, the K equation is established, then a Qualimeter model of the non-hazardousness of the road is established according to the appropriate P_1-P_n plain indicators in order to increase the non-hazardousness of the road. The aim here is to determine the maximal value of the complex demonstrator of the non-hazardousness of the movement designed without exceeding the allocated financial costs.

V. Mathematical Modeling of the Planning of Measures to Improve Road Safety

The methodology of planning measures to increase the safety of movement by means of road-maintenance services depends on the following situations. The non-hazardousness of movement for any road or part of it in the road network is determined by the required non-hazardous conditions and whether the road features are suitable. According to the methodology, the value of the K_k determined before the beginning of the planned period is characterized by the non-hazardousness of the movement and the suitability of the planned levels [10].

Considering all the financial resources allocated for the repairing and reconstruction of the road, after determining the current value of the K_k variable, a Qualimetric model of the safeness of the movement is established according to the appropriate Π_1 -Π_{19} plain pointers in order to increase the risklessness of the road (i.e., the improvement of the Π_1 is appropriate for the widening of the crossing part of the road, the bridges). expansion – Π_3 denoter etc.) [10, 11].

The justification of measures to increase the non-hazardousness of the movement is brought to determine the maximal value of the designed complex demonstrator of the non-hazardousness of the movement without exceeding the capacity of the allocated financial costs. The mathematical model of the problem is shown in (7)-(9):

$$\sum_{i=1}^{19} c_i(x_i - \Pi_i) \le C \quad (7)$$

$$\Pi_i \le x_i \le 5,\ i=1,2,\dots,19 \quad (8)$$

$$Max\ K_k = \sum_{i=1}^{19} a_i x_i \quad (9)$$

Here, x_i and Π_i are the input and output values of the simple parameters of the qualimetric model that show the effectiveness of road conditions on the non-hazardousness of the movement:

a_i, the valence coefficients of the parameters given above;

c_i, the unit value of measures to increase the value of demonstrators by one point;

C, the planned capacity of financial resources allocated to measures to increase the security of movement for one year.

The problem can be written more clearly:

$$C_1(x_1-\Pi_1) + C_2(x_2-\Pi_2) + \dots + C_{19}(x_{19}-\Pi_{19}) \le C, \quad (10)$$

$$\Pi_i \le x_i \le 5,\ (i=1,2,\dots,9,11,\dots 19), \quad (11)$$

$$C_{10} = 0 \quad (12)$$

$$C_{\Pi k} = 0 \quad (13)$$

The objective function (14) with its constraints is considered.

$$\text{Max } K_k = 0{,}15x_1 + 0{,}06\,x_2 + 0{,}05x_3 + 0{,}11x_4 + 0{,}13x_5 + 0{,}2x_6 + 0{,}03x_7 + 0{,}03x_8 + 0{,}03x_9 + 0{,}06\Pi_{10} + 0{,}09x_{11} + 0{,}08K\Pi_k + 0{,}10x_{16} + 0{,}03x_{17} + 0{,}01x_{18} + 0{,}02x_{19} \quad (14)$$

This model is a one-dimensional Knapsak problem with integers whose variables are limited on both sides [7].

The indicators used in this study are summarized according to the coating type, flexibility model, polishing of the coating surface, Noise, Roughness and repair continuity.

According to the information received from the General Directorate of Highways of Turkish Republic, the construction cost for the 10 km road section and the cost of each indicator for the 10 km road section were obtained [4].

Considering the budget of one year, the program for the knapsack problem with limited variables was implemented in C# language and calculations were made (DSKP Program). "The program used the method suggested by one of the authors in his study [12].

VI. WinQSB Package Program

WinQSB is a package program that contains the operations literature. It contains 19 modules. Each module contains algorithms and solution methods in the literature. LP-ILP Module, This module solves linear (LP) and integer linear (ILP) programming problems.

Among the previously explained road criteria, P_2 flexibility model is according to the pavement type (mpa), P_{17} is the shine of the pavement surface (lk), P_{19} is the noise level on the road (db), P_{11} is the friction coefficient of the road surface, P_{15} is the continuity of the repair made on the road, and its values are measured (Pn), scores between 1 and 5 (d_i) and costs (tl) are determined (w_n) for a 10 km road section. A budget of 10,000 TL has been allocated for all expenditures for the road surface.

VII. Conclusion

In this study, integer programming models of the planning of measures to increase road safety have been prepared. Qualimeter methods were used while preparing the models. The prepared model variables are expressed as the Knapsack Problem, which is limited from the bottom and the top. To solve this problem, a heuristic algorithm is proposed and a program system called DSKP (Knapsack Problem with Limited Variables) is implemented in C# programming language.

Calculation experiments were made on the test problems with the prepared program and the LP-ILP program of the WinQSB system was compared. According to this comparison, the results found by DSKP were always the same as those found by the LP-ILP program.

Prepared Mathematical Model and Program System was applied on Izmir's Aliaga highway data and the results are presented in [6].

References

[1] H.A. Taha, Operations Research: : An Introduction, 10th Edition - Pearson, 843 p, 2017.

[2] H. Kellerer, U. Pferschy, D. Pisinger, Knapsack Problems, Springer, Berlin, 546p, 2004.

[3] HBR., Accident Rates as Related to Design Elements of Rural Highways, National Cooperative Highway Research Program Report 47, 1968.

[4] Police Department, Traffic Services Presidency, Traffic Research Center Directorate., Low-Cost Road and Traffic Engineering Measures for Reducing Fatal Accidents, Ankara, 2001. (in Turkish)

[5] S. Işıldar, Cost-Benefit Relationships in Highway Traffic Safety Activities, Symposium Organized by 19 Mayıs University and Samsun Police Department, Samsun, 2000. (in Turkish)

[6] U. Nuriyev, F. Golghasemi Sorkhabi, Planning of Measures to Increase Road Safety with Road-Maintenance Vehicles in Road-Maintenance Units, 8th International Statistics Congress Antalya , p. 198-199, 27-30, October 2013. (in Turkish)

[7] S. Martello, P. Toth, Knapsack Problems: Algorithms and Computer Implementations, New York, J. Wiley, 285p, 1990.

[8] P.P. Kajgorodova, Application of the Kualimerte Method in Research on Competitive Advantages of Educational Institutions, 2013. (in Russian).

[9] N.G Nazarov, N.T. Krushnyak, What is measured in qualimetry?, Measurement Techniques, 49(3): 238-243 pp, 2006. (in Russian)

[10] V.M. Sidenko, O.T. Batrakov, M.I. Volkov, Ya.A. Kaluzhskiy, N.M. Kudryavtsev, S.I. Mikhovich, I.A. Romanenko, V.A. Fomin, E.V. Gavrilov, (Highways (Improvement of Design and Construction methods)). Kiev, Budivel'nik Publ , 278 p, 1973. (in Russian)

[11] V.M. Sidenko, S.Yu. Rokas, Quality management in road construction. Moscow, Transport, 252 p, 1981. (in Russian)

[12] A.I. Nikitin, U.G. Nuriyev, On a method of the solution of the knapsack problem, Kibernetika, 2:108-110 pp, 1983. (in Russian)

Environmental Security in the Transport Sector: Analysis of the Current Situation in Azerbaijan

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***Abstract*—The presented article examines the existing environmental problems in the field of road transport in Azerbaijan and their causes. The harmful effects of vehicles on the environment and ways to overcome these problems are analyzed on the basis of statistical computations. Using the special Eco Transit World software, which allows automatic calculation of energy consumption, carbon emissions, air pollutants and external costs for three types of transport services, including trains, trucks and ships, the level of environmental impact in the field of cargo transportation in Azerbaijan has been assessed. The paper concludes with particular proposals for strengthening the transport system of Azerbaijan and ensuring the environmental safety of vehicles.**

Keywords—vehcles, pollution, European environmental standards, Eco Transit World software, CNG engines

I. Introduction

As an independent and strategically important sector of the national economy, transport, being the object of achieving and managing commercial results, also serves to meet the needs of the country's economy for all types of transactions as well as cargo and passenger traffic. The purpose of transport is to ensure the dynamics of the movement of goods and labor resources. The role of transport in ensuring the normal functioning and developing the economy is undeniable, however there are both advantages and disadvantages. As the operation of vehicles is directly related to the environment, the increase in their number is causing the activities of various types of pollution in an anthropogenic way, especially in the atmosphere. Large amounts of toxic gases are released into the atmosphere every day, and as a result of high man-made impact on the ambient, there is a serious threat to the health of wildlife. In this regard, environmental security remains a global modern problem.

Understanding the laws of nature allows us to develop complex measures to predict many changes that may occur in nature. Efficient, planned use and protection of natural resources is one of the main tasks of society. Despite the fact that the law strictly prohibits the irregular use of natural resources, in many sectors of the economy, including transport, the misuse of natural resources creates the basis for harmful changes in the environment, such as air pollution, greenhouse and noise effects, electromagnetic pollution, deterioration of human and animal health. Maritime transport mostly affects the hydrosphere, air transport – the atmosphere, and electric transport – the biosphere, causing harmful substances such as water, soil pollution, carbon monoxide, oxides, heavy compounds and vapors into the atmosphere. As a result, not only the greenhouse effect, but also the acid rain, the number of diseases increases, there are problems with the health of wildlife, and the ecological balance is disturbed.

The article discusses the current situation with the environmental situation in the world associated with the growth of vehicles, measures taken in connection with the integration of developing countries into the global economy, European requirements in connection with the deterioration of the environment. The article presents a discussion of the article topic in the case of Azerbaijan, the authors propose specific recommendations for reducing environmental harm in the republic.

II. Literature Review

It is known that vehicles intended for international passenger and cargo transportation should, first of all, comply with the basic parameters defined by international agreements, road safety and environmental requirements, as well as the obligations for the storage of cargo and the protection of passenger health.

Long-term operation of vehicles leads to deterioration of their technical condition and adjustment parameters of internal combustion engines. The number of harmful substances released into the atmosphere is growing faster than the wear and tear of vehicles. The paper [1] on the base of statistical calculations shows that, for example, it is possible to keep the level of harmful emissions in new cars for only 1-3 years according to the level guaranteed by the manufacturer. In [2] the authors insist on fact that current malfunctions and violations of regulations during operation lead to deterioration of toxicity indicators and fuel economy. Unfavorable road conditions, low quality of fuels and lubricants lead to rapid wear of vehicle hubs and units, increased fuel consumption and toxic emissions. Lack of quality of maintenance and repair, low level of modern equipment and capable specialists often have a negative impact on the full recovery of vehicles. As a result, the efforts of the automotive industry in the production of improved engines that meet the requirements of environmental standards are not realized.

The action plan developed to solve this problem addresses the issue of bringing fuel and lubricants produced in Azerbaijan, as well as fuels used in transport, to European standards to meet the requirements for harmful substances emitted into the atmosphere from vehicles. The date of application of the mentioned Euro standards is related to environmental factors; the growing interest in CNG (Compressed natural gas) cars with electric motors and natural gas in the world [3] reckons also due to these factors. Towards the end of the last century, rising living standards in the developed world led to an increase in the number of vehicles, resulting in traffic jams, leaving cars behind industrial facilities and becoming a major threat to the environment.

In order to fight for the improvement of the environment in the world since 1992, modern environmental safety standards have been adopted to determine the levels of toxicity of gas emissions from car engines. In Azerbaijan since 1999 the "Law on Environmental Safety" [4] developed. In accordance with these standards, there are various EURO environmental benchmarks, which are characterized by a reduction in the number of harmful substances emitted into the atmosphere by cars. [5] details that the numbers 0, 1, 2, 3, 4, 5 and 6 in the title of the standard, which are inversely proportional to the number of pollutants emitted into the environment during the operation of a vehicle that meets the requirements of those standards, i.e. an increase in the figure characterizes a low amount of pollutants.

The paper [6] euro environmental standards (Euro 0-6) determines the amount of exhaust gases (hydrocarbons, carbon monoxide, nitrogen oxides, etc.) emitted into the atmosphere by cars. These standards were first introduced in Europe in 1991. The first standard, called Euro-0, was replaced in 1992 by the Euro-1 standard. If the Euro-0 standard forbade the release of more than 10 g/h of exhaust gas into the atmosphere, the Euro-1 environmental standard prohibited the release of about twice as less exhaust gas – 4.9 g/h. In 1995, the Euro-2 environmental standard was adopted, which prohibits the emission of exhaust gases more than 2.5 g/h. Starting that year, European countries, the United States and Japan switched to Euro-2. The Euro-3 standard set the rate at 1.5 g/h since 2000; the Euro-4 standard set the rate at 0.8 g/h since 2005. The Euro-5 standard, which set 0.6 g/s since September 2009, came into force. Since 2014, Euro-5 has given way to the Euro-6 standard.

It should be noted that currently the EU member states apply the more advanced Euro-5 standard. Euro standards make high demands on both the fuel composition and the technical condition of the cars. Since 2014, the implementation of the Euro-6 environmental standard for the number of harmful substances emitted into the atmosphere from car engines in Europe has begun. The paper [7] indicates that according to this standard, which applies to all cars produced from 2015 to date, emissions are reduced by 67% compared to the previous standard. This figure is achieved only by the installation of special equipment in the exhaust system of the car, and therefore it is not intended to apply any new standard on the composition of the fuel. Each type of fuel specified in the standards differs in the amount and composition of harmful substances released into the atmosphere during combustion. As mentioned above, an increase in the serial number indicated in the name of the standard is an indication of an increase in fuel quality. In this case, its use not only causes less damage to the environment, the car's engine and fuel system, but also allows to fully achieve the performance of the car.

The Euro standard covers not only the environment, but also the safety of vehicles and fuel quality. During the transition from one standard to another, the norm for harmful substances released into the atmosphere is tightened by an average of about half.

As [8] shows, Euro-3 standard has been applied in Azerbaijan since 2014. As regards to the changes in the country's market caused by new standards, it is normal for gasoline prices to rise after the transition. The implementation of another Euro standard costs $ 1 billion. Therefore, if the demand for motor fuel in the country is growing, and production of better products and meeting European standards are preferrable, the price of gasoline should increase accordingly. This tendence, which serves to improve the quality of gasoline in the future from Euro-3 to Euro-4 and from Euro-4 to Euro-6, and at the same time reduce the amount of gas emitted into the atmosphere, is a global trend that will be an important event in reducing environmental disasters. In the end, [9] determines that the implementation of the new standards will achieve significant results in the renewal, rejuvenation of the car fleet in our country and the prevention of future environmental disasters.

Currently, in [10] the authors confirm that the most reliable, environmentally friendly and economical type of all available insist that fuels is CNG. This is pure methane (CH_4). It is the only fuel that meets the requirements of Euro 5 environmental standards when the smoke is released into the air unprocessed. Natural gas does not contain aldehydes and other air toxins. The paper [11] shows that CNG engines make 30% less noise than other fuel-powered engines, and that natural gas produces very little greenhouse effect.

The increase in hot weather conditions and traffic jams of obsolete cars in the summer, as well as burns and breakdowns due to other malfunctions, in addition to increasing environmental problems, also create problems for road users.

III. Analysis of Important Current Indicators in the Transport Sector

The integration of independent states into the world economic system has a great impact on international relations and increases the economic efficiency of transport. Global processes, such as access to world markets, require the efficient use of labor in the transport sector. In addressing this issue and according to official statistics the distribution of the main vehicles used in Azerbaijan over the past 5 years is as follows (Table 1):

TABLE I. NUMBER OF VEHICLES, END OF YEAR, UNITS

	2016	2017	2018	2019	2020
Total	**1 330 551**	**1 342 324**	**1 370 574**	**1 418 404**	**1 473 563**
Passen-ger cars	1 136 983	1 147 437	1 170 672	1 214 093	1 264 542
Private cars	1 082 597	1 094 729	1 118 480	1 158 448	1 204 682
Buses	30 958	30 788	30 704	30 783	30 757
Trucks	141 525	142 857	147 343	150 547	154 659
Special purpose vehicles	11 158	11 024	11 232	11 924	11 613
Others	9 927	10 218	10 623	11 057	11 992
Motor-cycles	3 290	3 077	3 206	4 069	4 594

Sources: The State Statistical Committee of the Republic of Azerbaijan [12]

Based on the statistics for 2020, it was determined that 59.1% of cargo transportation in the transport sector in Azerbaijan falls to cars, and 29.7% – to pipelines. The share of passenger transportation by road is the second largest after sea transportation (60.7%). If we take into account that there are currently 30 757 internal combustion engines and 154 659 trucks in Azerbaijan, which are the main source of air pollution, it is not difficult to imagine the level of environmental danger.

Let's look at the age structure of the vehicle fleet for May 2021 (Table 2). The number of buses and trucks with a service life of more than 10 years in 2020 once again confirms this fact.

TABLE II. THE AGE STRUCTURE OF THE VEHICLE FLEET

Distribution by type of vehicle					
		Cars	Buses	Trucks	Special purpos e cars
2019	**Total**	**1 214 093**	**30 783**	**30 783**	**11 924**
	Up to 5 years	51 170	1 756	3 057	555
	5 to 10 years	223 890	3 584	16 708	2 489
	More than 10 years	939 033	25 443	130 782	8 880
2020	**Total**	**1 264 542**	**30 757**	**154 659**	**11 613**
	Up to 5 years	510 48	1 296	3 198	591
	5 to 10 years	220 129	3 632	15 724	2 245
	More than 10 years	993 365	25 829	135 737	8 777

Sources: The State Statistical Committee of the Republic of Azerbaijan [12]

Most of the cars in our country, which is experiencing a transition period of the economy in the process of globalization, are cars manufactured in the CIS countries. In addition, for more than 10 years, the country has been importing cars that are banned from operation in those countries due to the limit of their service life and environmental suitability. According to all key indicators (economy, reliability, safety, environmental suitability), car models lag behind industrialized countries by 8-10 years.

As a result of the operation of such vehicles, fuel consumption and the amount of harmful substances released into the atmosphere increase. In addition, the privatization of the vast majority of the car fleet in the country has had a negative impact on the environment as a result of the weakening of its material and technical base.

According to Natig Zarbaliyev, chairman of the Azerbaijan Automobile Dealers Association, which unites official importers and dealers of about 40 foreign car brands, as well as local car manufacturers, "the number of cars over 10 years old in the country is 80%. More than 300 000 were produced 20 years ago, more than 130 000 were produced 30 years ago, and more than 100 000 were produced 40 years ago" [13].

According to the law, cars with a service life of more than 10 years must be inspected annually, the purpose of this act is to prevent the commissioning of unusable cars or to eliminate malfunctions.

In countries with developed automotive industries, such as Russia, expired cars are purchased by the state and a certain amount of money is transferred to the citizen's account in return [13]. Due to the underdevelopment of the automotive industry in Azerbaijan, it is impossible to solve the problem in this way. In this regard, the issue of timely technical inspection of cars should be taken more seriously, and legislative norms related to their withdrawal should work.

According to some experts, the process of decommissioning non-compliant cars can be carried out in stages, and the compensation paid by the state for such cars will not have a significant impact on the state budget due to the low cost of cars [14].

If we take into account that two thirds of the cars currently used in the country are concentrated in Baku, it becomes clear how urgent are the problems in the field of environmental protection.

There are too many cars in the car market in Azerbaijan that do not meet Euro-5 and Euro-6 environmental standards due to their technical capabilities. Fuel produced in Azerbaijan meets Euro-2 requirements in accordance with environmental standards. However, currently developed countries already apply Euro-6 environmental standards, and refineries in the region (Turkmenistan, Kazakhstan and Russia) produce fuel in Euro-5 standards [15].

Every day, the number of unusable cars is growing due to the large number of imported vehicles that do not meet any safety requirements and environmental standards. Regardless of the country from which the car is imported, a document of all technical, safety and environmental requirements signed by the relevant authority of that country must be submitted. Otherwise, the import of these environmentally undesirable cars to the Azerbaijani market should be stopped, or the duties on these cars should be increased. Moreover, the import and sale of "old" cars should not be stimulated [16].

The pandemic has also affected the delay in the production of diesel and gasoline in Azerbaijan, which will meet Euro-5 standards. It is planned to develop in 2021-2022 this standard at the country's fuel producer Oil Refinery named after Heydar Aliyev and to increase production to 7.5 million tons in 2024-2025. One of the main goals of the project is to improve the environmental situation in Baku.

There are a number of risks to the environment in production processes, mainly during the operation of old facilities, and modernization will also minimize such risks. For this purpose, the application of modern and international standards of technology is envisaged.

If the prices of the current AI-92 gasoline, which accounts for 95% of the Azerbaijani gasoline market, change, consumers' interest in alternative fuels will increase. On the other hand, the price of diesel, which is mostly used in the public transport and commercial sectors, will undoubtedly increase. The way out of this situation is to increase the number of cars running on natural gas.

CNG is used in road transport around the world. According to forecasts, the number of CNG-powered cars in the world will exceed 100 million by 2030 [13]. High growth dynamics is characterized by factors such as its economic accessibility to a wide range of consumers and minimal impact on the environment. Advanced European countries have already developed a strategy to abandon diesel and alternatively to natural gas. In this regard, there are clear prospects for expanding the use of CNG in the transport sector of a country rich in natural gas, such as Azerbaijan, due to the simplicity of its processing and low costs.

In addition to being the main provider of economic development, transport also contributes to the growth of greenhouse gas emissions. According to official statistics, harmful emissions from motor vehicles have a larger share in air pollution in our country, and in 2020 this waste amounted to 661.0 thousand tons or 81.6 percent (Fig.1) [17].

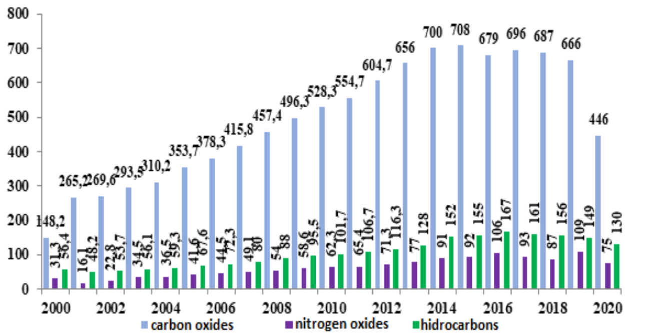

Fig. 1. The content of pollutants emitted into the atmosphere by road transport, thousand tons

Source: [17]

In 2018, a total of 172 400 tons of air pollutant emissions were registered in Azerbaijan, of which 16 700 tons are CO2 emissions. The transport, warehousing and communications sectors accounted for 23.7% of total air pollutant emissions and 4.7% of total CO2 emissions in the same year [18].

Azerbaijan allocated $ 8.5 billion in 2008 and $ 2 billion in 2010 for the development of the transport sector. However, a large part of the funding is directed to the development of highway infrastructure, which is unlikely to contribute to the reduction of CO2 emissions from the sector [19]. Between 2011 and 2016, the Government of Azerbaijan planted 549 000 trees and ornamental shrubs on public lands along highways to reduce the impact of harmful pollutants on the atmosphere [20].

One of the biggest challenges to mitigating climate change is to enable emerging economies to lift people out of poverty and at the same time reduce greenhouse gas emissions. To this end, the International Transport Forum's Decarbonising Transport in Emerging Economies project has helped developing countries' governments identify ways to reduce transport CO2 emissions and achieve climate goals. One of the four countries participating in this project is Azerbaijan, and the others are Argentina, India and Morocco. In 2016, transport accounted for 30% of CO2 emissions in the Organization for Economic Co-operation and Development (OECD).

The International Transport Workers' Federation estimates that transport emissions in OECD member countries are expected to decline by 1% annually by 2030 and by 2% in non-OECD countries [19]. This is due to the faster growth of demand for transport in these countries. Per capita transport CO2 emissions in developing countries are still well below the OECD average. CO2 per capita in India is about twenty-one percent of the average OECD country [21].

This project will support the organization of current and future transport activities and the assessment of transport emissions, taking into account the relevant characteristics of the participating countries.

IV. Environmental Impact Assessment of Cargo Transportation

Determining energy consumption during cargo transportation and selecting alternatives for the optimal implementation of this process is a matter of interest for every enterprise or company manager. On the other hand, the issue of assessing the number of harmful substances released into the environment during cargo transportation is equally important.

Eco Transit World [22] is the most widely used software in the world for the automatic calculation of energy consumption, carbon emissions, air pollutants and external costs for any type of transport services. It is based on the factors that determine the level of environmental impact in the field of cargo transportation. By selecting these factors in the interests of the enterprise, the user can determine the optimal situation, compare energy consumption and the amount of waste polluting the environment between the types of vehicles.

The implementation mechanism of the program is characterized by the following steps:

Step 1. **Mode selection.** One of the standard and advanced modes is selected for the actual calculation. The standard mode is intended for "fast" calculations, and the advanced mode allows for a more accurate description of the transport chain.

Step 2. **Definition of goods.** The weight, number and type of cargo (wholesale, medium goods, light goods) to be transported are specified.

Step 3. **Determination of the points of departure and destination (delivery).** By choosing between the city, railway station, port and airport (through Google Maps and zip code), the type of destination is determined.

Step 4. **Determination of the route.** One or more types of vehicles (train, plane, ship, truck, ferry), as well as the transport chain are selected. Advanced mode allows to specify technical and operational details. The emission class for trucks, the weight of the train for rail transport, or the load rating of the vehicle can also be determined individually.

Step 5. **Determination of the point of destination (delivery).** The destination is determined by making the choices listed in step 3.

After entering all the relevant parameters, the button labeled "Calculate" is pressed to start the calculation.

Step 6. **The results of the calculation** are presented in the form of bar charts and tables. The route can be tracked via Google Map or exported as Google Earth Route.

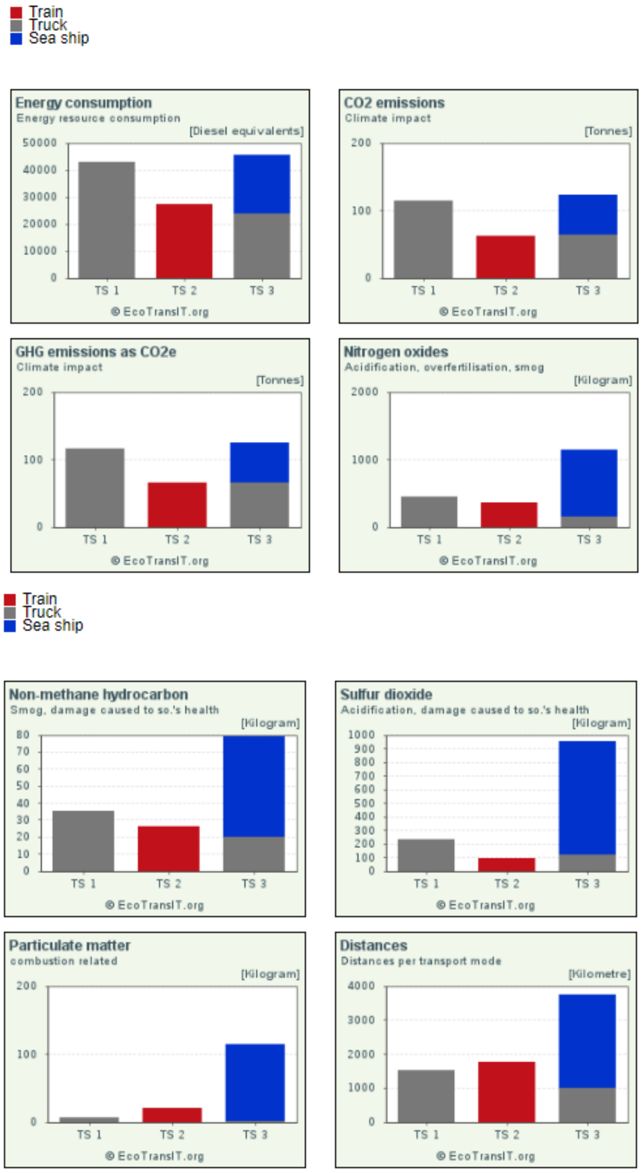

Fig. 2. Energy consumption and the amount of harmful waste

Source: Eco Transit World software calculation result

Made in Germany, this software allows to calculate energy costs and carbon emissions worldwide virtually for all modes of transport.

In calculations the transportation of 100 containers, each weighing 10 tons, from the Baku Railway Station to the Turkoglu region of Turkey is presented.

Appropriate technical parameters for estimating the energy consumption and environmental impact of three modes of transport, including trains, trucks and ships, are presented in the Eco Transit World program interface.

The user is free to choose the technical parameters. The diagrams showing the amount of electricity consumption and carbon emissions used to transport cargo on a selected route by Euro-4 diesel-equivalent fuel truck as well as the distance traveled by all three modes of transport are given in Figure 2.

Being the most promising mode of transport in modern times, the railway meets many standards in terms of speed and price, especially environmental requirements. In the example we saw, this fact proved itself once again. The results of the calculations showed that it is more profitable to transport cargo by train on the chosen route, both in terms of energy consumption and the level of environmental pollution.

Due to the need to make comparisons in solving specific problems, accurate indicators of the above-mentioned technical parameters are needed. Figure 3 shows the quantitative indicators of electricity consumption and the amount of waste dumped on the selected route.

Energy consumption (WTW)
Energy resource consumption [Diesel equivalents]

	TS 1	TS 2	TS 3
Truck	42,752	0	24,334
Train	0	26,974	0
Sea ship	0	0	21,109
Sum:	**42,752**	**26,974**	**45,443**

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CO2 emissions (WTW)
Climate impact [Tonnes]

	TS 1	TS 2	TS 3
Truck	114	0	65
Train	0	62	0
Sea ship	0	0	58
Sum:	**114**	**62**	**123**

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GHG emissions as CO2e (WTW)
Climate impact [Tonnes]

	TS 1	TS 2	TS 3
Truck	116	0	66
Train	0	65	0
Sea ship	0	0	59
Sum:	**116**	**65**	**125**

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Nitrogen oxides (WTW)
Acidification, overfertilisation, smog [kilogram]

	TS 1	TS 2	TS 3
Truck	435	0	166
Train	0	352	0
Sea ship	0	0	980
Sum:	**435**	**352**	**1,146**

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Non-methane hydrocarbon (WTW)
Smog, damage caused to so.'s health [kilogram]

	TS 1	TS 2	TS 3
Truck	35	0	20
Train	0	26	0
Sea ship	0	0	58
Sum:	**35**	**26**	**79**

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Sulfur dioxide (WTW)
Acidification, damage caused to so.'s health [kilogram]

	TS 1	TS 2	TS 3
Truck	229	0	130
Train	0	88	0
Sea ship	0	0	822
Sum:	**229**	**88**	**952**

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Particulate matter (WTW)
combustion related [kilogram]

	TS 1	TS 2	TS 3
Truck	5.85	0	3.31
Train	0	19.98	0
Sea ship	0	0	111.07
Sum:	**5.85**	**19.98**	**114.38**

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Distances (WTW)
Distances per transport mode [km]

	TS 1	TS 2	TS 3
Truck	1,523	0	1,026
Train	0	1,772	0
Sea ship	0	0	2,718
Sum:	**1,523**	**1,772**	**3,744**

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Fig. 3. Accurate indicators on the selected route

Source: Eco Transit World software calculation result

As can be seen from Figure 3, only the amount of waste emitted by the train to the environment within the selected technical parameters is low, fuel consumption is low, in this regard, it is more appropriate to deliver the selected cargo by train to the destination.

With the help of Eco Transit World software, it is very convenient to calculate the cost of transporting goods from one point to another anywhere in the world, as well as in the case of a chain route.

V. CONCLUSION

Today, the Republic of Azerbaijan actively participates in the implementation of international transport policy. Undoubtedly, in connection with the restoration of the "Historical Silk Road" under the "TACIS-TRACECA" program, the amount of harmful substances emitted during the transportation of international cargo by road will increase and aggravate the environmental situation in the country. Therefore, the implementation of important tasks such as strengthening the transport system of Azerbaijan and ensuring the environmental safety of vehicles requires great responsibility from the relevant authorities. For this purpose, it is necessary to increase the number of permanent ecological posts at border checkpoints of the republic, at the entrances and exits of major cities, as well as on highways. Also, the regulations governing the state environmental control and its implementation should be effectively applied. Normative acts should reflect the mechanism of interaction between the bodies exercising state control and clarify the rules and tariffs for payment for environmental pollution. In order to meet the requirements for vehicles and ensure environmental safety more effectively, a program for the gradual adoption of Euro environmental standards and an incentive system to reduce the harmful effects of road transport on the environment and accelerate the process of fleet renewal should be developed. In order to prevent the release of toxic gases from vehicles into the atmosphere, the movement of expired cars in the city should be restricted and the car fleet should be renewed.

In order to ensure the normal operation of transport networks, their appropriate infrastructure should be created and a modern automated monitoring system should be established in Baku and other major cities in order to improve atmospheric air monitoring.

It is advisable to discuss incentive projects related to import duties and VAT exemption for environmentally friendly vehicles, electric vehicles, as well as hybrid vehicles, and CNG vehicles, as well as taking the necessary measures to prevent the import of expired vehicles into Azerbaijan, and spare parts for them, the technical parameters of which do not meet modern standards, as well.

REFERENCES

[1] J. Simićević, and V. Momčilović, "Parking policy as an instrument for reducing passenger cars' harmful emissions," Put i Saobraćaj, 64(4), pp. 39–42, 2018, https://doi.org/10.31075/pis.64.04.05.

[2] I. Manko, Y. Shuba, A. Korpach, S. Gutarevyc, J. Ragulskiene, and A. Pauliukas, "Measurement of fuel consumption and harmful emissions of cars when using different types of fuel," Journal of Measurements in Engineering, 8(4), pp. 182–196, 2020, https://doi.org/10.21595/jme.2020.21847.

[3] V. Erokhov, "Means of filling gas-cylinder cars with compressed natural gas. Lecture № 8. Design features of stationary automobile gas filling compressor stations (CNG Stations)," AutoGas Filling Complex + Alternative Fuel, pp. 246–262, 2021, https://doi.org/10.36652/2073-8323-2021-20-6-246-262.

[4] 677-IQ - About environmental safety. Retrieved September 20, 2021, from http://www.e-qanun.az/framework/3851.

[5] R. Patil, "Solar Photo-Voltaic Box Validation According to EURO Standards Using FEA," International Journal of Science and Research (IJSR), 4(11), pp. 1967–1972, 2015, https://doi.org/10.21275/v4i11.nov151615.

[6] W. Mokrane, and A. Kettab, "Flow behaviour analysis through a venturi designed for industrial and environmental processes," Euro-Mediterranean Journal for Environmental Integration, 4(1), 2019, https://doi.org/10.1007/s41207-018-0093-6.

[7] A. Gorbunova, I. Anisimov, L. Burakova, and S. Klement'ev, "Study of the influenceof the «climate control» installation on fuel consumption and emissions of harmful substances by cars at idle with a running enginee," Innovatics and Expert Examination, 27, pp. 10–20, 2019, https://doi.org/10.35264/1996-2274-2019-2-10-20.

[8] F. Kerimli, Z. Mursalzade, and S. Isa-zade, "Cluster development as a significant perspective of entrepreneurial promotion in petrochemical industry," Azerbaijan Oil Industry, 2, pp. 44–53, 2021, https://doi.org/10.37474/0365-8554/2021-2-44-53.

[9] S. Hajiyeva, E. Gadirova, and A. Musayeva, "Ecological monitoring of some territories of Azerbaijan," Journal of biology and ecology, 2(2), pp. 18–21, 2020, https://doi.org/10.26739/2181-0575-2020-2-3.

[10] G. Britchenko, and T. A. Cherniavska, "Transport security as a factor of transport and communication system of ukraine self-sustaining development," Scientific Bulletin of Polissia, 1(1(9)), pp. 16–24, 2017, https://doi.org/10.25140/2410-9576-2017-1-1(9)-16-24.

[11] T. A. Shiau, and J. S. Liu, "Developing an indicator system for local governments to evaluate transport sustainability strategies," Ecological Indicators, 34, pp. 361–371, 2013, https://doi.org/10.1016/j.ecolind.2013.06.001.

[12] The state Statistical Committee of the Republic of Azerbaijan. Retrieved September 20, 2021, from https://www.stat.gov.az/?lang=en.

[13] S. Yunusov, "They are mainly cars, crushed, drowned ... "- Interview. Marja.az. Retrieved September 19, 2021, from https://marja.az/71015/esasen-qezadan-cixmis-ezilmis-suda-batmis-avtomobillerdir-musahibe.

[14] S. K. Hoekman, "Review of Nitrous Oxide (N2O) Emissions from Motor Vehicles," SAE International Journal of Fuels and Lubricants, 13(1), 2020, https://doi.org/10.4271/04-13-01-0005.

[15] S. Wierzbicki, "Evaluation of the effectiveness of on-board diagnostic systems in controlling exhaust gas emissions from motor vehicles," Diagnostyka, 20(4), pp. 75–79, 2019, https://doi.org/10.29354/diag/114834.

[16] H. Ismailova, and Z. Farzalizade, "Oil spills and ecological risks evaluation," Azerbaijan Oil Industry, 2, pp. 60–64, 2020, https://doi.org/10.37474/0365-8554/2020-2-60-64.

[17] M. Dyvak, A. Rot, R. Pasichnyk, V. Tymchyshyn, N. Huliiev, and Y. Maslyiak, "Monitoring and Mathematical Modeling of Soil and Groundwater Contamination by Harmful Emissions of Nitrogen Dioxide from Motor Vehicles," Sustainability, 13(5), 2768, 2021, https://doi.org/10.3390/su13052768.

[18] SSCAR, "National accounts and balance of payments system" (data base), The State Statistical Committee of the Republic of Azerbaijan, 2020 https://www.stat.gov.az/source/system_nat_accounts/?lang=en.

[19] UNEP, "Review of the green economy", 2012

[20] Government of Azerbaijan, "2nd Biennial Updated Report of the Republic of Azerbaijan to the UN Framework Convention on Climate Change", Baku, 2018 https://unfccc.int/sites/default/files/resource/Second%20Biennial%20Update%20Report%20-%20Azerbaijan-version%20for%20submission.pdf.

[21] V. Gnazzo, "Legislation on Quality and Harmful Emissions. Solid, Liquid and Gaseous Fuels," SSRN Electronic Journal. Published, 2018, https://doi.org/10.2139/ssrn.3621465.

[22] Eco Transit World . Eco Transit World , 2021, September 15. Retrieved September 20, 2021, from http://www.ecotransit.org/.

New Approach to Calculation of Transition Curves on Curved Roads

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***Abstract*—The article sets forth a new method for compiling transition curves for projected and constructed highways at the entrance from straight sections to horizontal curves. The expression for the transition curve is found, as a special case, from the solution of the differential equation of curvature. To substantiate the results, a monotonic increase in centrifugal acceleration along the curve was revealed.**

Keywords—curvature, serpentine, centrifugal acceleration, dimensionless parameter, road, transition curve, particular solution, trajectory

When the car moves on the road, when entering from straight sections to horizontal curves (for example, zigzag roads and serpentines), the driving condition changes and the influence of centrifugal force on the car begins. In theory, this force acts instantly on the car at entry points, but practically when the steering wheel is turned from the driver's side within small areas. Observations show that, as a rule, when cars enter curves with a radius of less than 600 m, drivers reduce their speed. To avoid abrupt changes in traffic conditions and reduce the convenience of movement between straight and curved sections of highways, additional curves are plotted, called transition curves. The curvature of the road axis within these two curves gradually changes from 1 / ∞ to 1 / R [1].

According to the current standards for the design of motor roads, on all motor roads (on roads of I ... V category), when the radius of the curves is less than 2000 m, transition curves are necessarily projected. The presented article examines the reliability of the results obtained using the expression for the proposed transition curve on the example of projected roads.

Designing a road plan is considered the most important and crucial stage in all road design. Since, the amount of road construction costs, transportation and operating costs, the level of convenience, safety issues, etc. depend on it. Part of highways consists of transition curves of the transition from the straight part of the road to the curves. A transition curve is a curve that gradually changes the radius of curvature. When deriving the equation of the transition curve, it is necessary to take into account the change in the modes of movement of the vehicle and the force acting on the vehicle when driving along the transition curve, as well as all the requirements for the safety and comfort of road traffic.

According to the current standards for the design of highways, to ensure the safe movement of vehicles on curves in the plan and longitudinal profile of roads, the main condition is a small change and limitation of speed. When you change the category of the road, the speed of movement also changes, and depending on it, the minimum values of the radius of the curves are different (table 1).

Various methods are used to construct transition curves (clothoid curve, Bernoulli lemniscate, cubic parabola, etc.) [2]. In the presented article, for the construction of transition curves to the above methods, an alternative method is created and the differential equation of curvature is solved by the analytical method, as an inverse problem of a particular case in a Cartesian coordinate system [3-5,7-9].

- $k(x)$ curvature is selected based on the following criteria:
- the function $k(x)$ must be simple and integrable;

the function $k(x)$ in a given interval must have one extremum and the value of the functions $k(x)$ must be negative in all values of the argument for the curve to be convex;

- at the starting point it is better to have a smooth transition from a straight line to a curved line.

Table 1

Road category	Calculated speed, km / h	Minimum (main) radius of curvature in the plan, m.
Ia	150	1200
Ib	120	1000
II	120	800
III	100	600
IV	80	300
V	60	150
	50	100

For this, the condition at the origin of coordinates $k(x) = 0$ must be satisfied.

The curved line defining the curvature must be smooth and convex upward in the specified interval. For example, on the interval [0, π] (1):

$$k(x) = -\mathrm{a} \cdot \sin(px) \tag{1}$$

$$k(x) = \frac{\frac{d^2y}{dx^2}}{\sqrt{\left(1+\left(\frac{dy}{dx}\right)^2\right)^3}} \tag{2}$$

when solving the differential equation of curvature (2) taking into account expression (1), the following expression (3) is obtained:

$$y_1(t) = \frac{1}{p} ln\left(\sin(pt) + \sqrt{B^2 - cos^2(pt)}\right) + C, \tag{3}$$

where: $B = p/a$; a is the maximum value of the curvature; p is the scale factor of the argument; *t* is a dimensionless parameter ($t = x/b$), the value of which varies in the interval [0,1].

X1, Y1 is the start point and X2, Y2 is the end point of the transition lines.

$C = -\ln(B^2 - 1)/2p$ is a constant, and is determined from the boundary conditions $X_1 = 0$, $Y_1 = 0$ (coordinates of the starting point of the transition curve) (Figure 1).

All dimensions are given in meters. To pass to a dimensionless quantity, all geometric

parameters are divided by *b*, where $b = |X2 - X1|$

$$x_r = \frac{X_r}{b}, \quad y_r = \frac{Y_r}{b}, \quad x_2 = \frac{X_2}{b}, \quad y_2 = \frac{Y_2}{b}, \quad r = \frac{R}{b},$$

The trajectory of a circular curve is expressed by the well-known circle formula:

$$y_2(t) = \sqrt{r^2 - (t - x_r)^2} + y_r, \tag{4}$$

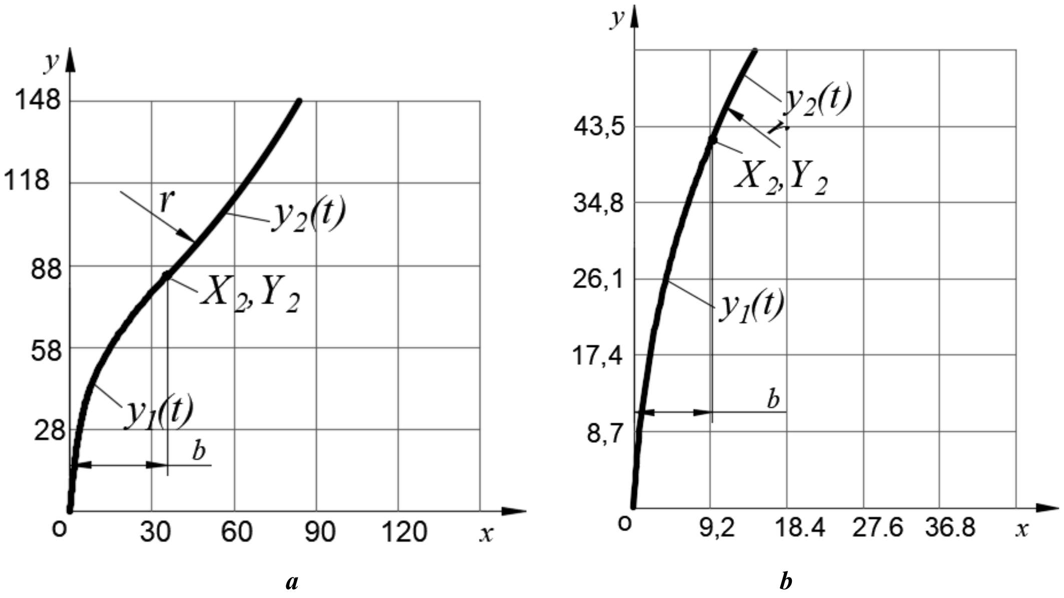

Figure 1.a) Trajectory of the road: y1 (t) transition curve, y2 (t) circular curve,

$R = 100, X_r = -40, Y_r = 100$ (radius and coordinates of the center of the circular curve);

b) $R = 100, X_r = 103, Y_r = 11$ (radius and coordinates of the center of the circular curve).

At the point (x_2, y_2), the tangents of both curves must coincide. That is, this expression must be executed: $\frac{dy_1(x_2)}{dx} = \frac{dy_2(x_2)}{dx}$. To obtain this condition, x_2 is iterated over.

$$y_2(t) = \sqrt{r^2 - (t - x_r)^2} + y_r$$

Figure 1b shows another trajectory of the road. Here a part of the circular curve of the road is built according to the formula (4).

The magnitude of the tangent at the start and end points of the transition curve of the road is determined by the formula (5):

$$\frac{dy_1(t)}{dt} = \frac{\cos(p \cdot t)}{\sqrt{\left(\frac{p}{a}\right)^2 - \cos(p \cdot t)^2}}, \tag{5}$$

The value of the vehicle speed on the transition curve is considered constant. The centrifugal force increases in direct proportion to the transition time of the transition curve, that is, from the starting point at a distance L with a radius of curvature R, it reaches within τ (seconds) after the vehicle enters the transition curve:

$$\frac{V^2}{R} = J \cdot \tau \tag{6}$$

where τ is the time during which the car passes the transition curve of length L; R is the radius of curvature of the curve at a given point; v is the speed of movement and J is the rate of increase of centrifugal acceleration. The rate of increase of centrifugal acceleration is found as follows:

$$J = \frac{V^3 \cdot k(t)}{L(t)} \tag{7}$$

where k (t) is the coefficient of curvature at a given point on the curve.

In formula (7), the distance from the beginning of the curve to a given point - $L(t)$, is determined from expression (8) taking into account (5):

$$L(t) = \int_0^t \sqrt{1 + \left(\frac{dy1(t)}{dt}\right)^2} dt = \frac{p}{a} \int_0^t \frac{dt}{\sqrt{\left(\frac{p}{a}\right)^2 - \cos(pt)^2}} \tag{8}$$

In fig. 2 shows a graph of the dependence of the path traveled along the transition curve on the x coordinate.

To ensure comfortable and safe driving on roads, the minimum length of the transition curve should be determined, taking into account the condition of maintaining the permissible value of the increase in the speed of centrifugal acceleration of the vehicle [6]. In the road design standards of most countries, it is assumed that the value of J is in the range of 0.3 ... 1 m/s^3. In Azerbaijan, the maximum value of the rate of increase of centrifugal acceleration is considered to be equal to 0.8 m/s^3 (for high-speed roads).

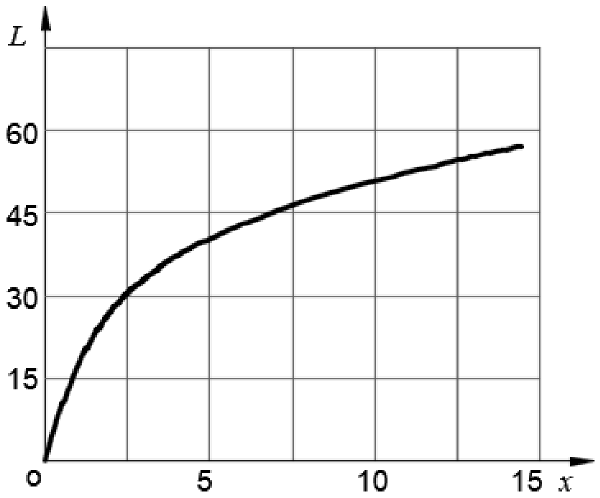

Figure 2. The path traversed by the transition curve

Coordinate x at any point of the road on the transition curve is determined from expression (8), and y - from expression (3). Table 2 shows the dependence of the coordinates of the transition curve on the distance traveled along the transition curve (Figure 1, b), calculated on the basis of expressions (3) and (8).

Table 2

Distance traveled	Coordinates	
L, м	X, м	Y, м
0	0	0
5	0,6454	4,9582
10	1,3118	9,9136
15	2,0211	14,8630
20	2,7961	19,8025
25	3,6618	24,7269
30	4,6456	29,6290
35	5,7783	34,4987
40	7,0941	39,3221
42,0988	7,7100	41,3285
45	8,6312	44,0794
50	10,4316	48,7432

The transition curve with the smallest length is determined by the condition of compliance with the standard values, the rate of increase of the centrifugal acceleration of the vehicle, as well as comfortable and safe movement on the road [6]:

$$l \geq \frac{V^3}{47 \cdot J \cdot R}, \tag{9}$$

where, V is the estimated speed of the vehicle, km / h; J is the standard value of the rate of increase of the centrifugal acceleration of the vehicle;

(When calculating for high-speed roads, 0.8 m/s^3 is taken, and for ordinary roads, 1 m/s^3).

R is the radius of the curve, m.

Based on the parameters below, the correct transition curve is verified.

For roads in Azerbaijan, $J = 0.8\ m/s^3$ is accepted.

With values *R = 100 m, V = 50 km / h* (in accordance with the normative table 1) from expression (9) we calculate l and find the values *l* = 33.2447 m. As can be seen from table 2, the length of the studied transition curve is 42 , 0988 m. And this fully corresponds to the conditions determined by expression (9).

The rate of increase of the centrifugal acceleration of a vehicle moving at a constant speed along the transition curve is determined as follows:

$$J(t) = k(t) \cdot \frac{V^3}{L(t)} \qquad (10)$$

From expression (10) it can be seen that when the car crosses the transition curve, the rate of increase of centrifugal acceleration monotonously changes from 0 (at the beginning of the transition curve) to the end of the transition curve.

In expression (3), the curvature at the start point is 0, and at the end point $-1/r$. This provides a smooth connection of the circular path of the road with a straight line using a transition curve expressed by formula (3).

As can be seen from Figure 3, the curvature changes smoothly and monotonically along the transition curve.

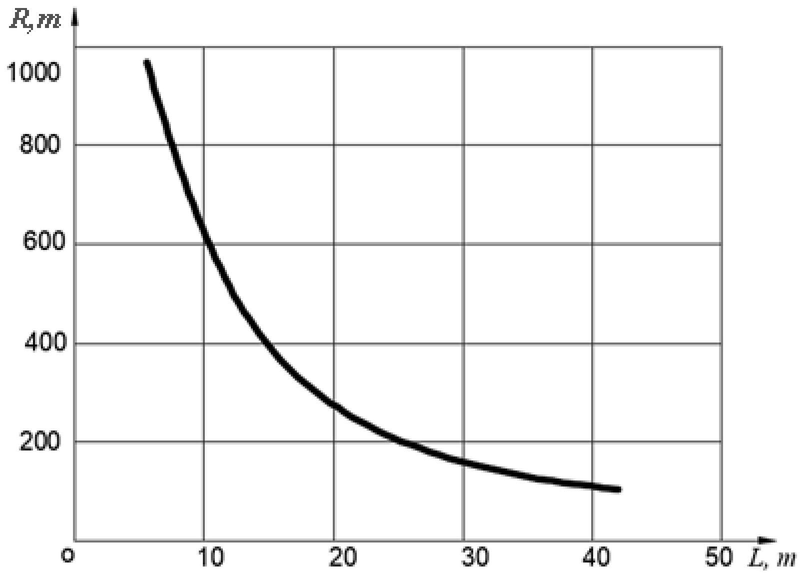

Figure 3. Graph of the dependence of the radius of curvature of the transition curve from the path traveled

Main conclusions. According to the proposed method, a monotonic change in the centrifugal acceleration along the transition curve, starting from zero (Figure 3), determines a smooth change in the centrifugal force. The application of this method allows more suitable roads to be designed and built with minimal braking when entering and exiting curves with increasing acceleration. In addition, the use of curves expressed by formula (3) on curved road sections more realistically and accurately determines the trajectory of the car when cornering.

References

[1] Piriyev Y.M. Avtomobil yolları. Dərslik. Bakı, «Azərbaycan» nəşriyyatı, 1999. -560 s.

[2] А.И. Титов, И.И. Позняк, К.Ю. Соколова. Разбивочные работы. Методические указания к расчетно-графическим работам по инженерной геодезии. Москва, МАДИ, 2014. -29 с.

[3] Иманов А.С. Профилирование лопаток по геометрическому критерию качества на основе решения обратной задач. Авиационная техника: Изв. Вузов. – 2003г. - №1. –С. 64-66.

[4] А.С. Иманов, П.Ш. Абдуллаев. Профилирование плоских авиационных лопаток на базе дифференциального уравнения кривизны. Запорожье АО «Мотор Сич», Вестник двигателестроения, № 2. 2015 г. - С. 154-158.

[5] Халилов И.А., Иманов А.С. Моделирование кулачкового механизма с учетом критериев качества. Вестник Херсонского технического университета: 4(63), 2017 г., -с. 126-134.

[6] С.И. Булдаков. Особенности проектирования автомобильных дорог. Учебное пособие. Екатеринбург, 2016. -271 с.

[7] Халилов И.А., Керимов С.Х., Иманов А.С. Аналитическое определение радиуса кривизны профиля кулачка кулачкового механизма с роликовым толкателем / Вестник Азербайджан / Инженерной Академии / Баку: 2017, Т9, №4, 6 с.

[8] İmanov Ə.S., Xəlilov İ.Ə. İki təsirli lövhəli hidromaşınların statorlarının profilinin əyrilik əsasında qurulması. Azər. və Tür. Universitetləri: «Təhsil, Elm, Texnologiya» I beynəlxalq elm. Prak. konfr. III hissə. 2019, səh.5

[9] İmanov Ə.S., Xəlilov İ.Ə. Əyriliyin kefiyyət göstəricisi əsasında qurulmuş yumruqlu mexanizmin kinematik analizi. «Ölçmə və kefiyyət: problemlər, prespektivlər» mövzusunda Beynəlxalq Elmi-texniki konfrans materialları, Aztu, Bakı 2018-ci il. səh. 182-186.

3D Object Recognition by Unmanned Aircraft to Ensure the Safety of Transport Corridors

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***Abstract*—To ensure safety by searching for and identifying suspicious or foreign objects in the area of transport corridors, in this work, it is proposed to use a 3D object recognition system, which is part of an unmanned aviation system. The method of recognition of 3D objects is based on the method of comparison with the standard. In the course of research, the authors obtained a system of equations showing the dependence of the change in the moments of inertia on the angles of rotation of the object image around the abscissa, ordinate and applicate axes. The reference image is formed by rotating through the obtained angles with subsequent direct comparison with the recognized image. If the new image of the template and the object to be recognized are the same, it is concluded that the recognized image corresponds to the template. Thus, after preliminary calculations, the listing of all possible positions is limited to a fixed number of possible positions. To confirm the obtained theoretical results, a computer simulation of the proposed method for recognizing 3D objects was carried out. The experiments were carried out on three images, which are reference images rotated in space at arbitrary angles. The simulation results showed that there is a clear connection between the moments of inertia of a plane figure during its triple rotation in space from the angles of rotation. Taking into account the characteristics of the objects to be recognized and the flight altitude of the unmanned aerial vehicle, it is possible to determine the required distance between them for reliable recognition. This will allow you to correctly build the flight route of the unmanned aerial vehicle and estimate the viewing range. This method can be used to recognize moving ground and air objects.**

Keywords—transport corridors, combating terrorism, 3D object, recognition, reliability, moments of inertia, unmanned aerial vehicle

I. Introduction

The New Silk Road was officially named by the Chinese as the "Belt and Road Initiative" project, and covers about 70 countries of the Eurasian continent. The concept of the project does not provide for the development of one land and one sea route. Instead, it actually includes the construction of a whole system of transport and economic links in the vast area connecting the Far East and Europe. Project development brings people from all countries along the routes together in a collaborative effort for common development and benefit-sharing through win-win cooperation [1, 2, 3].

In parallel, the "Program of Central Asian Regional Economic Cooperation" is actively developing. The partnership between China, the countries of Central Asia and the Caucasus stimulates the development of transport and energy and also facilitates trade in the vast territory of Eurasia [4].

Within the trans-Eurasian corridor connecting East Asia and Western Europe, the South Caucasus can be considered a central hub. Infrastructure projects such as the Baku-Tbilisi-Kars railway highlight the importance of this route. In addition, the delivery of goods from China and Asian countries to Europe via the Caspian Sea is a short and convenient way. Given the geographical location of the current economic development, Azerbaijan can be considered a focal point for both transnational exchange of goods and tourism projects [5, 6].

II. Problem Statement

Terrorism is not a new phenomenon. Many countries in Europe, Latin America, Africa and Asia have faced terrorist movements of all kinds, united by a willingness to use violence against innocent civilians to achieve their goals. Terrorists often use explosive devices as one of the most common weapons. Information on making explosive devices is readily available in books and other sources. The materials needed for the explosive device can be found in many places, including various home appliance and auto parts stores. The vast majority of attacks are carried out by individuals acting alone - often with limited training and readily available weapons - targeting densely populated or highly symbolic locations [7, 8, 9].

Currently, there are a large number of measures to prevent this kind of threat [10, 11]. However, the rapid development of technology at the end of the 20th century and the beginning of the 21st century, as well as the globalization of the economy, contributed to the emergence of highly organized terrorist groups ready to sacrifice thousands of lives to achieve their goals (for example, the attack on the World Trade Center on September 11 in New York). At the same time, the risk of mega-terrorism has become quite real, and the transport system has gained great importance in the eyes of security services around the world as the main target and / or a means for future attacks [12]. The development of high technologies has made it possible to reduce prices for sophisticated equipment, and the globalization of the "black market" has given even medium-sized terrorist organizations the opportunity to buy a combat drone, given that its price is comparable to the price of a car [13]. In addition, training for a participant in an organization to control a combat aircraft or vehicle has become available.

The rates are extremely high, as any major disruption to the transport system could cause significant damage to the country's economy and reduce its reputation in the world.

At present, sufficiently effective tools have been developed to protect marine corridors [14]. However, works are worse for land transport corridors. The location of the corridor in sparsely populated or hard-to-reach areas makes it difficult to ensure its safety. This is due to the fact that a combat aircraft can quickly enough and (using the terrain) imperceptibly approach, strike and hide.

Thus, we can say that ensuring the security of its transport corridors is and will be one of the main tasks of the national security of each country.

III. PROBLEM SOLVING

Drone is an informal name for devices known as unmanned aerial vehicles (UAV), unmanned aircraft systems (UAS), and small unmanned aircraft systems (sUAS). The term UAS refers to the entire system for using a drone, including the aircraft and the ground control unit, while UAV refers only to the vehicle itself [15].

Drone opportunities can be found in almost all fields of life. One of the directions in the civil sector is the use of UAS to prevent various types of crimes and terrorist acts [16].

The use of drones to automate routine and monotonous work can improve safety performance, reduce risks, and improve quality. It will also free people to focus on more responsible, interesting and rewarding work [17].

Fig. 1. presents a generalized block diagram of the UAS [18]. The standard set of equipment used in most UAS includes: a transmitter for controlling the UAV (Tr); the UAV itself, consisting of a control signal receiver and the transmitter of useful information (Re+Tr), a flight computer (FC), a navigation system (NS+GPS), a sensor unit (SU) and a camera for photo and video shooting; a ground control station (GCS) for semi-autonomous control and processing of the received information.

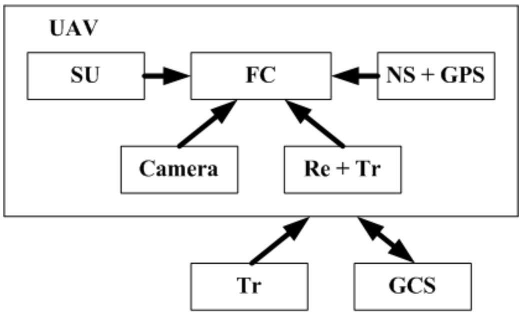


Fig. 1. UAS block diagram

To ensure safety, by searching and identifying suspicious or foreign objects in the area of transport corridors, this work proposes the use of a system for recognizing 3D objects. With the help of the organ of vision of the system (a camera located on a high-flying UAV), we obtain a two-dimensional image of the earth's surface. This image will also contain objects located at a low height. Further, this information will be transmitted to the ground for further processing.

Due to the fact that the object of interest (OI) in most cases will be away from the UAV (Fig. 2), its image will undergo such distortions as rotation and shift. As a result, all geometric features will be strongly distorted and recognition by geometric features becomes much more difficult.

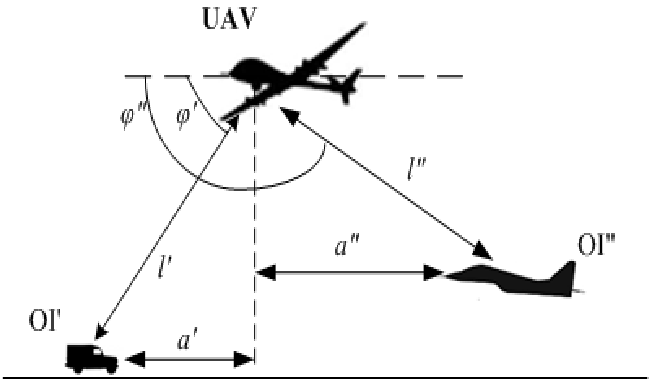


Fig. 2. The relative position of objects of interest relative to the UAV.

Currently, many techniques have been developed for the recognition of spatial images of objects, however, each of them has its own drawbacks. So in [19], parallel transfer and rotation of the image is considered, which is a special case of spatial displacements. In [20, 21], the analysis is carried out by reference points, the numbering of which should remain constant with spatial distortions, which is not always achievable. In [22, 23], the analysis of the image is carried out along the contour, which is the most sensitive to distorting factors. In [24], the moments of inertia are considered as the main features, however, the analysis of the properties of the moments of inertia showed that the moments of inertia, as features, are quite integral for a wide range of objects. This makes it difficult to recognize objects of the same cluster.

In this paper, it is proposed to use statistical moments as image landmarks, and based on this principle, develop an effective method for recognizing 3D objects.

One of the ways to recognize an object located in an arbitrary way in space is to recognize its sides from two-dimensional images by comparing them with reference images.

In fact, the image of the side of an object is a flat closed single-line or multi-line figure. The process of recognizing an object located arbitrarily in space can be reduced to recognizing several flat figures located arbitrarily in space. Because a flat figure is a solid body, then the analysis of its position in space can be performed by analyzing the position of a fixed marker point located on a flat figure. In this case, an arbitrary location of a plane figure, and therefore a marker point in space, is considered as rotations of a plane figure around three coordinate axes. The analysis of the position of a flat figure will be carried out by analyzing the position of the projection of the marker point on the frontal plane. In this case, the origin point is located in the center of the flat figure.

In the course of research [25], the authors obtained the dependence of the change in the coordinates of the projection of the marker point when the frontal plane rotates around the horizontal axis OX, followed by rotation around the vertical axis OY:

$$x_2 = x_0 \cdot \cos\beta , \qquad (1)$$

$$y_2 = y_0 \cdot \cos\alpha \pm x_0 \cdot \sin\beta \cdot \sin\alpha , \qquad (2)$$

Where x_0, y_0 – are the coordinates of the marker point on the original frontal plane, x_2, y_2 – are the coordinates of the marker longing after its double rotation, α – is the angle of rotation around the horizontal axis, β – is the angle of rotation around the vertical axis.

After integrating expressions (1) and (2) for the entire figure, we obtain expressions for the moments of inertia of a flat figure after its double rotation in space:

$$J_{X2} = \cos^3\alpha \cdot \cos\beta \cdot J_{X0} \pm 2 \cdot \cos^2\alpha \cdot \sin\alpha \cdot \sin\beta \cdot \cos\beta \cdot J_{X0Y0} +$$
$$+ \cos\alpha \cdot \sin^2\alpha \cdot \cos\beta \cdot \sin^2\beta \cdot J_{Y0}, \quad (3)$$

$$J_{Y2} = \cos\alpha \cdot \cos^3\beta \cdot J_{Y0}, \quad (4)$$

$$J_{X2Y2} = \cos^2\alpha \cdot \cos^2\beta \cdot J_{X0Y0} \pm \cos\alpha \cdot \sin\alpha \cdot \cos^2\beta \cdot \sin\beta \cdot J_{Y0}, \quad (5)$$

Where J_{X0}, J_{Y0}, J_{X0Y0} – respectively the moment of inertia of the original figure along the OX axis, along the OY axis and the centrifugal moment of inertia; J_{X2}, J_{Y2}, J_{X2Y2} – respectively, the moment of inertia of a flat figure, after its double rotation in space, along the OX axis, along the OY axis and the centrifugal moment of inertia.

As is known [20], the moments of inertia of the section when the axes passing in the section plane are rotated around the axis passing perpendicular to the section plane are related by equations (6) ÷ (8):

$$J_U = J_X \cdot \cos^2\gamma + J_Y \cdot \sin^2\gamma - J_{XY} \cdot \sin 2\gamma, \quad (6)$$

$$J_V = J_X \cdot \sin^2\gamma + J_Y \cdot \cos^2\gamma + J_{XY} \cdot \sin 2\gamma, \quad (7)$$

$$J_{UV} = J_{XY} \cdot \cos 2\gamma + \frac{J_X - J_Y}{2} \cdot \sin 2\gamma, \quad (8)$$

Where J_X, J_Y, J_{XY}– axial and centrifugal moments of inertia of the section relative to the original axes; J_U, J_V, J_{UV} – axial and centrifugal moments of inertia of the section relative to the rotated axes; γ – angle of rotation.

Substituting expressions (3) ÷ (5) into equations (6) ÷ (8) and denoting the constants J_U, J_V, J_{UV}, respectively, as J_{X3}, J_{Y3} and J_{X3Y3}, we obtain the dependence of the change in the moments of inertia of a plane figure during its triple rotation in space:

$$J_{X3} = f(\alpha, \beta, \gamma, J_{X0}, J_{Y0}, J_{X0Y0}), \quad (9)$$

$$J_{Y3} = f(\alpha, \beta, \gamma, J_{X0}, J_{Y0}, J_{X0Y0}), \quad (10)$$

$$J_{X3Y3} = f(\alpha, \beta, \gamma, J_{X0}, J_{Y0}, J_{X0Y0}), \quad (11)$$

By solving the system of equations (9) ÷ (11), expressions for the variables α, β and γ are determined.

Recognition is carried out in three stages:

- At the first stage, the reference image of the object is rotated by the calculated angles α, β, γ. U- turns are made in the following sequence: at the beginning, a turn around the center of mass by an angle γ; further rotation around the abscissa axis by an angle α (in this case, the ordinate axis will rotate along with the image); and at the end, a turn around the rotated ordinate by an angle β.

- At the second stage, the scale is adjusted. Using an on-board ranging instrument (laser or radio rangefinder), the distance to the object of interest *l* is determined *(fig. 2)*. Based on the distance, the change in the scale of the object's image is calculated. In the absence of rangefinders, the scale can be determined using the navigation system. The distance is determined indirectly from two images taken at different points in space. Knowing the exact location of the UAV in space, by the value of the angle between the longitudinal axis and the direction of the camera *φ (fig. 2)*. From two images, you can calculate the distance to the object of interest, and therefore the scale.

- At the third stage, a direct comparison of the resulting image with the recognizable. For this, the center of mass of the recognized image is reduced to the center of mass of the converted reference image.

If in any of the new positions of the reference images coincide, then it is concluded that the recognized image corresponds to the reference. In this case, the quantities α, β and γ determine the orientation of the object in space.

That is, after preliminary calculations, the enumeration of all possible positions is limited to a fixed number of possible positions.

However, there will be no complete coincidence of the images due to the presence of sampling distortion in the converted image. This manifests itself on its contour in the form of a change in the values of individual pixels. As a numerical estimate of the similarity between the reference and the recognized image, you can use the transformed measure of the Manhattan distance [26]:

$$Z = \sum_{i=1}^{m} |A(x,y)_i - B(x,y)_i| \leq \varepsilon = 2 \cdot P \quad (12)$$

Where: A (x, y) and B (x, y) - respectively the values of points belonging to the standard and the recognized image; x, y – pixel coordinates in the image; *i* – the number of pixels in the image; ε – the value of the confidence threshold depending on the size of the images and the computational error of the analysis; P – reference perimeter.

This measure shows the discrepancy between the images, i.e. number of mismatched pixels in direct comparison.

If the discrepancy for any image does not exceed the permissible deviation, then it is concluded that the image under consideration corresponds to the reference image, and the object is oriented in space in accordance with α, β and γ.

IV. Computer Simulations

To check the obtained theoretical results, computer simulation was carried out.

The proposed technique was investigated using images of objects of the same nature. The ability to fly and carry any combat load was taken as this character. For example, the MiG-25, SU-25 and SU-30 aircraft were taken.

In fig. 3 shows three flat figures, which are horizontal projections of these objects. These images can theoretically be acquired by a high-flying UAV that continuously probes the earth's surface. These images are entered into the ground control station (GCS) database, where recognition is performed, as reference objects.

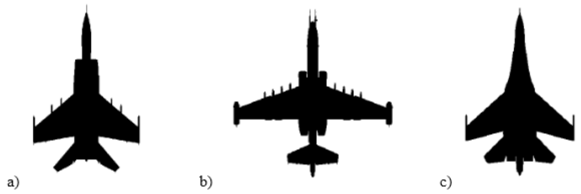


Fig. 3. Images from the database:

a – MIG-25; b – SU-25; c – SU-30

As a characteristic for determining the difference in the images of objects, one can take the "shape index" ρ [27]:

$$\rho = \frac{\text{Perimeter}^2}{Area}. \qquad (13)$$

For a more detailed study, several options for images of the proposed objects were considered, differing in size. Table 1 summarizes the main parameters of the considered images.

Table 1. Reference image parameters

Image	Object height, pixel	Object width, pixel	Object area, pixel	Object shape index, (ρ).
Fig. 1, a.	300	190	18646	107
	350	222	25370	
	400	253	32995	
	450	285	41910	
	500	317	51768	
Fig. 1, b.	300	284	20119	153
	350	331	27292	
	400	379	35464	
	450	426	44712	
	500	473	55437	
Fig. 1, c.	300	194	19766	93
	350	226	26772	
	400	258	34794	
	450	291	44113	
	500	323	54378	

The object of interest can be in four positions relative to the UAV:

1. The object of interest is located directly under the UAV. In this case, we can say that the camera with which the image was obtained is directed perpendicularly downward.

2. The object of interest is located away from the UAV, while the image of the longitudinal axis of the object is parallel or coincides with the longitudinal axis of the UAV.

3. The object of interest is located away from the UAV, while the image of the longitudinal spine of the object is perpendicular to the longitudinal axis of the UAV.

4. The object of interest is located away from the UAV and its position is random.

To obtain a set of images for the first position, the reference images were rotated around the center of mass by angles γ with a step of 40º (40º; 80º; 120º; 160º; 200º; 240º; 280º; 320º). As a result, 8 transformed images were obtained for each size of each shape. The obtained images were used to determine the axial (J_{Xfig}, J_{Yfig}) and centrifugal (J_{XYfig}) moments.

Also, according to formulas (9) ÷ (11) for these images, the moments of inertia J_{X3}, J_{Y3}, J_{X3Y3} were calculated. Considering that the image made only one rotation, the variables α and β during the calculations were equal to 0.

To obtain a set of images for the second position, the reference images were rotated around the abscissa axis by angles α with a step of 10º (10º; 20º; 30º; 40º; 50º; 60º; 70º; 80º). As a result, 8 transformed images were obtained for each size of each shape. The obtained images were used to determine the axial (J_{Xfig}, J_{Yfig}) and centrifugal (J_{XYfig}) moments.

Also, according to formulas (9) ÷ (11) for these images, the moments of inertia J_{X3}, J_{Y3}, J_{X3Y3} were calculated. Taking into account that the image made only one rotation, the variables β and γ in the course of calculations were equal to 0.

To obtain a set of images for the third position, the reference images were rotated around the ordinate by angles β with a step of 10º (10º; 20º; 30º; 40º; 50º; 60º; 70º; 80ºAs a result, 8 transformed images were obtained for each size of each shape. The obtained images were used to determine the axial (J_{Xfig}, J_{Yfig}) and centrifugal (J_{XYfig}) moments.

Also, according to formulas (9) ÷ (11) for these images, the moments of inertia J_{X3}, J_{Y3}, J_{X3Y3} were calculated. Taking into account that the image made only one rotation, the variables α and γ during the calculations were equal to 0.

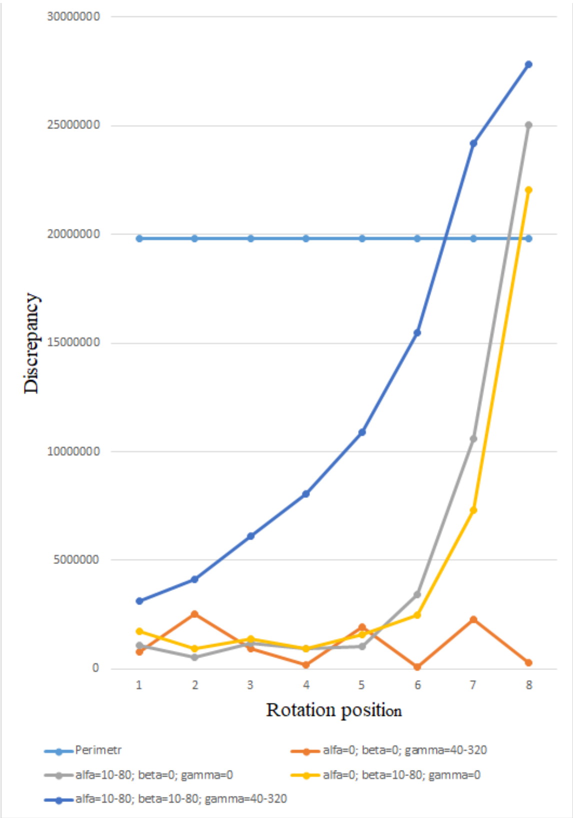
To obtain a set of images for the fourth position, the reference images were rotated around the center of mass at angles γ with a step equal to 40°, followed by turns around the horizontal axis at angles α with a step equal to 10 ° and around the vertical axis at angles β with a step equal to 10º (10º,10º,40º; 20º,20º,80º; 30º,30º,120º; 40º,40º,160º; 50º,50º,200º; 60º,60º,240º; 70º,70º,280º; 80º,80º,320º). As a result, 8 transformed images were obtained for each size of each shape. The obtained images were used to determine the axial (J_{Xfig}, J_{Yfig}) and centrifugal (J_{XYfig}) moments. Also, according to formulas (9) ÷ (11) for these images, the moments of inertia J_{X3}, J_{Y3}, J_{X3Y3} were calculated.

Further, the absolute discrepancies Δ were calculated between the corresponding moments of inertia obtained from the images and by the formulas (9) ÷ (11):

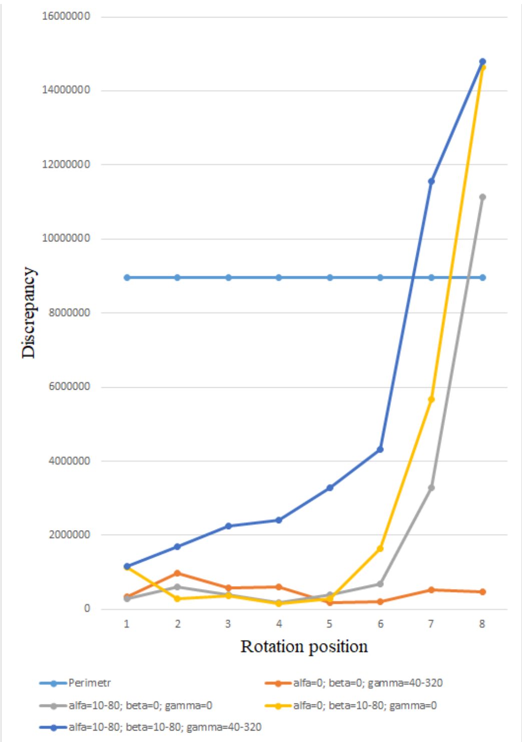
$$\Delta_X = |J_{Xfig} - J_{X3}|, \qquad \Delta_Y = |J_{Yfig} - J_{Y3}|, \qquad \Delta_{XY} = |J_{XYfig} - J_{X3Y3}|. \qquad (14)$$

In fig. 4 shows the averaged changes in the absolute discrepancy ΔX (fig. 4, a), ΔY (fig. 4, b) and ΔXY (fig. 4, c) for the object shown in fig. 3, a.

a)



b)



c)

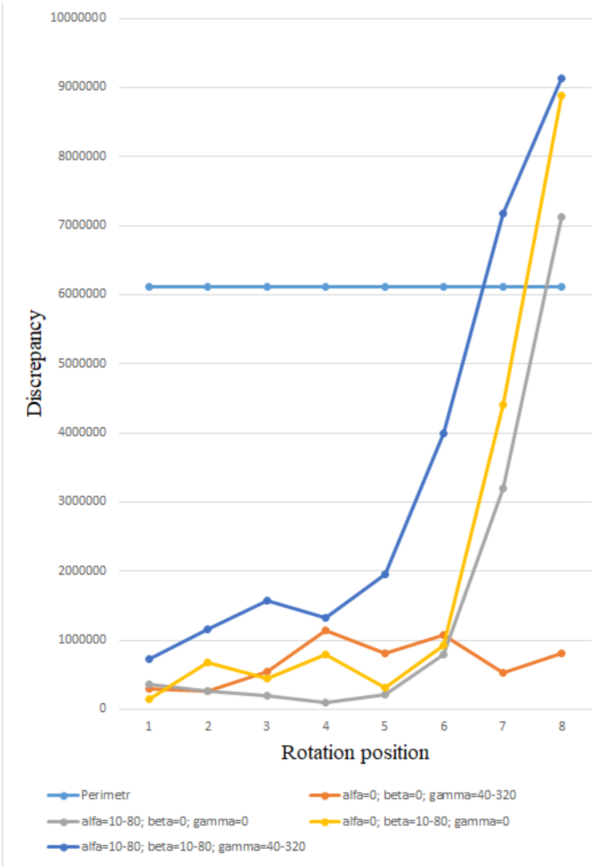
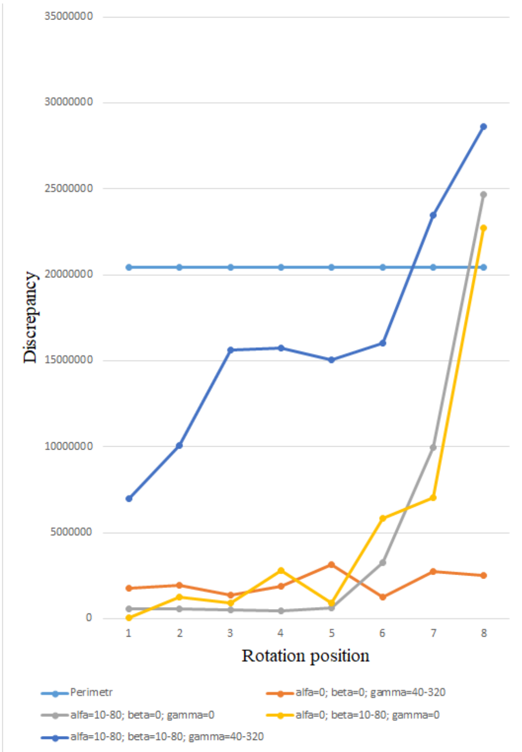


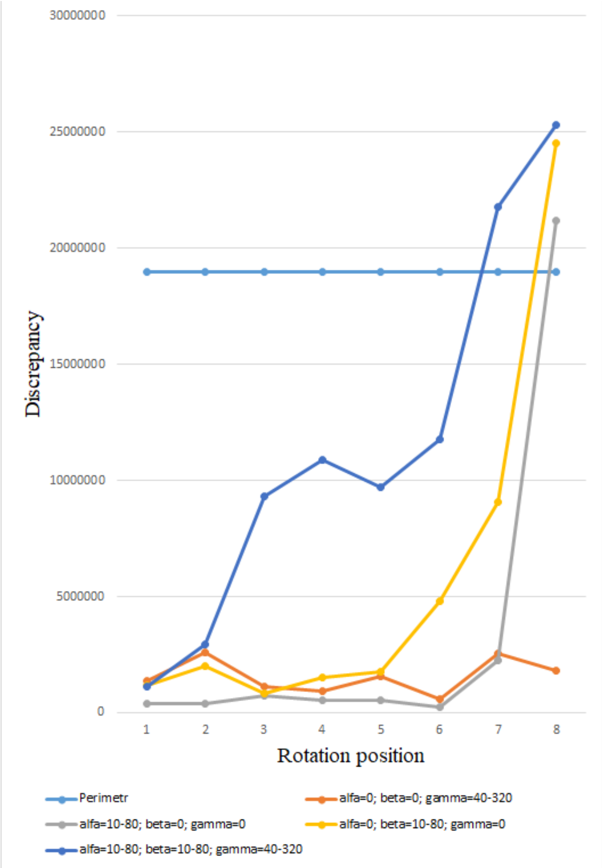
Fig. 4. Average changes in the absolute discrepancy in the moments of inertia for the image of the MIG-25 aircraft.

In fig. 5 shows the averaged changes in the absolute discrepancy ΔX (fig. 5, a), ΔY (fig. 5, b) and ΔXY (fig. 5, c) for the object shown in fig. 3, b.

a)



b)



c)

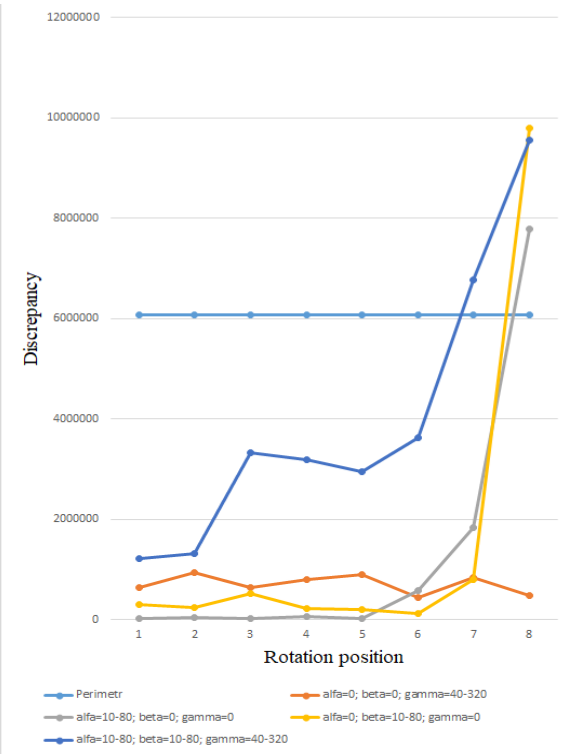
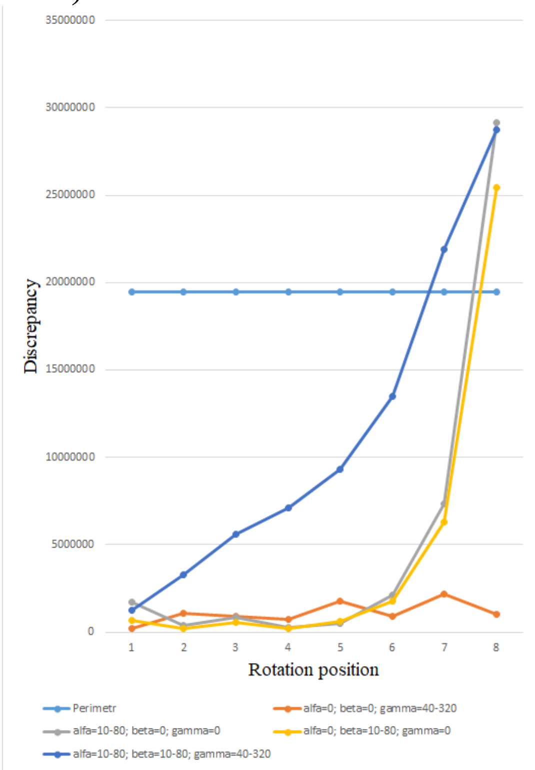


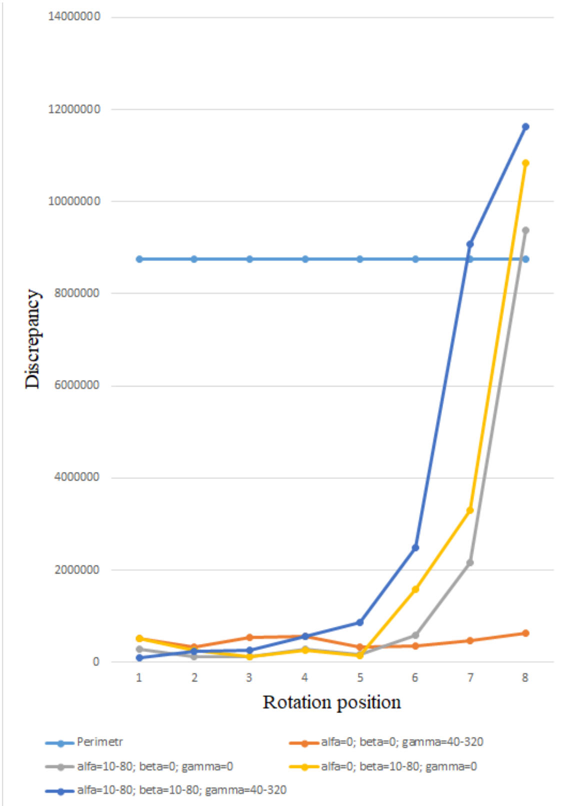
Fig. 5. Average changes in the absolute discrepancy in the moments of inertia for the SU-25 aircraft image.

In fig. 6 shows the averaged changes in the absolute discrepancy ΔX (fig. 6, a), ΔY (fig. 6, b) and ΔXY (fig. 6, c) for the object shown in fig. 3, c.

a)



b)



c)

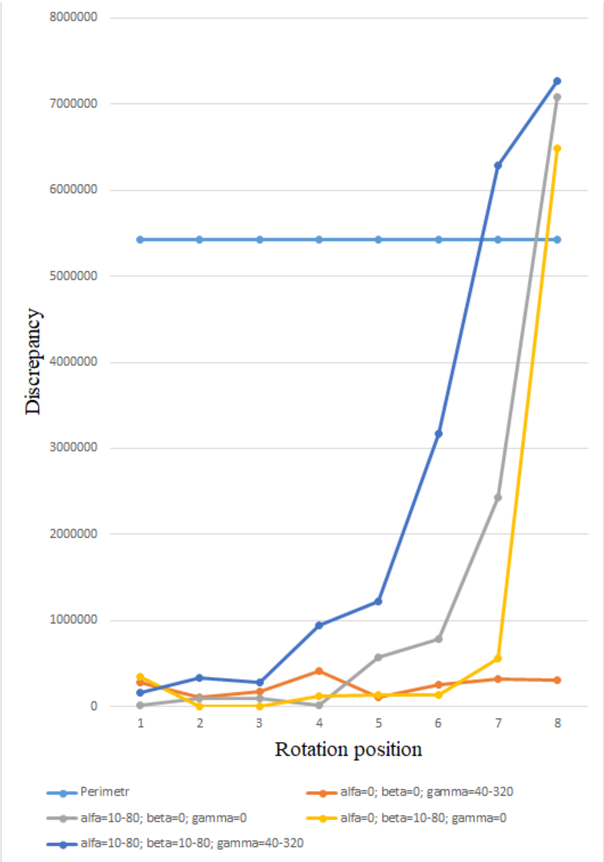


Fig. 6. Average changes in the absolute discrepancy in the moments of inertia for the SU-30 aircraft image.

For simplicity, the evaluation of the effectiveness of the proposals of the method was carried out according to the values of Δ. That is, if the value of Δ does not exceed the threshold value, then the recognition can be considered reliable. Since the perimeter of the object is the most sensitive to any image transformations, the corresponding moment of inertia of the perimeter was chosen as the threshold value.

V. CONCLUSİON

The analysis of the change in the moments of inertia of a plane figure during its rotation around three coordinate axes for recognition carried out by the authors showed that there is a clear relationship between the moments of inertia of a plane figure during its triple rotation in space on the angles of rotation.

Analyzing Fig. 4, fig. 5 and fig. 6, it can be assumed that: the law of variation of Δ is close to an increasing exponential, when there is rotation around the abscissa and / or ordinate axis; and the law of variation of Δ is close to harmonic oscillation when there is rotation only around the center of mass.

Further analysis shows that if the recognized image has α = 0 and β = 0, then for any value of γ the recognition will have a high reliability. Thus, we can say that this rotation has a minimal effect on the recognition process, and the discrepancy is mainly due to the computational error.

With an increase in α or β, with the exception of the limit values (more than 80^0), the recognition will have an acceptable reliability. With a simultaneous increase in α and β, high reliability will be at angles up to 40^0, and at angles more than 60^0, the recognition reliability will be low. This may be due to a decrease in the image area of the object of interest. Studies have shown that the larger the image area of the object, the higher the recognition reliability. However, increasing the area greatly slows down the recognition process, and powerful computing resources are required to implement it.

In addition, the shape index also affects the recognition reliability. As can be seen from Fig. 5, for objects with a high shape index, high reliability can be obtained only at small angles of image rotation (less than 20^0).

Taking into account the shape index of the objects of interest and the UAV flight altitude, it is possible to determine the required distance a (Fig. 2). This will allow you to correctly plot the UAV flight route and estimate the viewing range. This technique can also be applied to the recognition of moving ground objects.

REFERENCES

[1] Zoran Wittine , Hrvoje Josic and Antea Barisic. Analysis Of Characteristics And Potential Effects Of The New Silk Road Initiative // Conference of the International Journal of Arts & Sciences, ISSN: 1943-6114 :: 11(02):255–260 (2018).

[2] Aleksandar Janković. New Silk Road – New Growth Engine // The Review of International Affairs, Belgrade, vol. LXVII, No. 1161, (2016)

[3] New Stories of the Silk Road. No. 9, (2017)

[4] The New Silk Road. Ten Years of the Central Asia Regional Economic Cooperation Program. Mandaluyong City, Philippines: Asian Development Bank, (2011).

[5] Schuhbert, A., & Thees, H. Of routes and corridors: Challenges and opportunities for Silk Road destinations in the southern Caucasus. Journal of Tourism, Heritage & Services Marketing, 6(2),pp. 21-29, (2020).

[6] Tamila Sh. Khalilova, Renying Li, Elchin N. Khalilov. Caspian Route Of The Silk Road // International Journal of Asian History, Culture and Traditionб Vol.4, No.4, pp.1-9, (2017)

[7] Daniel O'Donnell. International Treaties Against Terrorism And The Use Of Terrorism During Armed Conflict And By Armed Forces // International Review of the Red Cross, Vol. 88, No 864, (2006)

[8] www.fema.gov/pdf/areyouready/terrorism.pdf.

[9] Communication From the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. A Counter-Terrorism Agenda for the EU: Anticipate, Prevent, Protect, Respond, (2020).

[10] Center for the Protection of National Infrastructure. Protecting Against Terrorism, (2010).

[11] United Kingdom Country Security Report, (2021).

[12] Organisation for Economic Co-operation and Development. Security in Martime Transport: Risk Factors and Economic Impact. Maritime Transport Committee, (2003).

[13] Ricardo Valerdi. Cost Metrics for Unmanned Aerial Vehicles // Collection of Technical Papers - InfoTech at Aerospace: Advancing Contemporary Aerospace Technologies and Their Integration. Vol. 3, pp. 1753 – 1758, (2005)

[14] NATO Public Diplomacy Division. Briefing. Combating terrorism at sea, (2008)

[15] Police Executive Research Forum. Drones: A Report on the Use of Drones by Public Safety Agencies—and a Wake-Up Call about the Threat of Malicious Drone Attacks. Washington, DC: Office of Community Oriented Policing Services, (2020).

[16] Bart Custers. The Future of Drone Use. Opportunities and Threats from Ethical and Legal Perspectives // Information Technology and Law Series, Vol. 27, (2016)

[17] PwC. Skies without limits. Drones - taking the UK's economy to new heights, (2018)

[18] Mitch Campion, Prakash Ranganathan, and Saleh Faruque. A Review and Future Directions of UAV Swarm Communication Architectures // IEEE International Conference on Electro/Information Technology, (2018)

[19] Мамедов Р.К., Муталлимова А.С., Алиев Т.Ч., Использование моментов инерции изображения для инвариантного к аффинным преобразованиям распознавания// Восточно-Европейский журнал передовых технологий. №4/3 (58), 2012, с. 4-7.

[20] Vimal Sudhakar Bodke, Omkar S Vaidya (2017). Object Recognition in a Cluttered Scene using Point Feature Matching. *International Journal for Research in Applied Science & Engineering Technology*, 286-290.

[21] Toshiaki Ejima, Shuichi Enokida, Toshiyuki Kouno (2014). 3D Object Recognition based on the Reference Point Ensemble. *International Conference on Computer Vision Theory and Applications*, 261-269.

[22] Farnoosh Ghadiri, Robert Bergevin, Guillaume-Alexandre Bilodeau: Carried Object Detection Based on an Ensemble of Contour Exemplars. 14th European Conference Computer Vision – ECCV 2016. Amsterdam, October 11–14, pp. 852-866 (2016).

[23] Xin Li, Fan Yang, Hong Cheng, Wei Liu, Dinggang Shen: Contour Knowledge Transfer for Salient Object Detection. 15th European Conference Computer Vision – ECCV 2018. Munich, September 8-14, pp. 370-385 (2018).

[24] Mohammad Arafah, Qusay Abu Moghli (2017). Efficient Image Recognition Technique Using Invariant Moments and Principle Component Analysis. Journal of Data Analysis and Information Processing, 1-10.

[25] Мамедов Р.К., Алиев Т.Ч. Контроль положения 3D-объектов в гибких автоматизированных системах. Повышение достоверности распознавания. – LAP LAMBERT academic publishing, 2016. - 90 с.

[26] Mammadov R.G., Aliyev T.Ch., Mutallimova A.S. Identification of spatial objects by their monochrome images of autonomous mobile robots // International journal of engineering research and science», vol.2, №11, November 2016, India, pp.125-128.

[27] Jens Feder. Fractals. Plenum press. New York. 1988

Formulation of the Problem and General Requirements for Optimization Methods of Operational and Organizational Control Systems

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***Abstract*−The problem statement for the optimization of operational and organizational control systems is formulated and the general requirements for methods of solution are given. A probabilistic and deterministic approach to the problem of operational and organizational control taking into account the time factor is considered.**

Keywords−control systems, optimization methods, operational control, problems of synthesis

I. Introduction

The term "operational and organizational control" in this paper means the processes of control and decision-making in organization systems and operational control systems based on the use of the prediction principle with periodic adjustments based on the processing of current information, i.e., rolling plan principle. Systems of this type find application in automated control systems at all hierarchy levels, are widely used to improve efficiency in all segments of industrial production, to optimize the control of vehicles, urban economy of large industrial centers, etc. Such operational control systems are successfully used to solve emergency management tasks [1]. The specifics of such tasks are associated with the need for an operational, i.e., prompt control decision making, and reflects the fact of time shortage. The time resource for control decision making in most cases is not constant, but depends on the current situation. Therefore, it is difficult to formalize mathematically correctly within the framework of the general formulation of the control problem. As a result, the design engineer has to rely on intuition or perform laborious and inefficient enumeration. In this paper, this problem is solved using the principle of complexity.

The term "operational and organizational control" reflects the two most significant features of the investigated control processes. The first of them is that the mathematical formalization of control problems of the control objects has constraints that are complex in form and various in content and do not fit entirely in the framework of known optimization problems, which requires taking into account a number of organizational measures. The second feature has to do with the need for operational, i.e., prompt control decision making and reflects the fact of time shortage.

The development of methods suitable for use in operational and organizational control systems has so far been carried out almost independently in the areas of optimal control theory, mathematical programming, operations research and artificial intelligence. We have made an attempt to classify all the numerous methods of approximate solution by their functional characteristics, reflecting the factors of taking into account the mathematical essence of the problem.

Problems of operational and organizational control are extremely widespread in the field of control, both for traditional dynamic objects and objects, the problems of optimal control of which have only begun to be studied in recent decades. These include, first of all, large transport networks, production sites of industrial enterprises, territories and facilities subject to catastrophic natural or man-made impacts, etc. To these objects, we can add large territorial associations, large information systems and, finally, computational processes and computing systems [2].

The optimization problems and methods investigated in this paper are widely used in all the above-mentioned areas of control. However, since the principles of their construction have certain peculiarities, the expediency of using operational and organizational control systems must be determined by comparison based on technical, operational and economic indicators with control systems of other types, such as systems based on the traditional principles of the automatic control theory [3]. At the same time, there is a fairly wide class of control objects in virtually all spheres of practical applications, where operational and organizational control systems are, apparently, the only means of achieving the set goal of control.

II. ORMULATION OF THE OPERATIONAL AND ORGANIZATIONAL CONTROL PROBLEM

Let us consider a control object characterized at each time instant t by a vector of state (output) parameters $\vec{x}\,(t)$ (this vector is also often called a phase vector), a vector of control variables $\vec{u}\,(t)$, a vector of disturbances t, and a vector of observable variables $\vec{y}(t)$. The latter are those generalized coordinates of the control object, information about the change of which is sent to the control system [4]. If the state parameters x^j can be changed directly, then $x^j = y^j$. Further, for simplicity, we assume that this condition is satisfied for all j and $\vec{x}\,(t) = \vec{y}\,(t)$.

The relationship between the vectors $\vec{x}\,(t), \vec{u}\,(t), \vec{\xi}\,(t)$ is given by the constraint equations

$$\vec{x}\,(t) = X\left[\vec{x}\,(t), \vec{u}\,(t_0, t), \vec{\xi}\,(t_0, t)\right], \qquad (1)$$

where t_0 is the initial time instant.

If the object can be characterized by differential equations, then instead of (1) we can write equations in the normal Cauchy form

$$\dot{\vec{x}}\,(t) = f\left(\vec{x}\,(t), \vec{u}\,(t), \vec{\xi}\,(t), t\right). \qquad (2)$$

To find $\vec{x}\,(t)$ from the known $\vec{u}\,(t)$ and $\vec{\xi}\,(t)$ on the time interval $[t_0, T]$, it is necessary to know the boundary conditions at its left end, i.e., $\vec{x}\,(t_0)$, or at the right end, i.e., $\vec{x}\,(T)$. In this case, the solution of equations (2) is called the solution of the Cauchy problem. In the case when it is necessary to transfer the object from the initial state $\vec{x}\,(t_0)$ to the final state $\vec{x}\,(T)$, i.e., both $\vec{x}\,(t_0)$ and $\vec{x}\,(T)$ are given, we say that the so-called two-point boundary value problem (or simply a boundary value problem) needs to be solved. The solution of the latter is much more challenging than the solution of the Cauchy problem.

Most practically important control problems include phase constraints (or constraints along the trajectory)

$$\vec{x}\,(t) \in E_x \qquad (3)$$

and control constraints

$$\vec{u}\,(t) \in E_u, \qquad (4)$$

where E_x and E_u are given varifolds in linear metric spaces R^{n+1} and R^{m+1}, respectively (n is the dimensionality of $\vec{x}$; m is the dimensionality of $\vec{u}$).

The choice of the vector function $\vec{u}\,(t)$ must comply with the requirement of the indicator of the control goal, given in the form of the following functional, reaching extremum:

$$E_{\text{id}}^{*} = E_{\text{id}}\left(\vec{x}\,(t), \vec{u}\,(t), \vec{\xi}\,(t)\right) \to extr. \qquad (5)$$

Reducing expression (5) to the extremum with constrain equations (1) or (2) and constraints (3), (4) in the general case is a difficult-to-solve problem. This is primarily due to the difficulties in obtaining equations (1) or (2) of the object presented to the control problems, as well as the difficulties in the practical implementation of the control law found for such a description of the object. Therefore, the implementation of the optimal control system, as a rule, is carried out as a result of the following two stages:

1) primary (ideal) optimization, when a simplified mathematical description of the control object is used to solve the variational problem; the vector control function found at this stage will be denoted by $\vec{u}_{\text{id}}\,(t)$, and the dependence $\vec{u}_{\text{id}}\,(t) = \vec{u}_{\text{id}}\,(\vec{x}\,(t), t)$ will be called the ideal control algorithm;

2) secondary optimization (optimization of control performance), which consists in finding such a realizable vector control function $\vec{u}^{*}\,(t)$, which, firstly, in the given sense differs minimally from $\vec{u}_{\text{id}}\,(t)$ and, secondly, takes into account the properties of the object to the degree of completeness, which is sufficient for the implementation of the set control goal.

3) As a measure of the approximation of an ideal control algorithm to the optimal one, functionals can be used, which connect:

4) extrema of the control goal achieved by the ideal and real control algorithm

5) $Q = Q\,[E_{\text{id}}^{*} - E^{*}]$;

6) ideal and real state vector

7) $\Phi = \Phi\,[\vec{\varepsilon}_{\text{id}}\,(t) = \vec{x}_{\text{id}}\,(t) - \vec{x}\,(t)]$.

8) The functional Q is called the control performance index, Φ – the accuracy factor, $\vec{\varepsilon}_{\text{id}}\,(t)$ – the error vector.

9) The use of the functional Q in comparison with the functional Φ is associated with much greater difficulties, which is due to the need to calculate the current values $E_{\text{id}}^{*}(t) - E^{*}\,(t) = \Delta E\,(t)$ and the possible ambiguity of the inverse dependence $\vec{u}\,(t) = \vec{u}\,(\Delta E\,(t), \vec{x}\,(t), t)$. For this reason, the accuracy factor Φ is used in practice. The diagram in which the functional Φ is used to form the control law in an automated system is shown in Fig. 1.

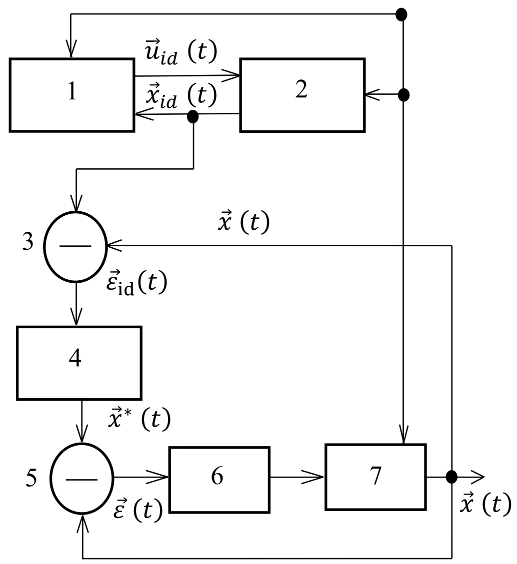

Fig. 1. The flowchart of an automatic control system based on the formation of an error signal from the setting vector $\vec{x}_{\text{id}}\,(t)$

Object *7* is influenced by uncontrolled impacts $\vec{\xi}\,(t)$, which in one form or another are taken into account by ideal model *2* formed on the basis of a simplified mathematical description of the object in form (1) or (2). Computer of ideal mode *1* solves the variational problem, the result of which results is $\vec{u}_{id}(t)$ and $\vec{x}_{id}(t)$. Comparison of $\vec{x}_{id}(t)$ and $\vec{x}(t)$ by device *3* allows us to determine $\vec{\varepsilon}_{id}(t)$, after which control accuracy optimizer *4* minimizes the functional Φ and calculates the optimal value of the state vector $\vec{x}^*(t)$. Comparator *5* calculates the difference $\vec{x}^*(t) - \vec{x}(t)$, which generates an error signal in a closed control circuit, which includes control object *7* and power amplifier *6*, which is usually necessary to implement control.

As a rule, a functional of the following form is chosen as the accuracy factor Φ:

$$\Phi = \int_0^{T_y} \varphi\{\vec{\varepsilon}_{id}(t)\}\, dt, \qquad (6)$$

where φ is some continuous function of the arguments $\varepsilon_{id}^1(t), \varepsilon_{id}^2(t), \ldots, \varepsilon_{id}^n(t)$; T_y is the moment of the end of object control.

In cases where the measure of the total deviation of the actual state vector $\vec{x}(t)$ from the ideal over a sufficiently large time interval is of interest, the integration limits in (6) are replaced with the boundary values of the interval $[-\infty \div +\infty]$. Sometimes, instead of (6), an estimate is used not on the interval $[0, T]$, but only at a certain instant $t = T$, i.e.,

$$\Phi = \varphi\,[\vec{\varepsilon}_{id}(T)]. \qquad (7)$$

Obviously, it may turn out to be useful not to use functional (6) or a single estimate (7) as a control accuracy factor, but a set of estimates carried out at discrete instants t_k, which must be selected taking into account the specifics of the object and the set control goal.

Suppose the control object characterized by equations (1) must operate on the time interval $[t_0, T_y]$, and $(T_y - t_0) \leq \infty$. At the instant t_0, $\vec{x}(t_0)$. is known. Let us choose the interval $[t_0, T]$, assuming $(T - t_0) \ll (T_y - t_0)$, and for this interval on an accelerated time scale, using the predictive ideal model, we determine the ideal vector functions of state and control $\vec{x}_{id}(t)$ and $\vec{u}_{id}(t)$. Since $\vec{u}_{id}(t)$, which is a solution to the variational problem (1), (3)-(5), is usually unrealizable, we find the optimal control vector $\vec{u}^*(t)$ for $t \in [t_0, t_0 + T]$. For this purpose, the accuracy factor is also minimized on an accelerated time scale:

$$E = \int_{t_0}^{t_0+T} F\{\vec{x}_{id}(t), \vec{x}(t), \vec{x}(t_0), \vec{u}(t)\}\, dt$$

Under connection constraints, control constraints and phase constraints of the type (1), (3) and (4), respectively, but taking into account the conditions of realizability of the control.

We will implement control $\vec{u}^*(t)$ on the interval $\Delta t \ll T$. In this case, the control system will operate in an open loop up to the instant $t_1 = t_0 + \Delta t$. At the instant t_1, it is necessary to estimate the actual state of the object $\vec{x}(t_1)$ and calculate $\vec{x}_{id}(t)$ and $\vec{u}_{id}(t)$ for the interval $[t_1, t_1 + T]$ and the initial state $\vec{x}_{id}(t_1) = \vec{x}(t_1)$ again on an accelerated time scale. Next, it is necessary to develop an optimal control $\vec{u}^*(t)$ and implement it on the object during the time interval $[t_1, t_1 + \Delta t]$. Upon its expiration, i.e., at the instant $t_2 = t_1 + \Delta t$, $\vec{x}(t_0)$ is re-estimated, $\vec{x}_{id}(t)$ and $\vec{u}_{id}(t)$ are found, etc. By the instant $t_3 = t_2 + \Delta t$, this procedure is repeated and then resumes every time at discrete instants $t_k = t_{k-1} + \Delta t$ until the entire time interval $[t_0, T_y]$ has been passed. Systems that implement this principle of construction will be called operational and organizational control systems.

The first problem solved according to this principle was probably the problem of using the water of the reservoir for irrigation investigated by N.N. Moiseyev [5, 6]. He also proposed naming this principle (sometimes the word "approach" or "method" is used) the sliding plan principle. This term is especially useful when studying problems in the field of economics, but a special explanation of the term "plan" is required for many technical applications. Therefore, along with the traditional term, we will further use the term "operational and organizational control".

Thus, the operational and organizational control system operating on the time interval $[t_0, T_y]$, at the given discrete time instants $t_0, t_1 = t_0 + \Delta t, t_2 = t_1 + \Delta t, \ldots, t_k = t_{k-1} + \Delta t, \ldots$, firstly, predicts the ideal vector-function of state $\vec{x}_{id}(t)$ and control $\vec{u}_{id}(t)$, using the actual values of the state vector $\vec{x}(t_k)$ fixed at the time instants $\vec{x}(t_k)$ the initial conditions for the prediction; secondly, it predicts the optimal control $\vec{u}^*(t)$, which is the solution to the variation problem

$$E = \int_{t_k}^{t_k+T} F\,[\vec{x}_{id}(t), \vec{x}(t), \vec{x}(t_k), \vec{u}(t)]\, dt \to min;$$

$$\vec{x}(t) = \vec{x}\left[\vec{x}(t_k), \vec{u}(t_k, t), \vec{\xi}(t_{k,t})\right]; \qquad (8)$$

$$\vec{x}(t) \in E_x;$$

$$\vec{u}(t) \in E_u.$$

and, thirdly, it implements control $\vec{u}^*(t)$ on the object during the time interval $[t_k, t_k + \Delta t]$.

The operational principle of such a system is illustrated by Fig. 2.

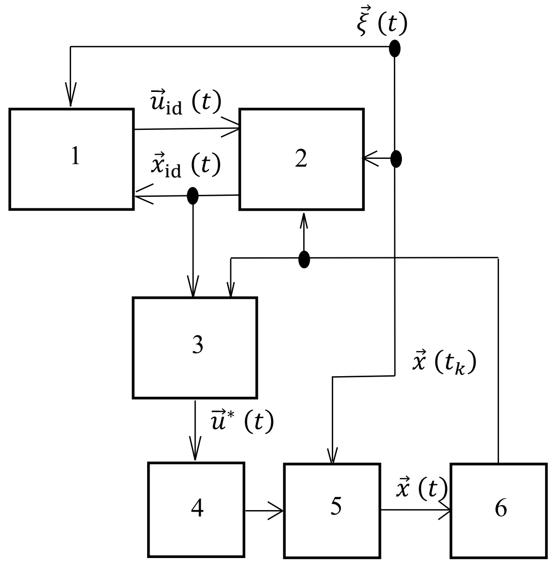

Fig. 2. The structural principle of an operational and organizational control system: 1 – computer of ideal mode; 2 – predictive ideal model; 3 – computer of $\vec{u}^*(t)$; 4 – actuating elements; 5 – object; 6 – meter of $\vec{x}(t_k)$

Let us call the time interval $[t_k, t_k + T]$, on which it is required to find the ideal and optimal controls, the scheduling interval, and the interval $[t_k, t_k + \Delta t]$ the scheduling repetition interval. These intervals can vary for the same object. The main considerations for their selection will be given in the following paragraphs.

It should be emphasized that for some types of control objects, there may be no need to solve the second variational problem with criterion (8). Indeed, if mathematical model (1) of the object and constraints (3) and (4) characterize the object sufficiently completely, then we can assume $\vec{x}_{\text{id}}(t) = \vec{x}^*(t)$ and $u_{\text{id}}(t) = \vec{u}^*(t)$. In this case, there will be no block *3* in the diagram shown in Fig. 2, and the input of block *4* will be the signal $\vec{u}^*(t) = \vec{u}_{\text{id}}(t)$.

It is advisable to consider some examples for a more visual explanation of the structural principle of an operational and organizational control system.

III. PROBLEMS OF OPTIMAL SYSTEM SYNTHESIS AND OPTIMIZATION OF OPERATIONAL AND ORGANIZATIONAL CONTROL

The design of modern optimal automatic control systems, as a rule, is performed in two stages: 1) calculation of the optimal programmed (reference or nominal) trajectory of the object's motion; 2) calculation of the optimal controller or the closed-loop system of optimal control proper, whose objective includes the optimal, in the given sense, approximation of the real motion of the object to the programmed trajectory [7]. This practice of division of tasks is a result of many years of engineering experience in the design of control systems. Exceptions are observed in two cases: when there is no need to calculate the optimal programmed motion, which occurs in many problems of the theory of automatic control, where the programmed mode is set unambiguously, for instance, in the form of a given engine speed; when the problem of designing the optimal system is so simple that both stages can be performed simultaneously. Unfortunately, the latter case is extremely rare in the practice of modern control system design.

Solving a common problem in two stages is a necessary measure due to the difficulty, and in most cases, the impossibility of combining both stages. However, in some cases, for instance, when the optimal system is synthesized according to the criterion of minimum energy costs and energy consumption for motion along the programmed trajectory is much higher than the costs for keeping the object near the programmed trajectory, separate handling of problems is mathematically justified. This means that the obtained optimal solution will be close to that which would give a combined solution to the problem of selecting a programmed trajectory and calculating the optimal controller. For other, more general cases, a proof of the possibility of separating tasks is required. In real-life design, this proof is often given in the form of engineering intuition and experience, because a rigorous mathematical solution to the problem has not yet been obtained.

The first stage of designing the optimal control system, i.e., the development of an optimal programmed trajectory (or just a program) is the simplest one. This is due to two main reasons. First, at this stage, we can consider simpler equations of the object's dynamics, which do not take into account a number of factors. Second, when calculating the programmed trajectory, it is sufficient to define the control law of the object as a function of time and boundary conditions (the initial and final state of the object).

When calculating the optimal controller at the second stage, it is necessary to find the optimal control as a function of the state of the object. These two problems have different physical and mathematical content.

In the problems of determining optimal programmed motion, the dynamics of an object is given by differential equations of the type (2) or, in a deterministic formulation, by the equations

$$\dot{\vec{x}} = \vec{f}(\vec{x}, \vec{u}, t), \tag{9}$$

where, as before, $\vec{x}$ is an *n*-dimensional state vector; $\vec{u}$ is an *m*-dimensional control vector.

The solution of equations (2) or (9) on the interval $[t_0, T_y]$ must ensure the extremum of the selected indicator of the control goal [denote it by $E_1(\vec{x}, \vec{u})$], satisfy the boundary conditions at the left, at the right, or at both ends of the trajectory: $\vec{x}(t_0) = \vec{x}_0, \vec{x}(T_y) = \vec{x}_r$ and be subjected to constraints (3) and (4).

Suppose the problem of selecting the optimal programmed trajectory has been solved by one of the methods and the vector functions $\vec{u}^*(t)$ and $\vec{x}^*(t)$ have been found for $t \in [t_0, T_y]$. Here, the problem of *optimal system analysis* is said to have been solved. However, the real motion of the object due to the influence of uncontrolled disturbances, the impossibility of absolutely accurately setting the object in its original initial state and absolutely accurately realizing the optimal programmed control $\vec{u}^*(t)\vec{u}^*(t)$, etc. will differ from the programmed one. If we introduce the notation

$$\vec{z}(t) = \vec{x}(t) - \vec{x}^*(t);$$
$$\vec{v}(t) = \vec{u}(t) - \vec{u}^*(t),$$

where $\vec{x}(t)$ is the trajectory of the real motion of the object during the control $\vec{u}(t)$; $\vec{v}(t)$ is an additional control, bringing the real motion closer to the programmed one, then it is possible to obtain the equations of the relative motion of the object during the control

$$\dot{\vec{z}}(t) = \vec{f}(\vec{x}, \vec{u}, \vec{\xi}, t) - \vec{f}(\vec{x}^*, \vec{u}^*, t).$$

The last equation, under the assumption that the deviation of the real trajectory from the programmed one is small, can be represented as

$$\dot{\vec{z}}(t) = \vec{f}(\vec{z}, \vec{v}, \vec{\xi}, t) \tag{10}$$

or, if linearization is acceptable, in the form

$$\dot{\vec{z}}(t) = A\vec{z}(t) + B\vec{v}(t) + \vec{\xi}(t), \tag{11}$$

where *A* and *B* are matrices with constant or variable coefficients; $\vec{\xi}$ is a disturbance vector.

The presence of the component $\vec{\xi}(t)$ in equations (10) or (11) leads to the need to formulate complex optimal control problems that are associated with minimizing the mathematical expectation of some criterion $E_2(\vec{z}, \vec{v})$ and are currently far from the final solution. The results available in this area can be found in [5, 6]. In the following paragraphs, we will consider deterministic problems of optimal control, when the components $\xi\ (t)$ in equations (10) and (11) can be neglected.

Obviously, to calculate the optimal controller that controls the real motion of the object, it is not enough to find the relationship between the control and time, i.e., $\vec{v}\ (t)$, this requires determining the relationship between the control and the coordinates of the object and time $\vec{v}\ (\vec{z}, t)$. This dependence has to be optimal, i.e., to minimize the value of the selected functional $E_2\ (\vec{z}, \vec{v})$. The functionals $E_1\ (\vec{x}, \vec{u})$ and $E_2\ (\vec{z}, \vec{v})$ can have both the same and different physical meanings. Generally speaking, when calculating the optimal controller, two different approaches are possible. The first approach is when the controller is created in such a way that when a misalignment occurs between the programmed and real trajectories, the controller must return the object to the programmed trajectory. For instance, for any type of the criterion $E_1\ (\vec{x}, \vec{u})$, the controller can be constructed in such a way as to minimize the time of the object's return to the programmed trajectory. In this case, the physical meaning of $E_1\ (\vec{x}, \vec{u})$ and $E_2\ (\vec{z}, \vec{v})$ is different. The second approach is based on the construction of a new programmed trajectory relative to the real state of the object and motion along this trajectory. This approach is called correction according to a given program. Obviously, in the second case, the criteria $E_1\ (\vec{x}, \vec{u})$ and $E_2\ (\vec{z}, \vec{v})$ have the same physical meaning.

Based on the above, the formulation of the problem of calculating optimal correcting controls will look as follows: find the control $\vec{v}^*(\vec{z}, t)$ as a function of phase coordinates and time minimizing the functional $E_2\ (\vec{z}, \vec{v})$ and satisfying equations of relative motion of the type (10) or (11).

The solution to this problem is called *optimal control synthesis*. Since determining $\vec{v}\ (\vec{z}, t)$ in most cases presents serious mathematical difficulties, we have to simplify the problem and look for $\vec{v}\ (\vec{z}, t)$ in some narrower class of admissible controls. In this case, we speak of the solution of the problem of possible or virtual synthesis [5, 6]. However, knowing the optimal controls $\vec{v}\ (\vec{z}, t)$ turns out to be insufficient for the design of an optimal control system. To do this, it is necessary to implement a controller that provides feedback, which in mathematical terms comes down to determining the operator W, which (e.g., in the linear case) has the form

$$W = a_k \frac{d^k}{dt^k} + \cdots + a_1 \frac{d}{dt} + a_0$$

and links the variables v and z: $v = Wz$. Such a problem is called *optimal system synthesis*. Its solution is a much more complicated problem than finding the optimal controls $\vec{v}\ (\vec{z}, t)$.. Formally, in the general case, it is reduced to nonlinear programming problems in function spaces. With the introduction of simplifications, e.g., when approximating W by finite-dimensional functions, it turns out to be possible to proceed to simpler problems - the problem of nonlinear programming in a finite-dimensional space or to the problem of optimal control synthesis [5, 6, 8].

There is another noteworthy fact. Suppose that equations (2) describe the dynamics of the object sufficiently completely. Then the solution to the synthesis problem will consist in finding a control $\vec{u}^*\ (\vec{x}, t)$ depending on the phase coordinates and time such that turns the criterion $E_1\ (\vec{x}, \vec{u})$ into an extremum, satisfies constraint equations (2), the boundary condition at the right end and constraints (3), (4).

If, in the problems of optimal system synthesis, we compare the principle of correction according to the final state with the principle of constructing systems of operational and organizational control, it is easy to find an analogy. Indeed, determining the optimal control $\vec{u}^*\ (t)$ on the interval $[t_0, T_y]$ with the help of operational and organizational control systems and realizing it during the time Δt, we obtain the state $\vec{x}\ (t_0 + \Delta t)$ different from $\vec{x}^*\ (t_0 + \Delta t)$. Next, an optimal control is generated with respect to the state $\vec{x}\ (t_0 + \Delta t)$ on the planning interval $[t_0 + \Delta t,\ T_y]$, at the time instant $t_0 + 2\Delta t$, a control is generated with respect to $\vec{x}\ (t_0 + 2\Delta t)$ on the interval $[t_0 + 2\Delta t,\ T_y]$, etc., up to the end time instant.

Two important conclusions can be drawn from a comparison of problems of optimal system synthesis and problems of operational and organizational control.

The implementation of the system of operational and organizational control does not require solving the problem of optimal control synthesis. The approximation of the real motion of the object to the optimal one is achieved by repeatedly solving the problem of developing optimal programs (analysis problems).

The use of operational and organizational control systems, just like the end-state correction systems, in a number of practically important cases can give significant technical or economic advantages in comparison with systems in which correction according to the given program is used [5, 6]. Let us illustrate this with the following example. Let it be required to solve the problem of ensuring the maximum range of the rocket with a given fuel supply. Considering the rocket as a material point, we can find the optimal trajectory of its motion. Due to a number of conditions mentioned earlier, the real motion will differ from the optimal one. Let us assume that as a result of the action of factors of a random nature, it turned out to be possible to achieve a greater range than expected. These circumstances should be used to the maximum, without worrying about the real trajectory having to be close to the optimal one. Obviously, when correcting according to the given program, it is impossible to use these circumstances.

IV. Operational and Organizational Control Systems Operating on the Principle of Approximation to a Given Program

Control systems based on the principle of correction according to a given program can have certain advantages over systems with end-state correction, which is mainly ensured by a simpler implementation of such systems. If the object under consideration indeed has such advantages, it is advisable to use them. We will show how this can be done when building a operational and organizational control system. Let us consider the problem in a deterministic formulation.

Let the dynamics of the object be characterized by equations of the type (2), but in the absence of the components $\vec{\xi}(t)$; boundary conditions at the right and left ends, constraints (3), (4) and criterion $E_1\ (\vec{x}, \vec{u})$ are given. Thus, we need to find a solution to the following problem:

$$E_1\ (\vec{x}, \vec{u}) \rightarrow min;$$

$$\dot{\vec{x}} = \vec{f}\ (\vec{x}, \vec{u}, t);$$

$$\vec{x}\,(t_0) = \vec{x}_0; \quad (12)$$

$$\vec{x}\,(T_y) = \vec{x}_T;$$

$$\vec{x}\,(t) \in E_x;$$

$$\vec{u}\,(t) \in E_u.$$

Let us denote, as before, the optimal control found as a result of solving problem (12) by $\vec{u}^*\,(t)$,, and the optimal trajectory by $\vec{x}^*\,(t)$. The found vector functions $\vec{u}^*\,(t)$ and $\vec{x}^*\,(t)$ are obtained for the initial condition $\vec{x}\,(t) = \vec{x}_0$. Let us expand the region of possible initial states and solve problem (12) for each state in this region. As a result, a set of optimal trajectories will be obtained. We find in this set the trajectory that corresponds to the smallest value of the criterion $E_1\,(\vec{x}, \vec{u})$ and call it ideal. In Fig. 3 for the set of initial states bounded by the segment *AB*, the optimal and ideal trajectories are denoted by $x^*\,(t)$ and $x^{**}\,(t)$, respectively.

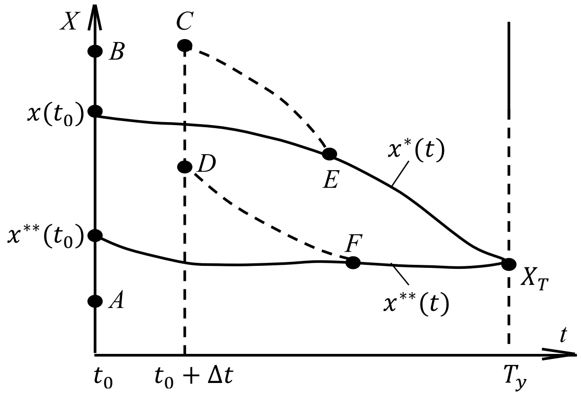

Fig. 3. Optimal $x^*\,(t)$ and ideal $x^{**}\,(t)$ trajectories

When implementing the operational and organizational control system, as a result of the action of the control $u^*(t)$, the object will go from the state $x\,(t_0)$ to the state $x\,(t_0 + \Delta t)$ after the time interval $[t_0,\ t_0 + \Delta t]$. Let this state be characterized by the point *C* (see Fig. 3). The calculation of the optimal program relative to the obtained state gives the trajectory of *CE* transferring the object to the given trajectory $x^*(t)$. If, as a result of the action of uncontrolled disturbances, the real state of the object is characterized by the point *D* (see Fig. 3), then the solution of problem (12) with respect to the new state and the time instant $t_0 + \Delta t$ can give a trajectory that transfers the object to the ideal trajectory $x^{**}\,(t)$, i.e., trajectory *DF*. Thus, in cases where the optimal and ideal programmed trajectories do not coincide, the operational and organizational control system can develop trajectories that approximate either optimal or ideal. An alignment of trajectories for some initial states $x\,(t_0 + k\Delta t)$ can occur at the point x_T. Let us consider a simple example to illustrate this.

We have the following problem:

$$E\,(x, u) = \int_0^T (x^2 + u^2)dt + \lambda\,[x\,(T) - \beta]^2 \to min;$$

$$\dot{x} = u;$$

$$u \in E_u = [u : -2, -1, 0, 1, 2]; \quad (13)$$

$$x_{min} \le x\,(t) \le x_{max};$$

$$0 \le x(t) \le \beta.$$

For the parameters $T = 10$; $\lambda = 2{,}5$; $\beta = 2$; $x_{min} = 0$; $x_{max} = 8$ and a quantization step in time and in x equal to 1, using the computational procedure of dynamic programming a set of optimal solutions for $0 \le x\,(t_0) \le 8$ was obtained.

Thus, approaching problems of synthesis of optimal trajectories from the standpoint of operational and organizational control led to the finding a new method of correction — correction according to an ideal program. For further constructions, let us clarify the concept of correction. By correction we mean the development of control actions that return the object from a deviated trajectory to the given state, to a programmed or ideal trajectory so that the extremum of the required functional is provided. In a special case, such a correction will correspond to a correction that gives the fastest possible return to the reference or ideal trajectory.

Let us now formulate two statements on the basis of which optimization algorithms can be constructed in operational and organizational control systems.

Statement 1. In the set of possible states of the system in the vicinity of the reference trajectory, there may exist those for which correction according to an ideal program is more effective in the sense of the sought-for functional than correction according to a given program.

Statement 2. The choice between the two said correction methods can be made by dividing the set of possible states into two classes $M\,(x^*)$ and $M\,(x^{**})$, the former of which indicates the preference for correction according to a given program over correction according to an ideal program, the latter indicating the opposite.

This division is called zoning. For the considered scalar problem, it can be performed in the simplest way as follows:

$$M\,(x^*) = [x : \rho\,(x, x^{**}) > \rho\,(x^*, x^{**})];$$

$$M\,(x^{**}) = [x : \rho\,(x, x^{**}) < \rho\,(x^*, x^{**})].$$

where x is the coordinate of the real trajectory; $\rho\,(a, b)$ is the distance between a and b.

Obviously, there is a quite wide class of problems for which: 1) $M\,(x^*) \cup M\,(x^{**})$ forms the entire set of possible states, i.e., corrections according to $x^*(t)$ and $x^{**}(t)$ solve the optimal synthesis problem; 2) corrections according to $x^*(t)$ and $x^{**}(t)$ are equivalent to corrections according to the criterion of maximum performance.

Statements 1 and 2 make it possible to simplify the algorithms for optimizing operational and organizational control, in which, as mentioned earlier, the end-state correction is used. In this case, the optimization process will consist in the following:

1) determining $x^*(t)$ and $x^{**}(t)$, here the function $x^{**}(t)$ can be obtained at the stage of preliminary calculations;

2) determining if concrete values of $x\,(t)$ belong to the class $M\,(x^*)$ or $M\,(x^{**})$;

3) implementation of correction according to $x^*(t)$, $x^{**}(t)$ or end state depending on the results of Step 1.

With an appropriate choice of the optimization method, the calculation of $x^*(t)$, $x^{**}(t)$ and correcting controls can be carried out using one algorithm.

V. PROBABILISTIC AND DETERMINISTIC APPROACH TO THE PROBLEM OF OPERATIONAL AND ORGANIZATIONAL CONTROL

The purpose of building control systems that have the structure and principle of operation of operational and organizational control systems is not only to overcome the difficulties associated with solving synthesis problems, but also the difficulties caused by the need to take into account random disturbances acting on the control object (difficulties of stochastic synthesis). There are significant possibilities for simplifying the calculation methods in the very principle of constructing such systems, which is associated with the periodic correction of previously developed control actions based on taking into account the actual state of the controlled process. Indeed, in those cases when the influence of random factors on the planning repetition interval turned out to be such that the actual state slightly differs from the calculated one, the development of correcting controls can be carried out based on the deterministic models of the object. Thus, for objects of this type, random disturbances can only be taken into account by correcting control actions at appropriately selected time intervals. Consequently, the choice of the planning repetition interval will determine the accuracy provided by the operational and organizational control system. The smaller this interval, the greater the accuracy, but the higher the requirements for the computing capacity of the control system [9].

When using probabilistic methods, the optimal solution should be developed taking into account the statistical characteristics of the vector of random disturbances. A more complete account of the properties of the object will allow the correction to be carried out less frequently, i.e., to increase the planning repetition interval with the same accuracy of the control system. But at the same time, the difficulties in implementing probabilistic methods will increase very significantly. Obviously, when choosing one of the two alternatives - using a deterministic or probabilistic approach in the task of constructing an operational and organizational control system - it is necessary to take into account the ensured accuracy of the solution, the value of the planning repetition interval and the difficulty of implementing the method by the computational means of the system. Usually, these difficulties are crucial, since in the deterministic formulation the solution to the problem of developing optimal controls (programs) is much simpler than in the probabilistic formulation.

It should be emphasized that the use of a deterministic approach, on which all further presentation of the material will be focused, does not at all mean a complete neglect of random disturbances acting on the control object in the process of calculating optimal controls. These disturbances are taken into account when constructing the model of the control object. The easiest way to do this is: 1) when constructing models in which the vector of the object's state is characterized by its mean values or mathematical expectation; 2) when constructing models with predicted values of the components of the state vector.

In the first case, when developing models, the moving average method can be effectively used [1], in the second case, predictive devices of various kinds (see, e.g., [3]).

In the process of analyzing the control object, it can be found that the level and nature of the action of random disturbances is such that neither an increase in the frequency of correction of control actions, nor the improvement of predictive devices can ensure the specified accuracy of the implementation of operational and organizational control systems. In these cases, the use of a deterministic approach is hardly justified. It is necessary to study the possibilities of probabilistic methods and other principles of building a control system.

Comparison of the results of stochastic synthesis with the results of operational and organizational control, which is an issue of natural interest, is currently not fully resolved. However, in [8], a theoretical analysis of the results of stochastic synthesis, piecewise-deterministic synthesis (at discrete instants in time, the disturbance prediction is carried out and the problem of deterministic synthesis is solved) and piecewise-programmed (operational and organizational) control for linear dynamic systems optimized by the quadratic functional. It is shown that in those cases when the disturbance predication is continuously corrected, i.e., the interval Δt is close to zero, the results of all the above control methods coincide both for the disturbance in the form of white noise and for the filtered white noise. In addition, the results of stochastic and piecewise deterministic synthesis coincide for any values of the planning repetition interval for disturbances in the form of white noise. For filtered white noise and prediction of disturbances at the instants $t_0 + k\Delta t$ the difference between the value of the functional for operational and organizational control and stochastic synthesis is non-negative and has the order Δt. Recall that here, in both cases, the functionals have the meaning of the mathematical expectation of the criterion used.

VI. OPTIMIZATION METHODS USED IN OPERATIONAL AND ORGANIZATIONAL CONTROL SYSTEMS AND THE REQUIREMENTS FOR THEM

Along with the term "operational and organizational control", the terms "operational control" and "organizational control" are widely used. In the latter case, we mean the control of the so-called organizational systems, i.e., systems that include objects of physical nature and teams of people. Systems of this type are also called large systems. The main definitions and problems standing in the way of managing large systems are outlined in [10]. It is important to emphasize here that the above principle of building control systems is widely used in building organizational systems. Examples include almost all problems associated with planning and taking action to carry out the plan.

In the term "operational and organizational control" the second word means not only the applicability of the principle of building such systems to the problems of managing organizational systems, but also control objects having certain specific features. These features are mathematically characterized by the presence of various kinds of logical conditions that must be taken into account in the control process. The presence of conditions of this type introduces additional features into the apparatus of mathematical programming methods used to solve the formulated problem of developing optimal controls. Sometimes these features are such that a standard, well-developed optimization method cannot be used, but sometimes they greatly facilitate the computation process.

The term "operational control" covers systems that have the same construction principle as operational and organizational control systems, however, the presence of specific features of a logical type is not reflected in the mathematical models of the object. Therefore, both these terms, if we do not emphasize the presence of logical conditions, can be considered synonymous.

The form of mathematical description of objects, for the control of which it is advisable to use operational and organizational control systems, may vary, but the presence of phase constraints (3) and control constraints (4), as well as conditions of a logical type, is an integral characteristic feature of such objects. This feature imposes certain requirements on the optimization methods used. Let us list the main requirements for optimization methods.

If the control object is described by differential equations, it is often necessary to solve a two-point boundary value problem. The only method that allows solving two-point boundary value problems without special laborious tricks is a computational procedure of dynamic programming.

Computational procedures of dynamic programming, as will be seen from the subsequent presentation, without significant modifications allow implementing both the deterministic and the probabilistic approach in operational and organizational control systems.

So, at present, considerable attention is paid to the development of methods for optimal control of dynamic systems under constraints on control of the integral form

$$\int_{t_0}^{T} \varphi\,(\vec{u})\,dt \ \le C.$$

The use of the proposed approach for constructing a system and computational procedures of dynamic programming does not cause fundamental difficulties in solving this problem.

To overcome the dimensionality problem, numerous techniques and methods have been proposed, many of which are outlined below and analyzed for both general and specialized problems.

Finally, note another extremely important limitation imposed on optimization methods by the specifics of their use for operational and organizational control systems - an extremely limited resource of time allocated for the calculation of optimal controls. More on this in the next section.

VII. TIME FACTOR IN OPERATIONAL AND ORGANIZATIONAL CONTROL SYSTEMS

The principle of operation of operational and organizational control systems is based on a periodic assessment of the actual state of the object, the development of optimal control actions based on this assessment and their implementation in the object until the next assessment of the state. Naturally, the problem of selection of the optimal controls should be solved during such a time interval $\tau_p < \Delta t$, after which the meaning of the implementation of the obtained control still does not disappear, and it is natural that the interval τ_p should be sufficiently small.

In this case, is chosen the following procedure of the system operation. At each time instant $(t_k - \tau_p)$, the actual state $\vec{x}(t_k - \tau_p)$ is estimated and the state $\vec{x}(t_k)$ is predicted. Knowing $\vec{x}(t_k)$, the optimal values of the control actions $\vec{u}^*(t)$ are calculated. The calculation should be completed by the instant t_k. Starting from this time instant, the developed control is implemented up to the time instant $t_{k+1} = t_k + \Delta t$.

If it is possible to predict $\vec{x}(t_k)$ accurately enough, the interval τ_p can be taken large enough but still not exceeding the planning repetition interval Δt.

If for some reason it is not possible to carry out a qualitative prediction, the operation of the operational and organizational control system should be arranged in a different way. In this case, it is necessary to periodically perform the following steps: to estimate the state vector $\vec{x}\,(t)$ at time instants $t_k, t_{k+1}, t_{k+2}, \ldots$ and select the optimal control $\vec{u}^*\,(t)$; to implement the developed control $\vec{u}^*\,(t)$ starting from the instant $t_k + \tau_p$.

Since the implementation of $\vec{u}^*\,(t)$ starts not from the instant t_k, but from the instant $t_k + \tau_p$, i.e., with the delay τ_p, additional errors may occur due to the fact that $\vec{x}\,(t_k)$ differs from $\vec{x}\,(t_k + \tau_p)$. Therefore, it is necessary to strive to make the interval τ_p as small as possible.

The problem of minimizing τ_p also arises for those operational and organizational control systems where the planning repetition intervals Δt are not constant and can even be random variables, and the state of the object during this time can change significantly.

Thus, the time factor when choosing an optimization method for operational and organizational control systems is very important and sometimes crucial. To obtain a solution in a timely manner, it is often necessary to completely abandon the choice of optimal controls and use approximate optimization methods, i.e., methods that give a suboptimal, but sufficiently close to optimal solution.

REFERENCES

[1] A.B. Sadigov, Models and technologies for solving problems of management in emergency situations. Baku, "Elm", 2017, 372 p. (in Russian)

[2] William S. Levine. Control System Applications. ISBN 9780367399061, Published by CRC Press, 2019, 360 p.

[3] A.B. Sadigov, R.M. Zeynalov, Optimal control in the problems of calculating the benefit/cost ratio in emergency response. Informatics and Control Problems, vol. 40, issue 1, 2020, pp. 47-56

[4] K. Aida-zade, J. Asadova, N. Suleymanov, Numerıcal Analysıs of Methods of Solvıng Optımal Control Problems wıth Non-Fıxed Tıme Proseedigs of the 2nd Int. Conf. “Problems of Cybernetics and Informatics” September 10-12, 2008, Baku, Azerbaijan. Section 5, “Control and Optimization”, pp. 94-97.

[5] N.N. Moiseev, Numerical methods in the theory of optimal systems. Moscow, Nauka, 1971, 424 p. (in Russian)

[6] N.N. Moiseev, Elements of the theory of optimal systems. Moscow, Nauka, 1975, 526 p. (in Russian)

[7] T. Sprocka, C. Bocka, F. McGinnis, Survey and Classification of Operational Control Problems in Discrete Event Logistics Systems(DELS). International Journal Prod Res. 2018: doi:10.1080/00207543.2018.1553314

[8] Weihai Zhang, Honglei Xu, Huanqing Wang, Zhongwei Lin, Stochastic Systems and Control: Theory and Applications. Mathematical Problems in Engineering, Volume 2017, Article ID 4063015, 4 p.

[9] V. Menshikh, A. Samorokovskiy, O. Avsentev, Models of resource allocation optimization when solving the control problems in organizational systems. Journal of Physics: Conf. Series 973, 2018, 012040

[10] P. Riedinger, I.-C. Morarescu, A numerical framework for optimal control of switched affine systems with state constraint. Proceedings of the 4th IFAC Conference on Analysis and Design of Hybrid Systems (ADHS 12) June 6-8, 2012. Eindhoven, The Netherlands. pp. 141-146.

Polymer Composites on the Basis of the Residual Polyethylene and Modified Minerals

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***Abstract*—The polymer composites on the basis of secondary polyethylene and the minerals spread in Georgia (andesite from Bakuriani, Sachkhere quartz sand and Okami slag) have been obtained. There are studied some physical-mechanical properties, thermal stability and water absorption. It is shown that the ultimate strength and thermal stability of the composites extremely depend on the type and concentration of the filler. Introduction of the fillers modified by tetraetoxisilane to the composites leads to enhancing of the physical properties of the materials because of creation of the buffer zone between polymer matrix and filler particles. For composites containing binary filler the sinergistic effect - anomaly increasing of the ultimate strength at definite ratio of the fillers is shown.**

***Keywords*—polymer materials**

1. Introduction

Different details and constructions of the mobile machines now are made from the polymer materials. Therefore the development of them presents very high significance for progress of transport.

Environment ecological protection and utilization of the industrial wastes present today very important and actual problems. From the scientific- technical literature it is known that if the development of the composites based on secondary thermoplastic materials, in which the different dispersive or natural and artificial fiber fillers are used, about 40 % of the primary ores can be spared. In the secondary polymer composites the industrial technological wastes as trimming, injection molding heads technical tare, films, bottles and so on are used. The content of such wastes was varied in the range 10 - 60 %.

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Polyethylene now is one of more spread polymer, which is due to many positive exploitation properties and low cost [1- 4]. The high pressure polyethylene industrial wastes as binder are used in our work.

2. Experimental

2.1. Research objects and methods of obtaining.

There were used the fine dispersive powders, obtained in result of grinding of different polyethylene bags of domestic destination. Most of them are made from polyethylene of high pressure (with low density). Three types of minerals Bakuriani andesite, Sachkhere quartz sand and Okami slag were used as composite fillers with wide range concentrations.
Below the short characteristics of these fillers are presented.

- *andesite* (word basis - American mountains Ands) volcanic origination dark red color dense, but sometimes is porous material. This mineral is wide spread material in the AdJara- Trialeti mountain (Borjomi-Bakuriani, Tsikhisjvari) kazbegi region (mkinvartsvery, Kabarjina), in the sources of the rivers Liakhvi, Ksani, and Aragvi, on the Javakheti plateau. Andesite isused as a building and acid proof material;
- *Quartz sand from Sachkhere* includes the quartz particles, content of silicon oxide near70-85% and

rest are iron, calcium and magnesium oxides. Besides of the sand includes 5% clay and dust particles.

- *slam from Okami* is red color micro-porous volcanic generated mineral with high specific surface. In Georgia this mineral is used as warm-isolated material. The slam is belonging to basalt type porous variety. It is the glass with alumo-silicate content (75-80%). 20% of this material is crystallic. Density 2630 kg/m^3.

At the initial stage the mixing of composite ingredients in the propeller mill during 2-3 min was fulfilled.
In result of mixing of the polymers and different fillers the homogeneous powder was obtained, which after preliminary drying at 50-70^{o}C underwent to the pressing in the standard press-forms (cylindrical and rectangular). The samples were obtained after pressing at 8-10 MPa and temperature 140-150^{o}C during 10-15 min.

2.2. Methods of samples testing

The samples were tested on the strengthening at compression, bending and impact vidcosity. Mechanical parameters were defined on the Germany device of type Dinstant. The temperature stability was defined on the apparatus of Vica. The water absorption was defined separately.

3. Results and discussion

First of all it was necessary the determination of dependence of material properties on the type and concentration of fillers. With this aim on the basis of polyethylene we obtained the composites, in which mineral powders with concentrations 20-60wt% were included.
On the Figs 1, 2 and 3 the dependences of composite mechanical strengthening at compression, bending and impact viscosity on the filler concentration are presented. From these Figures one can see that this dependence for all samples has an extreme character - on the curves the maximums are appeared.

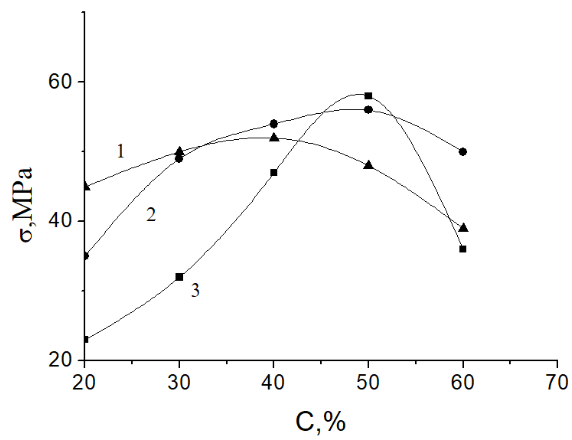

Fig.1. Dependence of the composite ultimate strength (at compression) based on PE containing quartz containing the sand (1), slam(2) and andesite (3) on the filler concentration

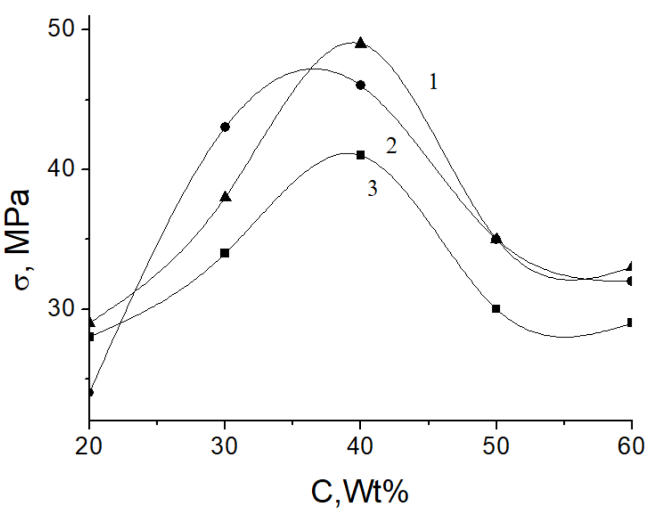

Fig.2. Dependence of ultimate strength (at bending) of composites based on PE containing andesite (1), slam (2) and quartz sand (3) on the filler concentration

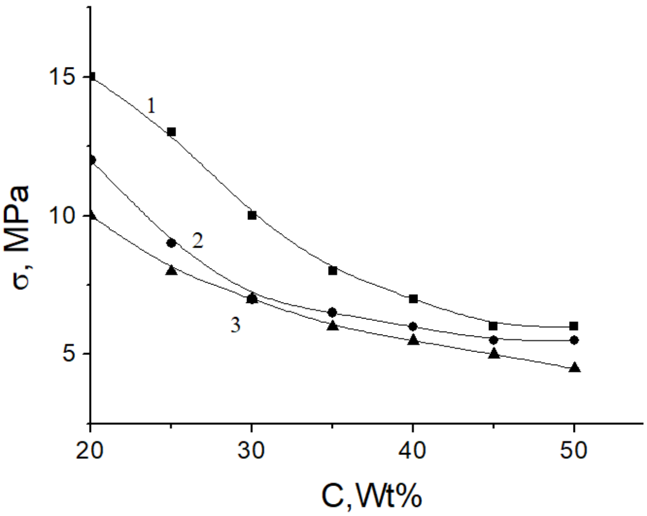

Fig.3. Dependence of impact viscosity of composites on the base of PE containing andesite (1), slam (2) and quartz sand (3) on the filler concentration

The Dependences shown on the Figs 1-3 lead to conclusion that the differences between corresponding curves are determined by different level of intensity of interaction between polymer matrix and filler particles. First of all the essential effect on the mechanical characteristics has a micro structure of the filler particles. It is clear that the higher is a sum surface of filler particles the higher is the inter-phase square and consequently -the adhesive forces between polymer matrix and filler particles. Besides of the existence of active chemical groups on the surface of filler particles additively can enhance composite because of formation of covalent bonds between phases. On the basis of these supposes it can be concluded, that mineral andesite particle surfaces are characterized with relatively inhomogeneous structure and roughness on surface of which some active chemical groups are displaced.

The difference between curves is described by difference of filler types. This difference is expressed in the character of particles surface profile (partially surface smoothness). The particles with deep irregularities contribute to penetration of the polymer segments to the micro-empties of filler particles and formation of engagements. In this way physical bonds are formed (formation of Van-der-Waals bonds), which lead to increasing of mechanical strengthening of the composite. Besides of here it is possibility the formation of chemical bonds between active chemical groups on the filler surface and macromolecules, which will further strengthen the composite.

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The character of the noted dependence appears also in the properties of thermal stability (Fig.4). Namely, the lower are the significances of the maximal deepening of the indentor in the sample (measure by Vicate method) the higher is thermal stability of the composite. From this Figure one can see that thermal stability of investigated materials fully corresponds to mechanical properties of ones and therefore the character of this parameter may be expressed in the same terms as in case of mechanical properties.

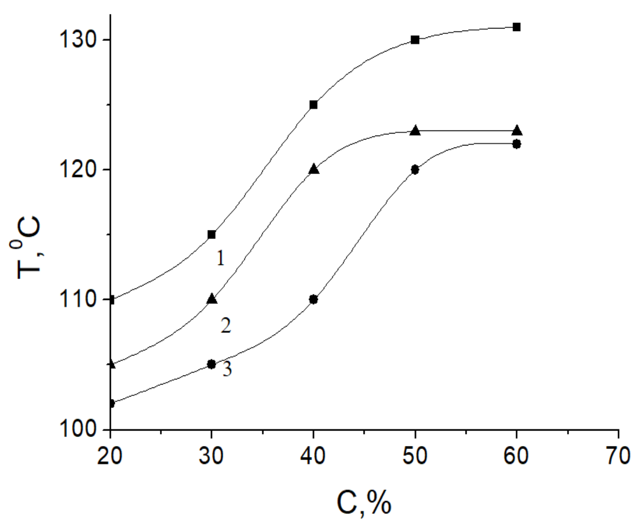

Fig.4. Dependence of the composite softening (by Vica method) of the PE composites containing quartz sand (1), slam(2) and andesite (3) on the filler concentration

It is known that in some cases the physical properties of composites may be increased by use of binary fillers [5].

With this aim we prepared the composites based on PE and binary fillers used above, concentrations of which was varied in two groups of sum concentrations: 40wt% and 50wt%. In accordance with the experimental data on determination of the dependence of ultimate strengthening of composites on the different proportion of the fillers in them these curves are characterized with maximums. On the Fig.5 the maximum of ultimate strength appears for composites containing the fillers slam and quartz sand with proportion 30/70 (curve 1), when the sum of the fillers is 50wt%. Analogical maximum has the curve 2 of the same dependence at proportion of the same fillers 40/60, when the sum of the fillers is 40wt%. The maximums on the curves are corresponded to s. c. synergistic effect - non-additive improving of the material properties at definite proportion of ingredients in the binary filler [6,7].

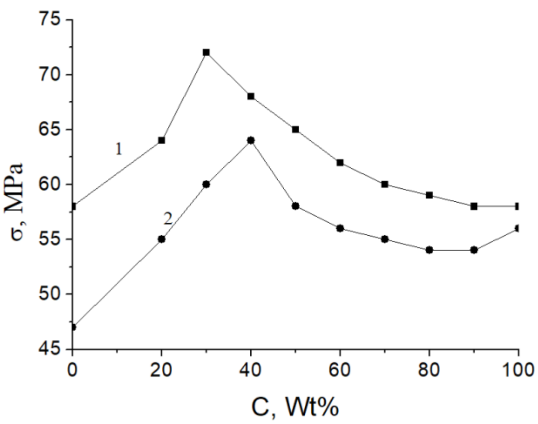

Fig.5. Dependence of the composite ultimate strength (at compression) of the PE composites with binary filler (quartz sand + slam) at the filler sum concentration 50wt % (1) and 40 wt% (2). On the *x* axis - the concentration of the slam in the fillers part

In the table 1 there are presented the numerical data of some physical-mechanical properties of the composites with binary fillers. Comparison of numerical data of obtained dependences for composites containing binary fillers and composites with one filler shows that by combination of the fillers it is possible to enhance the mechanical and thermal properties of the composites.

Table 1

The characteristics of composites based on PE and binary fillers

Filler (proportion of the fillers in composite)	Impact viscosity, kJ/M^2	Ultimate strength at bending, MPa	Ultimate strength at compression, MPa	Thermal stability, ^0C (by Vica)
Slam	6.8	45.5	62.3	120
Andesite	6.0	46.8	65.1	125
Quartz sand	5.1	45.5	60.4	122
Slam/andesite (2/3)	8.2	55.5	70.0	135
Slam /quartz sand (1/1)	7.7	56.6	69.5	137
quartz sand / andesite (2/3)	7.8	54.2	80.1	126

With aim of improvement of the exploitation properties of the obtained composites the structural modifier of type tetraethoxisilane (TEOS) was used (it must be noted that early this substance gave essential effect in the composites based on epoxy resin [8]). This modifier was introduced to the composite with amount 5wt% solved in the toluene for obtaining of homogeneous solution, which was evaporated after definite time.

On the Table 2 there are presented some technical characteristics of the composites with modified and unmodified by TEOS fillers. Analysis of the table 2 data shows that TEOS decreases fragility of composites and increases in the same time the compatibility of ingredients, decreases the formation of the defects, as empties (Fig. 6). At high concentrations of andesite appears so called effect of high filling, which is decreased under influence of the modifier. The molecules of modifier envelop the fillers particles and form the buffer zone between polymer matrix and filler (Fig. 7). Comparison of the mechanical properties, softening temperature and water absorption for polymer composites based on residual polyethylene and unmodified and modified by TEOS of used mineral nanofillers leads to conclusion that modify agent stipulates the formation of heterogeneous structures with higher compatibility of ingredients and consequently promote to enhancing of technical characteristics.

Table 2

Technical characteristics of composites based on PE containing modified by TEOS fillers (in brakets corresponding characteristics for analogues with unmodified fillers)

#	Filler (50 wt%)	Specific weight, Kg/m^3	Impact viscosity, kJ/M^2	Ultimate strength at bending, MPa	Ultimate strength at compre-ssion, MPa	Thermal stability, ^{0}C (by Vica)
1	Slam	1082	8,5	48,9	63.8	140
2	Quartz sand	1115	7,0	61,4	64.3	145
3	Andesite	1183	6,6	60,1	65.1	135

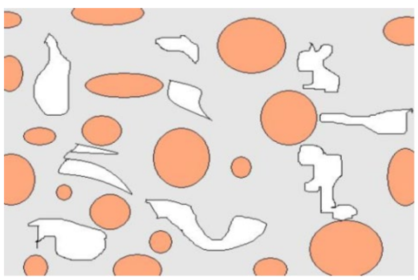

Fig.6. Model of imagination of microstructure composite with unmodified mineral.
The circles - mineral particles, white areas-empties, white grey area - polymer matrix.

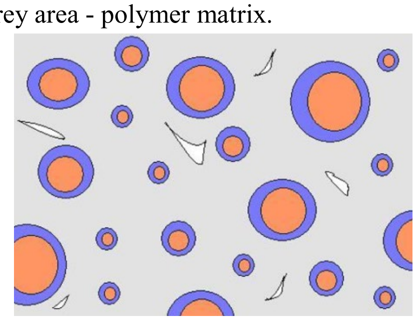

Fig.7. Model imagination of microstructure
The circles - mineral particles, white areas-empties, white grey area - polymer matrix, mineral, rings - TEOS molecules

It must be noted that the experiments on investigation of hydrophobic properties of the composites show that water absorption by composites is rather low (no more that 1.5%). This fact shows that the microstructure of the composites contains a rather low amount of structural defects (partially empties, cracks, etc).

Conclusions

1. On the basis of industrial and domestic wastes of PE there are obtained and studied polymer composites containing fine dispersed andesite, slam and quartz sand.
2. Experimentally is established that the physical-mechanical and thermal properties are essentially depend on the type and concentration of the fillers. At definite (for each fillers separately) concentrations of the fillers the materials with best properties are obtained.
3. In case of the composites containing binary fillers it is fond the optimal proportion of the fillers in the blend, which ensure some physical properties better than for composites containing one filler from binary blend.
4. The composites of PE containing modified by tetraethoxisilane fillers differ from analogues with unmodified fillers with improved technical characteristics.
5. Water absorption by composites is rather low (no more that 1.5%).

Acknowledgments

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References

[1] Achilias D.S., Roupakias C., Megalokonomos P., Lappas A.: //Journal of Hazardous Materials,2007, 149, 536.

[2] Jassim A.K.: //Procedia Manufacturing, 2017, 8, 635.

[3] Araujo R.S., Rezende C.C., Marques M.F., Gentile G. // J.Appl. Pol.Sci., 2017, 28, pp.134-142

[4] Kucukdogan N., Ozturk S., Sutcu M. //Archieves of Material Science and Engineering, 2016 (1), pp.12-18.

[5] Asare E., Basir A., Tu W., Porwal H., Zhang H., Liu Y.: //Nanocomposites, 2016, 2, 58.

[6] Asare E., Basir A., Tu W., Porwal H., Zhang H., Liu Y.: //Nanocomposites, 2016, 2, 58.

[7] Pedrazzoli D., Pegoretti A., Kalaitzidou K.: //J.Appl.Pol.Sci., 2015, 132, 4168.

[8] Aneli J., Shamanauri L., Mukbaniani O., Markarashvili E.// Problems of Mechanics, 2010, N1, pp.82-87.

Development of Effective Algorithms for Assessment of Risks in Logistics

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***Abstract*—The main factors determining the development of transport are the introduction of dynamic, safe, flexible, modern technological systems and traffic flow monitoring systems [1]. One of the most pressing issues in the decision-making process of solving various complex problems that arise at different stages of this process is the selection of a rational option on the basis of the well-established mathematical model. In this work, decision-making algorithms are used to select of the rational option among transport alternatives on the basis of expert information, arising multi-criteria optimization problems in fuzzy formulation were investigated, and a methodology to construct the membership function was given. Decision-making algorithms have been developed in the case of equivalence and dominance of the importance of criteria for the evaluation of linguistic variables on the basis of qualitative expert information in the fuzzy formulation.**

Keywords—multi-criteria optimization, fuzzy logic, dominance of criteria, risk assessment, decision-making algorithms.

The study of the logistics and transportation problems is always of great interest to to their great practical importance. Improving this process, which depends on various factors, requires serious scientific approach. Thus, it is principally important to choose a rational option from the possible alternatives that include different criteria for the strategies of operation of logistics centers [2].

The importance of registration of a large number of indicators when choosing a rational option from various alternatives in logistics and transport, the superior quality of indicators taken into account in the analysis and synthesis of the system, the significant interrelationship and interdependence of these indicators, the requirements for synthesis There are problems such as the difficulty of obtaining the original data [3].

These features make it practically impossible to apply traditional mathematical methods, including mathematical statistics, probability theory, as well as classical optimization methods, in solving the problem of application of analysis and synthesis for the selection of a rational option in logistics and transport.

The complexity of the decision-making process makes it possible, and sometimes important, to process quality expert information to select a rational option among the alternatives when the classical mathematical apparatus is ineffective. One of the most promising directions in the development of decision-making methods based on expert information is the theory of fuzzy sets and the linguistic approach in the linguistic database [4]. This article also explores decision-making algorithms when selecting a rational option among transport alternatives based on expert information. Thus, the issue of multi-criteria optimization in the fuzzy setting was investigated, and a methodology for constructing affiliation functions was given. In case of equality of importance of criteria for evaluation of linguistic terms on the basis of qualitative expert information, software was created in object-oriented programming language, method of using Matlab Fuzzy Toolbox package in case of dominance of criteria was presented.

REFERENCES

[1] Pletnev P. Risk management in logistics. SPbHEU Publishing House, 2014.

[2] Pashayev A.F. Choice of rational variant of CAS of finding out dangerous loads in air traffics on the basis of expert information. The Fifth International Scientific and Technical Conference on Microelectronic Transformers and Devices, Baku-Sumgait 2005, pp.62-65.

[3] Rotshtein A.P., Shtovba S.D. Fuzzy multicriteria analysis of options using pairwise comparisons. Izvestiya RAN. Theory and control systems. 2001, No.3, pp.150-154.

[4] Gasimov Y., Pashayev A., Azizov B., Agamalieva L., Lacinová V., & Šmerek M. (2019). Application of decision-making expert systems in transportation. NAŠE MORE: znanstveni časopis za more i pomorstvo, 66(3), pp.130-134.

Dynamic Models in Operational and Organizational Control Systems: Dynamic Programming Method

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***Abstract*−Computational procedures for dynamic programming are described. The principle of optimality is considered on a specific example. The problem of terminal control is considered. The main advantages of computational dynamic programming procedures are formulated.**

***Keywords*−control systems, dynamic programming, optimality principle, optimization methods, combinatorial methods, operational control**

I. Introduction

Optimization problems of operational and organizational control in modern systems, which, as a rule, have a complex hierarchical structure, are solved most often at the upper levels of the hierarchy. In this case, mainly static models of control objects are used. However, there are wide classes of problems when it is necessary to use dynamic models in the construction of operational and organizational control systems. First, these are control problems at the upper levels of the hierarchy, which are solved using dynamic models. A feature of these models is that the dynamic characteristics of objects are sufficiently inertial and the planning repetition interval exceeds the time required for calculating optimal programs on computers. Secondly, these are problems of control of dynamic objects at the lower levels of the hierarchy (technological processes and shop floor systems), which allow, mainly due to the time factor, using the principle of building operational and organizational control systems. Thirdly, these are problems of control of objects with a human in the control loop, making decisions on the choice of control modes for a dynamic object or corrective control actions. Besides, the theory of optimal control of dynamical systems is a classical and best studied area of optimal control, therefore, using the example of problems from this area, it is convenient to consider all the key features of optimization methods.

Despite the fact that the use of operational and organizational control systems allows avoiding the need to solve the problem of optimal system synthesis, the difficulties in implementing optimal programs using both analytical and numerical methods remain significant. The choice of the optimization method here is crucial.

The problems of solving two-point boundary value problems of taking into account control constraints and phase constraints can serve as an obstacle to the application of the classical calculus of variations, the maximum principle and dynamic programming (Bellman equations) [1], i.e., methods using the necessary optimality conditions. In another group of methods - direct optimization methods, which should include all gradient descent methods, various methods of purposeful enumeration (combinatorial methods), computational procedures for dynamic programming, etc., the account of control constraints and phase constraints is much less difficult. Among them, we should especially distinguish the computational procedures of dynamic programming, the presentation of which is discussed in this paper.

II. Optimality principle. Bellman equation

Dynamic programming, which has two forms - analytical, associated with solving the Bellman equation, and numerical, implemented in the form of computational procedures of dynamic programming, is based on the optimality principle formulated by the American mathematician R. Bellman [1].

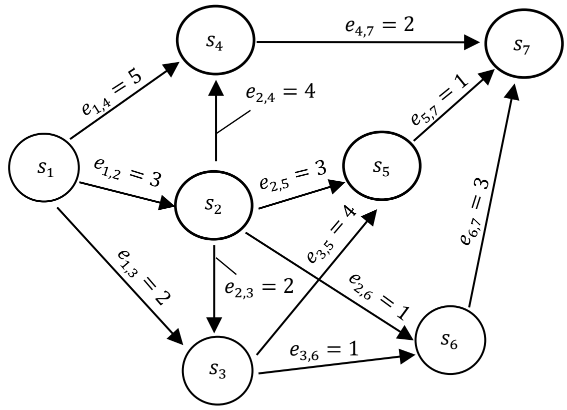

Fig. 1. The diagram explaining the optimality principle

Let us consider the optimality principle using a specific example. Suppose it is required to transfer the system from a given state s_1 to the final state s_7 (Fig.1) in such a way that during the transition a minimum cost (or time) is ensured:

$$E = \sum_{k,j} e_{k,j},$$

where $e_{k,j}$ is the costs related to the transition from the state s_k to the state s_j (or during the transition from s_k to s_j). The transition from the state s_k to the state s_j is carried out as a result of the action of the control $u_{k,j}$.

In other words, in an oriented scheme $\Gamma = \{S, U\}$, where S is the set of vertices and U is the set of edges, it is necessary to find a minimum length path between the vertices s_1 and s_7.

The solution to this problem can be obtained by complete enumeration of all paths from s_1 to s_7 [2], but if the number of possible states is large, complete enumeration may not be feasible. The dynamic programming method allows implementing the most economical enumeration procedure.

Let us introduce the function ω_k, which determines the minimum increment of the criterion E when going from the vertex s_k to the final vertex s_k. Successively determine $\omega_7, \omega_6, \omega_5, \dots, \omega_1$. Determining

$$\omega_1 \triangleq \min_{\{k,j\}} \sum_{k,j} e_{k,j},$$

and calculating ω_1 gives the sought-for result. Let us calculate

$$\omega_7 = 0;\ \omega_6 = e_{6,7} = 3;\ \omega_5 = e_{5,7} = 1;\ \omega_4 = e_{4,7} = 2.$$

From the vertex s_3, we can go to s_7 either through the vertex s_5, or through the vertex s_6. Since ω_5 and ω_6 are already known, we write

$$\omega_3 = min\begin{Bmatrix} e_{3,5} + \omega_5 = 4 + 1 = 5; \\ e_{3,6} + \omega_6 = 1 + 3 = 4 \end{Bmatrix} = 4.$$

Let us keep in mind the value of ω_3 and the vertex s_6, through which the path $s_3 \to s_6 \to s_7$ goes, and similarly calculate

$$\omega_2 = min\begin{Bmatrix} e_{2,3} + \omega_3 = 2 + 4 = 6; \\ e_{2,4} + \omega_4 = 4 + 2 = 6; \\ e_{2,5} + \omega_5 = 3 + 1 = 4 \end{Bmatrix} = 4,$$

let us also keep in mind $\omega_2 = 4$, as well as the path $s_2 \to s_5 \to s_7$.

To determine ω_1, we perform operations of the same type:

$$\omega_1 = min\begin{Bmatrix} e_{1,2} + \omega_2 = 3 + 4 = 7; \\ e_{1,3} + \omega_3 = 2 + 4 = 6; \\ e_{1,4} + \omega_4 = 5 + 2 = 7 \end{Bmatrix} = 6.$$

Thus, the path $s_1 \to s_3 \to s_6 \to s_7$ is optimal. The simple equations used to obtain it are called functional equations of dynamic programming. The effect of their application is that the general solution falls into several steps (stages) and the solution at each step is easier to obtain than from versions of a general solution. Besides, when building a general optimal solution, the results of the previous solutions are used as much as possible.

The dynamic programming method, as noted above, is based on the optimality principle. In the considered example, this principle was used in the sequential calculation of the functions ω_k, called Bellman functions. The functional equations

$$\omega_k = \min_{\{j\}}(e_{k,j} + \omega_j), \qquad (1)$$

used above are applied in computational procedures. In an analytical solution of optimal control problems, the so-called Bellman equation is used, the derivation of which is convenient to demonstrate on the simplest problem of the classical calculus of variations — the Lagrange problem:

$$E = \int_0^T F(x, u)dt \to min; \qquad (2)$$

$$\dot{x} = f(x, u); \qquad (3)$$

$$x(0) = a. \qquad (4)$$

Here, x is a state variable; u is the control action; a is the given boundary condition at the left end.

Since we need to find an analytical solution that is valid for any values of the initial state a and the integration interval $[0, T]$, we consider the parameters a and T as variables.

The Bellman function for problem (2)–(4) is defined by the expression

$$\omega(a, T) = \min_{u[0,T]} \int_0^T F(x, u)dt,$$

the notation $u[0, T]$ meaning that minimization (2) is carried out on the entire interval $[0, T]$. If we break the interval $[0, T]$ into two subintervals $[0, s]$ and $[s, T]$, then the expression for $\omega[a, T]$ can be represented as follows:

$$\omega(a, T) = \min_{u[0,s]} \min_{u[s,T]} \left[\int_0^s F(x, u)dt + \int_0^T F(x, u)dt \right].$$

or if we write it as follows:

$$\omega(a, T) = \min_{u[0,s]} \left[\int_0^s F(x, u)dt + \min_{u[s,T]} \int_0^T F(x, u)dt \right] \qquad (5)$$

and carry out minimization on the interval $[0, s]$, using the entire totality of optimal trajectories found on the interval $[s, T]$. These trajectories will have initial states $a(s)$. Thus, equation (5) corresponds to the optimality principle.

By definition of $\omega[a, T]$, the second term on the right-hand side of equation (5) is the function of the initial state $a(s)$ and the interval $[s, T]$ with the duration $T - s$. Therefore,

$$\min_{u[s,T]} \int_s^T F(x, u)dt \triangleq \omega(a(s), T - s),$$

will take on the form

$$\omega(a,T)=\min_{u[0,s]}\left[\int_0^s F(x,u)dt+\omega(a(s),T-s)\right]. \quad (6)$$

Equation (6) has the same structure as equation (1), and is also called the functional equation of dynamic programming.

If we now introduce the notation $u[0,s]=\vartheta$ and select the interval $[0,s]$ as sufficiently small, that is, such that it should be possible to carry out with a high degree of accuracy the approximation

$$\int_0^s F(x,u)dt \approx F(a,\vartheta)s;$$

$$\dot{x}|_{t=0}\approx\frac{a(s)-a}{s}=f(a,\vartheta),$$

then it follows from the last formula that

$$a(s)=a+s\cdot f(a,\vartheta),$$

and equation (6) is transformed, taking the form

$$\omega(a,T)=\min_{\vartheta}[F(a,\vartheta)s+\omega(a+s\cdot f(a,\vartheta),T-s)].$$

Let us expand $\omega(a+s\cdot f(a,\vartheta),T-s)$ as a Taylor series relative to the point with the coordinates a and T in the increments $s\cdot f(a,\vartheta)$ and s, respectively. As a result, for the terms of the first-order series, we obtain

$$\omega(a+s\cdot f(a,\vartheta),T-s)=$$
$$=\omega(a,T)+s\cdot f(a,\vartheta)\frac{\partial\omega(a,T)}{\partial a}-s\frac{\partial\omega(a,T)}{\partial T}.$$

Substituting this expression into the equation for $\omega(a,T)$, we get

$$\omega(a,T)=\min_{\vartheta}[F(a,\vartheta)\cdot s+\omega(a,T)+$$
$$+s\cdot f(a,\vartheta)\frac{\partial\omega(a,T)}{\partial a}-s\frac{\partial\omega(a,T)}{\partial T}\Big].$$

Since $\min_{\vartheta}\omega(a,T)=\omega(a,T)$, and s is a small but finite quantity, the last equation can be transformed as

$$0=\min_{\vartheta}\left[F(a,\vartheta)+f(a,\vartheta)\frac{\partial\omega(a,T)}{\partial a}-\frac{\partial\omega(a,T)}{\partial T}\right] \quad (7)$$

This nonlinear partial differential equation is called the Bellman equation. It determines the necessary and sufficient conditions for the existence of an extremum for the original problem. It corresponds to two equations commonly used in calculations:

$$0=F(a,\vartheta)+f(a,\vartheta)\frac{\partial\omega(a,T)}{\partial a}-\frac{\partial\omega(a,T)}{\partial T}; \quad (8)$$

$$0=\frac{\partial F(a,\vartheta)}{\partial\vartheta}+\frac{\partial f(a,\vartheta)}{\partial\vartheta}\frac{\partial\omega(a,T)}{\partial a}. \quad (9)$$

Equation (8) was obtained by substituting the optimal control ϑ in (7), equation (9) – by differentiating (8) with respect to ϑ.

The physical meaning of the Bellman equation can be explained as follows. At the initial time instant, the control $u[0,s]$ is determined for a known value $x(0)=a$, which is equivalent to determining $\frac{dx}{dt}$. It is obvious from the fact that selecting $u[0,s]$ gives the value

$$x(s)=a+s\cdot f(a,u[0,s]).$$

At $s\to 0$, the value of f increasingly approaches the value $\frac{dx}{dt}$, since

$$f(a,u[0,s])\approx\frac{a(s)-a}{s}\approx\frac{dx}{dt}$$

This is also the case for other time instants over the entire interval $[0,T]$. Therefore, when implementing the method of dynamic programming, the extremum is defined as the envelope of the family of tangents to the optimal trajectory. In the classical calculus of variations, the extremum is found as a geometrical locus of points that form the desired trajectory.

The Bellman equation can take a different form depending on the mathematical form of the optimization problem being solved. For example, with the minimization

$$E=\int_0^\infty F(x,u)\,dt$$

and conditions (7) and (4), we obtain

$$0=\min_{\vartheta}\left[F(a,\vartheta)+f(a,\vartheta)\frac{\partial\omega\ (a)}{\partial a}\right].$$

Although equations of the type of (8) following from Bellman equation (7) were known in the calculus of variations as the Hamilton–Jacobi equations, the Bellman equation is a generalization of the latter, extending to the case of the presence of control constraints. In this case, it takes the form

$$0=\inf_{\vartheta}\left[F(a,\vartheta)+f(a,\vartheta)\frac{\partial\omega\ (a,T)}{\partial a}-\frac{\partial\omega\ (a,T)}{\partial T}\right].$$

where inf is the exact lower bound of the backeted expression.

The Bellman equation is widely used to solve relatively simple problems of optimal control theory, in particular, problems of analytical design of controllers. For this class of problems, a linear description of control systems and a quadratic functional are used [3], which makes it quite simple to find a solution. At the same time, the Bellman equation is a nonlinear partial differential equation, and solving equations of this type is not a trivial task. From the theory of partial differential equations, we know the method of characteristics, which turns out to be the most acceptable. An example of using the method of characteristics is given in [4]. The applicability of the Bellman equation is also limited by the requirement for the existence of the derivative $\frac{\partial \omega}{\partial a}$, which is not always fulfilled. Of course, it would be possible to solve the Bellman equation by numerical methods, but that will involve no fewer difficulties in the implementation of computational dynamic programming schemes based on the solution of the functional equation, and not the Bellman equation.

III. THE FIRST COMPUTATIONAL PROCEDURE OF DYNAMIC PROGRAMMING

Earlier, a functional dynamic programming equation (6) was obtained for problem (2)-(4).

Suppose $[0, s] = \Delta$. Then equation (6) can be written as

$$\omega_0 (x_0) = \min_{u_0}[F (x_0, u_0) \Delta + \omega_1 (x_1)]. \qquad (10)$$

Here, the indices 0 and 1 denote the variables for the time instants $t = 0$ and $t = \Delta$, respectively; the arguments T and T have been omitted, being replaced with the indices 0 and 1. The physical meaning of equations (6) and (10) is the same, $\omega_0 (x_0)$ is the optimal value of the criterion during the transition of the system from the state x_0 to the state x_N.

It is clear from (10) that to calculate $\omega_0 (x_0) = \min E (x, u)$ we need to know $\omega_1 (x_1)$. Obviously, $\omega_1 (x_1)$ can be calculated similar to $\omega_0 (x_0)$, but that requires knowing $\omega_2 (x_2)$. To calculate $\omega_2 (x_2)$, we need to know $\omega_3 (x_3)$, etc., up to $\omega_N (x_N)$. Therefore, the search for a solution must be carried out successively step by step, completely similar to how it was done when selecting the optimal path, but taking discrete time values as the step $N\Delta, (N-1)\Delta, (N-2)\Delta, \dots, \Delta, 0$. For any $1 \le k \le N$, functional equations of the type of (10), in which only the indexing of the variables changes, will hold true:

$$\omega_k (x_k) = \min_{u_k}[F (x_k, u_k) \Delta + \omega_{k+1} (x_{k+1})]. \qquad (11)$$

Obviously, at $t = N\Delta$, since the trajectory does not get an increment, $\omega_N \equiv 0$ for all x_N. The first step is to calculate $\omega_{N-1} (x_{N-1})$.

We enumerate sequentially all possible states from $x_{N-1} = M_x^-$ and to $x_{N-1} = M_x^+$ with the step δ, and for each of them, we enumerate all quantized values of the control action $M_u^-, M_u^- + \nu, \dots, M_u^+ - \nu, M_u^+$. For each value of u_{N-1} at the given x_{N-1}, $F (x_{N-1}, u_{N-1})\Delta$ is calculated and the smallest one is selected, which corresponds to the solution of the equation

$$\omega_{N-1} (x_{N-1}) = \min_{u_{N-1}} F (x_{N-1}, u_{N-1})\Delta.$$

Thus, analyzing the state $x_{N-1} = \delta$ and five possible trajectories, each of which has its own corresponding value u_{N-1}, we should choose the one that corresponds to the minimum increment of the functional.

Let us proceed to the analysis of the second step, recording the optimal controls u_{N-1} for all possible states x_{N-1}. Let us set a specific value of x_{N-2}, e.g., $x_{N-2} = 0$, and enumerate all discrete values of u_{N-2}. As a result of the action u_{N-2}, the system will go from the state $x_{N-2} = 0$ to some state $x_{N-1} = x_{N-2} + \Delta f (x_{N-2}, u_{N-2})$, and the criterion will receive the increment $F (x_{N-2}, u_{N-2}) \Delta$. . Optimal trajectories from any states x_{N-1} to the states x_N are already known. Therefore, the total trajectory of the transition from a given state x_{N-2} to x_N, taking into account the analyzed value of u_{N-2}, will be estimated by the expression $F (x_{N-2}, u_{N-2}) \Delta + \omega_{N-1}(x_{N-1})$.

Enumerating all admissible values of u_{N-2} for the specified x_{N-2}, calculating $F (x_{N-2}, u_{N-2}) \Delta$ and x_{N-1}, and also selecting the address of x_{N-1} the corresponding value of $\omega_{N-1}(x_{N-1})$, we can find

$$\omega_{N-2}(x_{N-2}) = \min_{u_{N-2}}[F (x_{N-2}, u_{N-2}) \Delta + \omega_{N-1} (x_{N-1})].$$

Similar calculations are performed for all possible values of x_{N-2}.

These exact calculations should be carried out for all the remaining steps. The process ends with the calculation of $\omega_0(x_0)$ and u_0.

If $\vec{x}$ is an n-dimensional vector, and $\vec{u}$ is an m-dimensional vector, it is necessary to solve the problem

$$E (\vec{x}, \vec{u}) = \int_0^T F (\vec{x}, \vec{u})\, dt;$$

$$\dot{\vec{x}} = \vec{f} (\vec{x}, \vec{u});$$

$$\vec{x}(0) = \vec{a};$$

$$\vec{x} (T) = \vec{b} \text{ or not fixed};$$

$$\vec{x} (t) \in E_x;$$

$$\vec{u} (t) \in E_u,$$

which is reduced to a mathematical programming problem of the form

$$E (\vec{x}_k, \vec{u}_k) = \sum_{k=0}^{N-1} F (\vec{x}_k, \vec{u}_k) \Delta;$$

$$\vec{x}_{k+1} = \vec{x}_k + \Delta\dot{\vec{f}} (\vec{x}_k, \vec{u}_k);$$

$$\vec{x}_0 = \vec{a};$$

$$\vec{x}_N = \vec{b} \text{ or not fixed};$$

$$\vec{x}_k \in E_x, \qquad k = \overline{0, N};$$

$$\vec{u}_k \in E_u, \qquad k = \overline{0, N},$$

where k is the number of the quantization step of the variable t, then the structure of functional equation (11) remains the same:

$$\omega_k\,(\vec{x}_k) = \min_{\vec{u}_k}[F\,(\vec{x}_k, \vec{u}_k)\,\Delta + \omega_{k+1}\,(\vec{x}_{k+1})].$$

However, since each $\vec{x}_k$ is now a vector with the coordinates $x_1, x_2, \dots, x_n$, and $\vec{u}_k$ is a vector with the coordinates $u_1, u_2, \dots, u_m$, the amount of computation increases significantly.

The above computational procedure of dynamic programming has two shortcomings.

1. Let the state $x_k == M_x^+$ be analyzed for some k-th step. Then, when calculating x_{k+1} from the formula $x_{k+1} = M_x^+ + \Delta f\,(M_x^+, u_k)$, if $f\,(M_x^+, u_k) > 0$, the state $x_{k+1} > M_x^+$. This case is called the expanding variable grid. Computer programs that implement this dynamic programming procedure should include special operations that either really expand the variable grid or stop the computation at $x_{k+1} > M_x^+$ and $x_{k+1} < M_x^-$.

2. An assumption was made earlier that the quantization of the variables u and x was carried out in such a way that discrete values of the control u correspond to discrete values that coincide with the quantized $M_x^-, M_x^- + \delta, \dots, M_x^+ - \delta, M_x^+$. However, in most cases, this assumption is not fulfilled. Therefore, it is necessary to use interpolation formulas to select such values of the control action that ensure that the calculated values of the state variables coincide with their quantized values with a specified degree of accuracy.

The computational procedure of dynamic programming, in which the second method of reducing optimal control problems to mathematical programming problems is used, does not have these two shortcomings.

IV. THE SECOND COMPUTATIONAL PROCEDURE OF DYNAMIC PROGRAMMING

Let us use the second method of reducing problems of optimal control to problems of mathematical programming in the version when the control $u_k = const$ on each of the intervals $[t_k, t_{k+1}]$ and can be calculated from difference equation for the known values of x_k and x_{k+1}. So, original problem is reduced to the following one:

$$E\,(x_k, u_k) = \sum_{k=0}^{N-1} F\,(x_k, u_k)\,\Delta;$$

$$x_{k+1} = x_k + \Delta \cdot f\,(x_k, u_k);$$

$$x_0 = a;$$

$$x_k \in [M_x^-, M_x^- + \delta, M_x^- + 2\delta, \dots, M_x^+ - \delta, M_x^+];$$

$$M_u^- \le u_k \le M_u^+.$$

Let $\widehat{\omega}_k\,(x_k)$ denote the optimal value of the criterion $E\,(x_k, u_k)$ associated with a change in x from the value x_k at the instant $t = t_k = k\Delta$ to some arbitrary (since the right end is not fixed) value x_N at the instant $t = T = N\Delta$. Obviously, $\widehat{\omega}_N\,(x_N) = 0$ for all x_N, and $\widehat{\omega}_0 = \min E\,(x_k, u_k)$.

In accordance with the optimality principle, we successively determine

$$\widehat{\omega}_{N-1}\,(x_{N-1}), \widehat{\omega}_{N-2}\,(x_{N-2}), \dots, \widehat{\omega}_2\,(x_2), \widehat{\omega}_1\,(x_1), \widehat{\omega}_0\,(x_0).$$

In the first step, $\widehat{\omega}_{N-1}\,(x_{N-1})$ is calculated. To do this, it is necessary to enumerate all the values of x_{N-1} and for each of them successively analyze all admissible values of x_N, calculating the corresponding u_{N-1}, increments of the criterion $F\,(x_{N-1}, u_{N-1}\,(x_N))\Delta$ and selecting the smallest of them. Formally, this process can be presented by the formula

$$\widehat{\omega}_{N-1}\,(x_{N-1}) = \min_{(x_N)}[F\,(x_{N-1}, u_{N-1}(x_N))\,]\,\Delta;$$

$$x_N = x_{N-1} + \Delta \cdot f(x_{N-1}, u_{N-1}).$$

In the second step, for each possible state x_{N-2}, we calculate:

a) for all possible values of x_{N-1}, the corresponding values of u_{N-2} from the formula

$$x_{N-1} = x_{N-2} + \Delta \cdot f\,(x_{N-2}, u_{N-2});$$

b) from the known values of x_{N-2} and u_{N-2}, the increments of the criterion $F\,(x_{N-2}, u_{N-2}\,(x_{N-1}))\Delta$;

c) at the address x_{N-1}, the values of $\widehat{\omega}_{N-1}\,(x_{N-1})$;

d) the minimum value of $\widehat{\omega}_{N-2}\,(x_{N-2})$ from the formula

$$\widehat{\omega}_{N-2}\,(x_{N-2}) = \min_{(x_{N-1})}\Big[F\,\big(x_{N-2}, u_{N-2}(x_{N-1})\Delta + \widehat{\omega}_{N-1}(x_{N-1})\big)\Big].$$

Similar operations are carried out in all other steps. Thus, for an arbitrary k-th step, the functional equation has the form

$$\widehat{\omega}_k\,(x_k) = \min_{(x_{k+1})}\Big[F\,\big(x_k, u_k(x_{k+1})\big)\Delta + \widehat{\omega}_{k+1}(x_{k+1})\big)\Big]. \qquad (12)$$

In the final step, we calculate

$$\omega_0(x_0) = \min_{(x_1)}\Big[F\,\big(x_0, u_0(x_1)\Delta + \widehat{\omega}_1(x_1)\big)\Big],$$

In the considered computational procedure of dynamic programming, the order of calculation of $\widehat{\omega}_k$ from $k = N$ is used, i.e., from $t = T$ to $k = t_0 = 0$.

Suppose $\widehat{\omega}_k\,(x_k)$ is the optimal value of the criterion obtained during the transition of the system from the arbitrary state x_0 (the boundary condition at the left end is considered unspecified) to the state x_k. The process of calculating $\widehat{\omega}_k$ is carried out starting from $\widehat{\omega}_1\,(x_1)$. For this purpose, for each of the possible states of x_1 all possible states of x_0 are enumerated and the corresponding value of u_0 is calculated from the formula $x_1 = x_0 + + \Delta f\,(x_0, u_0)$, and then

$$\widehat{\omega}_1\,(x_1) = \min_{x_0}[F\,(x_0, u_0)\Delta].$$

is found.

If the value $x_0 = a$ is specified, the calculation process in the first step is simplified. When carrying out the calculations in the second step, the relations $x_2 = x_1 + \Delta f\,(x_1, u_1)$ are used, from which u_1 is calculated using the specified x_2 and x_1. The functional equation for the two-step process will have the form

$$\widehat{\omega}_2\ (x_2) = \min_{x_1}[F\ (x_1, u_1)\Delta + \widehat{\omega}_1\ (x_1)],$$

the values of $\widehat{\omega}_1\ (x_1)$ are taken from the table filled in the first step.

In the general case, for any $0\ \leq k\ \leq N$, we will have the equation

$$\widehat{\omega}_k\ (x_k) = \min_{x_{k-1}}[F\ (x_k, u_k)\Delta + \widehat{\omega}_{k-1}\ (x_{k-1})]. \quad (13)$$

In cases when $\vec{x}$ is a vector and $\vec{u}$ is a vector, functional equations (12) for the second computational procedure of dynamic programming take the form

$$\widehat{\omega}_k\ (\vec{x}_k) = \min_{\vec{x}_{k-1}}[F\ (\vec{x}_k, \vec{u}_k)\Delta + \widehat{\omega}_{k-1}\ (\vec{x}_{k-1})];\ \ k = \overline{0, N}.$$

It can be seen from the above that when using the second computational procedure, we do not need to perform interpolation and take into account the possibilities of expanding the variable grid, unlike the first computational procedure. Nevertheless, it also has some shortcomings, the main of which may be the difficulty of solving the system of algebraic equations $\vec{x}_{k+1} = \vec{x}_k + \Delta f\ (\vec{x}_k, \vec{u}_k)$ with respect to $\vec{u}_k$, especially if the dimensions of the vectors $\vec{x}$ and $\vec{u}$ do not coincide.

V. TAKING INTO ACCOUNT CONTROL CONSTRAINTS, PHASE CONSTRAINTS, AND BOUNDARY CONDITIONS

Compared with other optimization methods, computational procedures of dynamic programming have the advantage that they make it easy to take into account all possible forms of constraints on control and phase coordinates, as well as boundary conditions at both ends of the trajectory.

Let us first consider the first computational procedure. We assumed earlier that $M_u^- \leq u\ (t) \leq M_u^+$. Following this constraint, when carrying out calculations in each step, it is necessary to consider only those quantum values of u_k that are limited by the interval $[M_u^-, M_u^+]$. To do this, in a program that implements the method on a computer, we introduce either the entire set of values $[M_u^-, M_u^- + \delta, M_u^- + 2\delta, \dots, M_u^+ - \delta, M_u^+]$, or conditions prohibiting the use of those u_k, that lie outside the interval $[M_u^-, M_u^+]$. If this interval is not constant in time, then the values $M_u^-(k\Delta)$ and $M_u^+(k\Delta)$ $(k = \overline{0, N-1})$ are fixed and before checking whether u_k belongs to the interval $[M_u^-(k\Delta), M_u^+(k\Delta)]$, the corresponding values $M_u^-(k\Delta)$ and $M_u^+(k\Delta)$, refined at each step, are introduced into the formula for verification. Obviously, the introduction of these values will not significantly complicate the computation program, even if the dependences $M_u^-(k\Delta)$ and $M_u^+(k\Delta)$ cannot be specified by analytical expressions and it will be necessary to store their tabulated values in the computer memory in the form of a table.

Let us consider the process of taking into account phase constraints. When calculating $x_{k+1} = x_k + \Delta f\ (x_k, u_k)$ for given x_k and u_k, it is necessary to check whether the calculated x_{k+1} belongs to the interval $[M_x^-(k\Delta), M_x^+\ (k\Delta)]$.

Let us now consider the process of solving a two-point boundary value problem. The presence of the boundary condition $x_N = b$ along with the condition $x_0 = a$ leads to a change in the calculations of only ω_{N-1} in the computational procedure of dynamic programming, and this change is related not to the complication, but to the simplification of the calculations. Indeed, if the following formula was used in the problem with two variable end-points

$$\omega_{N-1}\ (x_{N-1}) = \min_{u_{N-1}} F\ (x_{N-1}, u_{N-1})\ \Delta,$$

then for a fixed $x_N = b$ for each possible state x_{N-1} there will be a unique control that transfers the system from the state x_{N-1} to $x_N = b$. Thus, when calculating $\omega_{N-1}\ (x_{N-1})$, it is no longer necessary to choose the best of the controls, but to find the only control that transfers the system from x_{N-1} to $x_N = b$. Going through all possible values of u_{N-1}, we check the correspondence of the obtained x_N to the value $x_N = b$ and calculate $\omega_{N-1}\ (x_{N-1}) = F\ (x_{N-1}, u_{N-1})\Delta$. The condition $x_N = b$ has no effect on the further course of calculations.

Let us turn to the second computational procedure. By enumeration the values for the given value of x_k, the values of u_k are calculated here. Obviously, to take into account the control constraints for each calculated value of u_k, it is necessary to check the condition $u_k \in [M_u^-(k\Delta), M_u^+\ (k\Delta)]$, and, if it is not satisfied, exclude this value of u_k from consideration.

When selecting the values of x_{k+1} to calculate u_k for a given x_k, it is necessary to check the conditions $x_k \in [M_x^-(k\Delta), M_x^+\ (k\Delta)]$ as well, and once this condition is violated, proceed to the consideration of the new value of x_k (it is assumed that the enumeration of x_{k+1} is performed successively starting from $M_x^-(k\Delta)$ or in the opposite direction).

Taking into account the boundary condition $x_N = b$ in the second computational procedure turns out to be even simpler than in the first. In the first step, the value of u_{N-1} is calculated for each of the valid x_{N-1} from the formula

$$b = x_{N-1} + \Delta f\ (x_{N-1}, u_{N-1}),$$

and then $\widehat{\omega}_{N-1}\ (x_{N-1}) = F\ (x_{N-1}, u_{N-1})\Delta$. The same order of calculation can be used in the first computational procedure to determine $\omega_{N-1}(x_{N-1})$, as it allows foregoing the enumeration of all admissible controls u_{N-1}.

To illustrate the nature of the computational process implemented in dynamic programming, let us consider a simple problem, which, after being reduced to a mathematical programming problem, takes the form

$$E = (x_k, u_k) = \sum_{k=0}^{N-1} (x_k^2 + u_k^2)\ \Delta + \lambda\ (x_N - 2)^2\ \rightarrow min;$$

$$x_{k+1} = x_k + \Delta\, u_k;$$

$$u_k \in E_u = [-2, -1, 0, 1, 2];$$

$$0 = M_x^- \leq x_k \leq M_x^+ = 8;$$

$$0 \leq x_N \leq 2.$$

We select quantization steps $\delta = 1$ and $\Delta = 1$ and use the second computational procedure of dynamic programming. For $\Delta = 1$ at $T = 10$, we will get $N = 10$.

Since the values of x_N are subject to a constraint and a fine $\lambda\,(x_N - 2)^2$ (specified $\lambda = 2.5$) is imposed for the non-compliance with the condition $x_N = 2$, then another row must be entered into the table of results to store the values of $\widehat{\omega}_N(0) = 2.5 \cdot 4 = 10, \widehat{\omega}_N(1) = 2.5, \widehat{\omega}_N(2) = 0$. The states $x_N > 2$ are inadmissible. We will write the results of the computations in Table 1.

In the first step, we fix the state $x_{N-1} = 0$ and start the enumeration of the states $x_N = 0, x_N = 1, x_N = 2$. For $x_N = 0$, we find the value $u_{N-1} = 0$ from the equation $x_N = x_{N-1} + \Delta\, u_{N-1}$. For $x_N = 1$, we get $u_{N-1} = 1$, and for $x_N = 2$, we determine $u_{N-1} = 2$. Now we calculate

$$\widehat{\omega}_{N-1}\,(x_{N-1}) = \min_{x_N}[(x_{N-1}^2 + u_{N-1}^2) + \widehat{\omega}_N\,(x_N)].$$

For $x_N = 0, x_N = 1, x_N = 2$, we write successively

$$\widehat{\omega}_{N-1}\,(0) = \min_{x_N}\begin{Bmatrix} (0^2 + 0^2) + 10 = 10; \\ (0^2 + 1^2) + 2.5 = 3.5; \\ (0^2 + 2^2) + 0 = 4. \end{Bmatrix}$$

Thus, for the state $x_{N-1} = 0$, the transition to the state $x_N = 1$ is optimal. Similar calculations are performed in all steps of the computation. For instance, in the second step for the state $x_{N-2} = x_8 = 2$, it is necessary to analyze the states $0 \leq x_9 \leq 4$. Successively considering $x_9 = 0, 1, 2, 3, 4$, we find the values $u_8 = -2, -1, 0, 1, 2$ from the equation $x_9 = x_8 + \Delta\, u_8$. For each of them, we need to calculate the increments of the criterion $(x_8^2 + u_8^2)\Delta$. Successively substituting $u_8 = -2, -1, 0, 1, 2$, we find $(x_8^2 + u_8^2)\Delta = 8, 5, 4, 5, 8$. These values will correspond to the states $x_9 = 0, 1, 2, 3, 4$, which are characterized by the values $\widehat{\omega}_9 = 3.5; 2, 4, 10, 20$. The values of $\widehat{\omega}_8\,(2)$ will be found from the formula

$$\widehat{\omega}_8\,(2) = \min_{x_N}\,[(2^2 + u_8^2) + \widehat{\omega}_9\,(x_9)] = \begin{bmatrix} 8 + 3.5 \\ 5 + 2 \\ 4 + 4 \\ 5 + 10 \\ 8 + 20 \end{bmatrix} = 7.$$

Therefore, the optimal transition from the state $x_8 = 2$ is into the state $x_9 = 1$ under the influence of the control $u_8 = 1$. By means of calculations of this type, we fill Table 1.

TABLE I.

x	0	1	2	3	4	5	6	7	8
$\widehat{\omega}_{10}$	10	2,5	0	×	×	×	×	×	×
$\widehat{\omega}_9$	3,5	2	4	10	20	×	×	×	×
x_{10}	1	2	2	2	2	×	×	×	×
$\widehat{\omega}_8$	3	3	7	14	24	39	60	×	×
x_9	1	1	1	2	2	3	4	×	×
$\widehat{\omega}_7$	3	4	8	16	27	43	64	92	128
x_8	0	1	1	1	2	3	4	5	6
$\widehat{\omega}_6$	3	5	9	17	28	45	67	96	132
x_7	0	0 or 1	1	1	2	3	4	5	6
$\widehat{\omega}_5$	3	5	10	18	29	46	68	98	135
x_6	0	0	1	1	2	3	4	5	6
$\widehat{\omega}_4$	3	5	10	18	30	47	69	99	136
x_5	0	0	1	1	2	3	4	5	6
$\widehat{\omega}_3$	3	5	10	18	30	47	70	100	137
x_4	0	0	1	1	2	3	4	5	6
$\widehat{\omega}_2$	3	5	10	18	30	47	70	100	138
x_3	0	0	1	1	2	3	4	5	6
$\widehat{\omega}_1$	3	5	10	18	30	47	70	100	138
x_2	0	0	1	1	2	3	4	5	6
$\widehat{\omega}_0$	3	5	10	18	30	47	70	100	138
x_1	0	0	1	1	2	3	4	5	6

VI. THE PROBLEM OF LOGICAL-DYNAMIC SYSTEMS

The need to solve increasingly complex problems of control of real objects not only stimulates the development of traditional methods of control, but also gives rise to completely new methods of solving them with the involvement of an unconventional mathematical apparatus. One of the classes of such problems is the class of control problems for logical-dynamic systems. The main quality that characterizes a logical-dynamic system is the presence of a finite set of states and a jump-like transition from one state to another [5, 6, 7]. At the same time, outside the jump-like (logical) transitions, the system functions as a dynamic one. In other words, a logical-dynamic system should be considered such a system, the continuous dynamic nature of operation of which is significantly influenced by logical conditions leading to a change in its dynamic characteristics.

Let us consider the problem of logical-dynamic systems in the light of the construction of operational and organizational control systems. Following [7, 8], we write the equation of a logical-dynamical system in the form

$$\dot{\vec{x}}(t) = AL^A \vec{x}\,(t) + BL^B \vec{u}\,(t),$$

where $\vec{x}\,(t)$ and $\vec{u}\,(t)$ are, as before, phase vector function and control vector function, respectively; AL^A and BL^B are logical-operator matrices, the values of the elements of which can change abruptly depending on the logical conditions.

This equation can be represented in a more general form:

$$\dot{\vec{x}}(t) = \vec{f}(\vec{x}\,(t), \vec{u}\,(t), L(\vec{x}, \vec{u}\,)), \qquad (14)$$

where $L(\vec{x}, \vec{u}\,)$ is a totality of logical conditions that change the equation parameters depending on $\vec{x}$ and $\vec{u}$ or transfer the system in a jump-like manner from one state to another.

When using the principle of operational and organizational control, as noted earlier, there is no need to solve the synthesis problem, but the problem of obtaining optimal program controls remains. We will use the second method of reducing problems of optimal control to problems of mathematical programming. For this purpose, we introduce the quantization step of the variable t equal to the constant Δ, and select in the space of variables $x_1, x_2, \dots, x_n, t$ those points where the action of logical conditions leads to an abrupt change of states or a change in the parameters of equation (14). If there were no logical conditions, it would be possible to introduce an elementary operation, but the presence of logical conditions forces us to write an elementary operation in the form

$$B\ (x_k, x_{k+1}) = \begin{Bmatrix} \gamma_{k,k+1}, & u_k \\ \hat{L}\ (x_k, x_{k+1}) \end{Bmatrix}, \quad (15)$$

i.e., along with the existence of a continuous trajectory $\gamma_{k,k+1}$ we suppose the possibility of a jump-like transition from x_k to x_{k+1} along the trajectory $\hat{L}\ (x_k, x_{k+1})$ under the influence of the logical condition $L\ (x_k, x_{k+1})$. When using the second computational procedure of dynamic programming, the transition to (15) requires additional saving all conditions $L\ (x_k, x_{k+1})$ in the computer memory and calculating $\widehat{\omega}_k\ (x_k)$ with account for these conditions.

Thus, the problem of accounting for logical conditions in operational and organizational control systems is associated only with an increase in the amount of computation and does not cause any fundamental problems. It should be added that, as the calculation of simple problems has shown, even the increase in the amount of computation turns out to be insignificant.

VII. AVERAGING CONTROL AND TERMINAL CONTROL

The optimal control problems considered previously far belong to the class of so-called averaging control problems[9, 10, 11, 12]. An integral functional was used as a criterion in them, and the choice of control at any moment of time affected this functional. At the same time, there is a large class of problems in the practice of optimal control, in which the behavior of an object on the interval $[0, T]$ is not of interest, but the result achieved at the finite time instant is important. This result depends on the final state $\vec{x}\ (T)$ and is determined by the criterion $\Phi\ (\vec{x}\ (T))$. Problems of this type are called terminal control problems. In the classical calculus of variations, these problems are called Mayer problems, and the criterion $\Phi\ (\vec{x}\ (T))$ is called the Mayer criterion. (Problems of reaching the extremum of a mixed-type criterion

$$E\ (\vec{x}, \vec{u}) = \int_{t_0}^{T} F\ (\vec{x}, \vec{u})\ dt + \Phi\left(\vec{x}\ (T)\right)$$

in the classical calculus of variations are called Bolza problems).

The Lagrange problem

$$E\ (\vec{x}, \vec{u}) = \int_{t_0}^{T} F\ (\vec{x}, \vec{u})\ dt\ \rightarrow min;$$

$$\dot{\vec{x}}(t) = \vec{f}(\vec{x}, \vec{u});$$

$$\vec{x}\ (t_0) = \vec{x}^0$$

can always be reduced to a Mayer problem by introducing an additional coordinate x_{n+1} that satisfies the equation

$$\dot{x}_{n+1} = f_{m+1} = F\ (\vec{x}, \vec{u}), \quad x_{n+1}(t_0) = 0.$$

Using the augmented vector $\vec{x} = |\vec{x}, x_{n+1}|$ instead of $\vec{x}$ and the vector $\vec{f}$ instead of $\vec{f}$, we arrive at the following Mayer problem:

$$\Phi\ (\vec{x}, \vec{u}) = x_{n+1}\ (T)\ \rightarrow min;$$

$$\dot{\bar{x}} = \bar{f}\ (\bar{x}, \vec{u});$$

$$\bar{x}\ (t_0) = \bar{x}_0.$$

However, it is possible to reduce a Mayer problem to a Lagrange problem only in rare special cases, and therefore it becomes necessary to develop specific methods for solving Mayer problems. In this respect, let us consider the possibilities of computational procedures of dynamic programming.

So, we have the following terminal control problem:

$$\left.\begin{matrix} E\ (x, u) = \Phi\left(x\ (T)\right) \rightarrow min \\ \dot{x} = f\ (x, u); \\ x_0 = a; \\ u(t) \in E_u. \end{matrix}\right\} \quad (16)$$

Using the first method of reducing problems of optimal control to problems of mathematical programming, we proceed from problem (59) to problem

$$E\ (x_k, u_k) = \Phi\ (x_N);$$

$$x_{k+1} = x_k + \Delta f\ (x_k, u_k), \ k = \overline{0, N-1};\ x_0 = a; \quad (17)$$

$$u_k \in E_u.$$

Let us introduce into consideration the function $\omega_k\ (x_k)$, which expresses the optimal value of the criterion $\Phi\ (x_N)$, which can be achieved from the state x_k, and calculate in advance the values $\omega_N\ (x_N) = \Phi\ (x_N)$ for all possible values of x_N. At the same time, we had to set the range of possible values of x again, limiting it to the interval $[M_x^-, M_x^+]$. Of course, among the values $x \in [M_x^-, M_x^+]$, it is easy to find the one that guarantees $\min \Phi\ (x_N)$.. But the question is whether this value is reachable from the state $x_0 = a$,, and if it is, then in what way, and if it is not, then what will be the optimal reachable state and how to arrive at it.

VIII. THE MAIN ADVANTAGES AND SHORTCOMINGS OF COMPUTATIONAL PROCEDURES OF DYNAMIC PROGRAMMING. ASSESSMENT OF COMPUTATIONAL DIFFICULTIES

Let us formulate the key advantages of computational procedures of dynamic programming using the above results.

1. Computational procedures of dynamic programming have some properties of an "analytical" nature. First, it is possible to recover the optimal trajectory from tables of optimal solutions for any initial conditions in the interval $[M_x^-, M_x^+]$. Second, from the same tables it is possible to obtain the optimal solution for any time interval $[0, T']$ at $T' \leq T$. To do this, it is necessary to start restoring the

optimal strategy, not from $x_0 = a$, but from $x_l = a$, where $l = (T - T') / \Delta$.

For instance, suppose the problem has $T = 7$ and $x(0) = = 1$. Then $l = 3$. In this case, we need to start restoring the optimal trajectory from the seventh row from the bottom of Table 3, selecting the value $x_4 = 0$ at the address $x = 1$. Then we will determine the state $x_5 = 0$, and so on.

2. The presence of various kinds of constraints does not complicate, but facilitates the solution process.

Suppose, for instance, that the control constraints have the form $|u_k| \leq \gamma$. Then, if the computational scheme for the first method of reducing the optimal control problem to a mathematical programming problem is used, the smaller γ, the smaller the number of running values of u_k and, therefore, the faster the computation process.

If phase constraints $x_k \in [M_x^-(k\Delta), M_x^+(k\Delta)]$, are specified, then their fulfillment for each u_k is verified. The stricter the phase constraints, the fewer cells in the table, the shorter the computation process.

The presence of boundary conditions at the right end practically does not change the computational procedure of the dynamic programming method. The exception is the first step, where ω_{N-1} or $\widehat{\omega}_{N-1}$, are determined, but the calculations for the two-point boundary value problem there turn out to be even simpler than in the problem with two variable endpoints.

3. Computational procedures of dynamic programming are well adapted for taking into account various kinds of constraints, not only given in the simplest form (e.g., in the form of inequalities), but also for constraints of a more complex form, in particular, those including logical conditions.

4. Using computational procedures of dynamic programming, it is possible to solve averaging optimization problems (with interval functional), but also terminal optimization problems, with the computational difficulties of the solution not increasing.

5. Both computational procedures can be used to solve optimization problems with practically any criterion in terms of form, both linear and nonlinear. Moreover, the criterion may not even be specified analytically, but only formulated in the form of a table for the discrete values of the variables.

6. Finally, using computational procedures of dynamic programming, it turns out to be possible to investigate both deterministic and stochastic processes. Taking into account the effects of random parameters does not affect the essence of the method, but only leads to the need to analyze a much larger number of control options.

It follows from the above that it is difficult to find a problem that could not be solved in principle using computational procedures of dynamic programming. However, the theoretic possibility in many practical cases is not supported by the practical possibility. This is explained by a very serious drawback of the dynamic programming method, which is that in order to obtain an optimal solution, it is sometimes necessary to analyze so many control options that the most modern computers will be incapable of doing it. The main difficulty in the practical implementation of computational procedures of dynamic programming is overcoming the dimensionality problem, or, in the figurative expression of R. Bellman, "the curse of dimensionality". Usually, in dynamic programming, the dimensionality is understood as the number of solution options required for analysis during all N calculation steps. The dimensionality of the problem is closely related to the dimensionality of the phase vector, the number of quantization steps of variables and time, i.e., proportional to the number of nodes in the grid of variables determined as

$$\left(\prod_{j=1}^{n} M_{x_j}\right) N = M_{\vec{x}} N, \tag{18}$$

where $M_{\vec{x}}$ is the number of levels of quantization of the variable x_j carried out with the step δ_j;

$$M_{x_j} = \left[\frac{M_{x_j}^{+} - M_{x_j}^{-}}{\delta_j}\right] + 1, \tag{19}$$

the square brackets denoting the integer part of the number enclosed in them.

Let us characterize quantitatively the labor intensity of calculations for the first computational procedure of dynamic programming.

The number of possible control variations for each of the states $\vec{x}_k$ is determined from the expression

$$M_{\vec{u}} = \prod_{i=1}^{m} M_{u_i}.$$

Since at one step the total number of possible states $\vec{x}_k$ is equal to the number of nodes of the grid of variables at this step, i.e., $M_{\vec{x}}$, the total number of local control options to be investigated at each step is equal to $M_{\vec{u}}\, M_{\vec{x}}$, and at all N steps

$$W^1 = M_{\vec{u}}\, M_{\vec{x}} N. \tag{20}$$

Taking into account (20), we can write a formula for an approximate, in this case, the upper-bound, estimate of the time of solution of the optimization problem using the first computational procedure

$$W_t^1 = \alpha^1 W^1 = \alpha^1 M_{\vec{u}}\, M_{\vec{x}} N, \tag{21}$$

where α^1 is proportionality coefficient, taking into account that to calculate one local solution at each step it is necessary to:

1) take one of the possible options of the control vector$\vec{u}_k$;

2) calculate the value of $\vec{x}_{k+1}$;

3) determine the increment of the criterion caused by the transition from $\vec{x}_k$ to $\vec{x}_{k+1}$, i.e., $F(\vec{x}_k, \vec{u}_k)\,\Delta$;

4) take from the table the value of ω_k corresponding to the calculated $\vec{x}_{k+1}$;

5) add $F(\vec{x}_k, \vec{u}_k)\,\Delta$ and ω_k together, and then compare the result with the previous option and choose the smallest one.

The specific numeric value of the coefficient α^1 should be determined based on the analysis of the real calculation process for a specific computer, its operating system and the language in which the program is written.

An assessment of the amount of memory required to implement the dynamic programming procedure can be carried out by the formula

$$W_n^1 = (m+1)\, M_{\vec{x}} N. \quad (22)$$

This is a lower-bound estimate that essentially determines only the size of the table for storing the values of $\omega_k\ (x_k)$ and the corresponding m components of the vector $\vec{u}_k$.

Let us compare the results obtained with those estimates of the computational difficulties that are characteristic of the complete enumeration method. For one fixed initial state, when using the complete enumeration method, an analysis of $M_{\vec{u}}$ options is required at the first step, an analysis of $(M_{\vec{u}})^2$ options is required at two solution steps, and an analysis of $(M_{\vec{u}})^N$ options is required at N steps. Since the total number of initial states is $M_{\vec{x}}$, the total number of solution options in the complete enumeration method is $M_{\vec{x}}\ (M_{\vec{u}})^N$. Now, similarly to [13], we can write a formula for determining the solution time:

$$W_t^{11} = \alpha^{11} M_{\vec{x}}\ (M_{\vec{u}})^N \quad (23)$$

where α^{11}, just as α^1, is a proportionality coefficient characterizing the time of calculation of one solution by the complete enumeration method.

If we compare both methods in terms of the number of options, then the first computational procedure of the dynamic programming method turns out to be $(M_{\vec{u}})^{N-1} / N$ times more efficient than the complete enumeration method. Suppose, for instance, $m = 2; n = 2;\ M_{u_i} = M_{x_j} = 10;\ \forall i, \forall j; N = 10$. Then, assuming $\alpha^{\Pi} = 1$ in (23) and using estimate (20), we find that in the computational procedure of dynamic programming it is necessary to analyze 10^5 options of the solution, whereas in the case of the complete enumeration method $- 10^{22}$ options.

It should be noted that estimates (20), (21) were obtained under the assumption that all of the possible combinations of the parameters of the vector $\vec{u}$ are admissible, just like all possible combinations of $\vec{x}$. The presence of additional constraints on $\vec{u}$ and $\vec{x}$ leads to a decrease in estimates (20) and (21).

To assess the computational difficulties of the second computational procedure of dynamic programming, we take into account that the number of solution options required for the analysis for a given $\vec{x}_k$ will be $M_{\vec{x}}$, and for all possible x_k-th steps $- (M_{\vec{x}})^2$. As before, $M_{\vec{x}}$ is calculated from formulas (18) and (19). For all N steps of the analysis, the number of options to be calculated will be

$$W^{11} = (M_{\vec{x}})^2 N. \quad (24)$$

Similarly to (21), one can introduce a coefficient α^{11}, which determines the time spent on calculating one control option, and obtain an upper-bound estimate for the calculation time

$$W_t^{11} = \alpha^{11} W^{11} = \alpha^{11} (M_{\vec{x}})^2 N. \quad (25)$$

When implementing a computational procedure, to store a table with optimal results, we will need

$$W_n^{11} = (n+1)\, M_{\vec{x}} N. \quad (26)$$

memory cells. Formula (26), like formula (22), gives a lower-bound value for the memory size.

So, in comparison with the method of complete enumeration, the computational procedures of dynamic programming have immense advantages, since they can significantly reduce the computational difficulties. However, the dimensionality problem remains the main obstacle to the widespread use of dynamic programming. It will be shown further by what means and to what extent the dimensionality problem can be overcome.

References

[1] Richard Bellman, Dynamic Programming, Princeton University Press, 2010, 392 pp.

[2] A.B. Sadigov, Models and technologies for solving problems of management in emergency situations, Baku, "Elm", 2017, 372 p. (in Russian)

[3] A.V. Mattis, Optimal control of the movement of marine mobile complexes, Automation of management processes, 1 (23), 2011, pp. 88-92. (in Russian)

[4] T.G. Sotnikova, D.G. Gulakov, Dynamic programming method for tasks of modes optimization by decrease size of ore granules implementation, Bulletin of the Volodymyr Dahl East Ukrainian National University, No. 7 (224), 2015, pp. 91-95. (in Russian)

[5] A.S. Bortakovskiy, Optimal control of logic-dynamical systems, Dissertation for the degree of Doctor of Physical and Mathematical Sciences, HAC RF 05.13.01, 2010, 169 p. (in Russian)

[6] O.A. Slavin, A.V. Solovyov, An.V. Solovyov, Development of a methodology for creating a logical and mathematical model of traffic movement at the stage of creating a concept of a smart city, Proceedings of the ISA RAS, Volume 63, 3/2013, pp. 31-41. (in Russian)

[7] A.A. Kadyrov, A.A. Kadyrova, Structuring and graph modeling of logic-dynamic control systems, Bulletin of BSTU im. V.G. Shukhova, 2014, No. 1, pp. 185-188. (in Russian)

[8] A.B. Sadigov, Modeling of Appearance of Instability of Complex Systems. Reports of IV International conference «Problems of Cybernetics and Informatics», September 12-14, 2012, Baku, Azerbaijan, pp. 70-73.

[9] A.V. Lezhnyov, Dynamic programming in economic problems, Tutorial, Moscow, BINOM, 2006, 176 p. (in Russian)

[10] A.V. Brodsky, Automation of the solution of optimization problems in the design of aerospace technology, Automation of the solution of optimization problems in the design of aerospace technology, Electronic journal, "Proceedings of the MAI", Issue 71 (in Russian)

[11] D.A. Karpov, V.I. Struchenkov, Dynamic Programming as a Method of Spline Approximation in the CAD Systems of Linear Constructions, Russian Technological Journal, 2019, 7(3), pp. 77-88. (in Russian)

[12] Yaofei Ma, Xiaole Ma, Xiao Song, A Case Study on Air Combat Decision Using Approximated Dynamic Programming. Hindawi Publishing Corporation, Mathematical Problems in Engineering, Volume 2014, Article ID 183401, 10 pages.

[13] P.I. Kishteev, Design decisions making based on the principle of complexity, Dissertation for the degree of candidate of technical sciences, HAC RF, 05.13.01, 1983, 203 p. (in Russian)

The Intelligent Monitoring and Evaluation of the Psychophysiological State of the Ship Crew in Maritime Transport

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***Abstract*—The article offers the conceptual basis of the system for the monitoring of the psychophysiological health status of the ship crew and assessing its suitability for the position. The fact that up to 80-85% of accidents in maritime logistics are related to the human factor shows the relevance of this issue. The article analyzes the specific features of the crew's professional activity and shows that the deterioration of their health and psychological condition due to the long-term "ship environment" is inevitable. It offers to develop an intelligent system for monitoring the psychophysiological condition of sailors and to assess its suitability for their position with the reference to the Cattell test and fuzzy patterns recognition. The development and systematic operation of such a system may timely detect undesirable consequences for the health status of crew members and prevent wrong decisions due to the "human factor".**

Keywords—maritime logistics, human factor, Cattell test, fuzzy patterns, decision making

I. Introduction

Transport logistics is of great importance in the integration of regional, national, international logistics systems, as well as material, information, financial and service logistics flows. Maritime transport plays a key and leading role in transport logistics [1, 2].

Maritime logistics refers to the organization and provision of cargo transportation by sea, i.e., a transport service that determines the activities of most customers. While there are options for road and rail transports in terrestrial shipping, maritime transport is the only way of transporting goods by sea over long distances. Maritime transportation is the main means of transporting large volumes of cargo and raw materials by water from one country to another, from one continent to another.

Oil and oil products, coal, grain, mixed cargo, chemical products and other special transportations, containers and people (liners, passenger ships) are transported by different types of maritime transport. Low cost for large carrying capacity, the possibility of intercontinental transportation and low cost of transportation are the reasons to prefer maritime transport [3].

[4] shows that 90% of world trade is carried out by sea. Maritime cruises are estimated to be the fastest growing tourist field, with demand for cruises increasing by 20,5% in 2015-2019. The cruise industry is estimated to worth 150 billion USD in 2018, nonetheless the COVID-19 pandemic has caused a crisis in this area in recent years. Due to the impact of the COVID-19 pandemic, there was a 14% decline in 2020. This increase may be 3% in 2021 and 2022, [5, 6]. Maritime transport has also played an important role in the immediate response to the spread of coronavirus infection by providing food, medicine and other vital products. Despite the difficult situation, many ports around the world are open for cargo transportation requests, although not for passengers [7].

Currently, the commodity turnover between Asia and Europe is also mainly carried out by sea: more than 95% of the volume (in metric tons) and almost 70% of the value (in US dollars) of cargo is transported by sea. Air transportation between Asia and Europe accounted for less than two percent by volume but more than 30 percent in value, while railways implemented only one percent of the volume and more than two percent of the value [4].

Thus, the development of maritime logistics is one of the main priorities of the giant countries. The importance of maritime transport has highlighted the development of innovative approaches to address a number of issues in this segment. These issues may include optimal route planning and selection based on fuzzy logic [8–11], selection of more suitable customers taking into account the nature of the transported cargo [12], timely delivery of products (especially medicines) using IoT technologies [13], etc.

The specificity of the work of seafarers has led to a special emphasis on the "human factor" in maritime logic. This specificity is due to the long-term stay of sailors on board [14–16]. All the factors (noise, vibration, high-frequency electromagnetic radiation, harmful substances in air, etc.) accumulated in the integrated concept of "ship environment" affect the sailors' organism, causing functional changes, psychological problems, and the development of pathological conditions [17]. These lead to the reduction of sailors' working ability, their health deterioration and, consequently, the loss of sailors' working ability.

Such a situation has led to the emergence of concepts as "human factor" and "fatigue" in marine. Analysis of incidents in maritime transport shows that 80-85% of them are related to human activities [3].

The accidents chiefly occur due to errors and mistakes made by decision-makers during the operation of the ship, rather than due to any equipment failure. Psychological and psychophysiological stress of sailors, especially ship navigator officers and captains, is the main source of incidents at sea.

At present, the Industry 4.0 characterized by the development of high technologies, the Internet of Things, nanotechnology, biotechnology, artificial intelligence, etc., has created innovative research trends to overcome these problems [16, 18, 19–21]. This article proposes a new innovative approach to focus on the human factor to prevent shipwrecks. It offers the conceptual framework of the intelligent system to monitor the health status of ship crew and assess their ability to perform their duties based on artificial intelligence, intelligent technology and a system analysis of specific characteristics of each member of the ship crew.

II. Analysis of the Specific Features of Crew's Professional Activity in Marine Transport from the Perspective of Human Health Ensuring

Noise is the most important factor influencing the working ability and life of ship workers [14]. Noise is generated during the operation of technical equipment of ship, all its moving machines and mechanisms cause air vibrations during operation are the noise sources. High-speed ship engines are used to increase the speed of modern ships. However, their exploitation worsens living conditions. The noise generated by vessels has quite high-frequency intensity to affect the human organism severely. Intensive exposure to noise changes the functional state of the central nervous system, which manifests itself in impaired attention, delayed mental reactions, fatigue, and impaired accuracy of movement. Along with auditory organs, the noise also affects the cardiovascular system, causing decreased blood pressure (muscle spasms), variations in cardiac arrhythmias, and changes in heart rate.

Vibration is the second factor negatively affecting the functional condition and working capacity of seafarers. Vibration occurs due to external forces during when propellers rotate, and in some cases, it increases significantly. The digestive organs are most the vulnerable to vibration.

High-frequency electromagnetic radiation is one of the physical factors complicating the sailors' work [22]. The modern ships are highly supplied with radio equipment of various contents. These may include ultra-high and extremely-high frequency radio transmitters, satellite communications, and radar stations. Specialists working with radio-electronic devices actually perform their professional activities in the area of "antenna fields" and are exposed to electromagnetic radiation.

Moreover, swaying, hydrodynamic shocks and other external influences on the ship negatively impact the health status of ship crew [23]. Chemical factors and gases in the air are of special importance among these effects. Dozens of harmful chemicals may present in the working and living areas. Emission gases, heat and oil vapors produced during the operation of technical equipment merge with the air in the room.

The air of working and living spaces on the ship also depends on the quality of material used to generate this space. They can emit toxic substances affected by maintenance and external factors (high temperature, ionizing radiation, sunlight).

Note that there is a high risk of chemical accidents on special ships transporting gas, chemicals and oil. The bodies of personnel working in such vehicles are exposed to the impact of the product being transported. Studies show that more than two-thirds of sailors working in such a fleet suffer from liver antitoxic disorders, changes in the central nervous, cardiovascular, respiratory and digestive systems. Toxic substances emitted into the air negatively affect the sailors' organism, cause allergic reactions, skin damage and poisoning. These indicators are much lower in the crews of ships and containers carrying dry products.

One of the main physical factors affecting the health and performance of the ship crew is the microclimate. It is determined both by the climate of the regions through which the ship passes, and by the heat released from the technical equipment placed in the cabins for heating, ventilation and air conditioning to create working conditions on the ship. The physical properties of air acting as a thermoregulator of the human body, are determined, first of all, by its humidity and air flow rate. Excessively hot or cold, windy and rainy weather leads to disruption of physiological functions in the human body, weakening the health status [14, 22, 23].

The problems related to microclimate are more pronounced on special cruise, such as the North Sea cruise, where low temperature leads to the spread of diseases associated with the catching cold, and this problem accounts for 50% of medical requests [14].

A huge influx of new technologies on ships, such as Very High Frequency (VHF) radio for communications with port authorities and other vessels, autopilot navigation, Global Positioning System (GPS), Advanced Radar Plotting Aids (ARPA) for displaying the position of local marine traffic, and electronic map and information display system change the tasks performed by the crew, and the Electronic Chart Display and Information System change the tasks performed by the crew. The influx of new technologies, the lack of integration among them, the need to use some of them simultaneously complicates the work of seafarers, and causes stress [16, 21].

Analysis of the main factors of ship environment clarifies the specifics of the living conditions of seafarers on cruises. When assessing the impact of these factors on the crew's health status, the total factors of the ship environment, the degree of their total effect on the body should be taken into account. Unquestionably, solution of these problems is aimed at solving important medical issues, moreover, it also necessitates the development of legislation in the crew's work, special standards and requirements governing the working hours and rest of crew members.

According to these standards, the captains, assistant captains and ordinary personnel on duty must have at least 10 hours of rest in 24 hours and 77 hours of rest in a 7-day period [3, 24]. Rest hours can be divided into two periods, one of which should not be less than 6 hours, i.e., the rest time of staff should be regulated, however, in reality, the implementation of this convention is not strictly followed. As far back as 2000, the International Transport Workers' Federation appealed to the captains of the global maritime fleet regarding the poor working and leisure conditions of seafarers. According to the study of Cardiff University expert group implemented in 1998 and submitted to the International Maritime Organization, 63% of captains surveyed said their work and leisure regimes posed a threat to their health and safety; 56% said that the current work and leisure regime is a threat to the performance on the ship; and 50% stated that it was impossible to provide 10 hours of daily rest in accordance with the requirements of the Convention on Labor and Recreation [3]. Many ships do not have work and leisure norms. All these factors have a catastrophic effect on the sailors' working capacity and health status. Realizing that the majority of accidents at sea to be caused by human factors, but demonstrating a frivolous position, the shipowners prefer to solve this problem at the expense of insurance. Many shipowners "looking for own profit" are now trying to achieve their goals by reducing the number of crew members. Such an attitude leads to a sharp violation of requirements for the work and rest regime, and the rapid introduction of the concepts of "human factor" and "fatigue" into the shipping industry.

Thus, the working and living conditions of ship workers, and external influences determine the following specific features of their professional activities:

- working and living in confined spaces and polluted environments that increase the risk of infectious diseases and danger to the workers' life;
- shift work schedule within a certain time interval, which is a source of psychosocial risks, stress, and depression;
- employee's fatigue due to irregular working hours and stressful working conditions, assessed as one of the most dangerous risks of making mistakes;
- exposure of employees to hazardous contaminants, as well as harmful factors (industrial noise, vibration, risks of toxic substance release, etc.) threatening their health and life;
- unfavorable external factors (cold, wind, fog, dust, rain, storm) affecting the physiological state, working capacity and labor productivity.
- serious consequences of accidents, necessitating the improvement of methods for monitoring and control of workers' health.

III. THE STUDY OF THE HUMAN FACTOR IN MARITIME LOGISTICS AND THE PROBLEM STATEMENT

Uncertainty determined by the "human factor" is capable to make management decisions in non-standard situations, and the role of human is irreplaceable in creating conditions to ensure the reliability of facility [25]. However, the human factor also causes the wrong actions inherent in each human being. Human error in road transport accounts for 90% of all accidents. In 57% of cases, human error is the only factor causing the accident. Human error accounts for 70–80% of accidents in air and sea transport, and 50% in railways [26].

The recent influx of new technologies into the ship environment, the introduction of IoT-based remote monitoring and control systems has led to decision-making by analyzing constantly changing data sensed from multiple sources. Different technologies, human-machine interfaces, rapidly growing dynamic data conditions, and the need to be aware of the situation on the ship further complicates the work of sailors, causes stress, affects the decision-making process, and increases consideration of human factor [16, 20]. The multifaceted nature of human factor, the serious and undesirable consequences of the wrong decisions of crew members, as well as the lack of study of the nature and causes of this phenomenon require the development of new approaches to its study.

In this case, the specific object of the study is the ship crew members, who perform various duties for the successful performance of maritime transport, i.e., shift workers provided with living and working activities.

The target of research is the development of new technologies to manage the health status of shift workers to eliminate and minimize the impact of human factor.

The emergence of the human factor concept in maritime logistics is associated with the accidents occurring due to incorrect decisions made by workers during the ship operation. The above analysis once again shows that such mistakes made by crew members are not intentional, but due to the specifics of their professional activities [19, 27]. All the physical, psychological, medical, social, production and environmental factors inherent in the ship environment act as a potential source of sea voyages, affect the human activity system, and lead to dangerous actions of crew members [20]. Deviations in the employees' health status while performing their duty and living on ship can lead to "dangerous" behavior, actions, psychological disorders and, consequently, wrong decisions and accidents. Making wrong decisions by crew members directly depends on their health condition, which affects the crew members' behavior and performance in accordance with their professional activities. Therefore, the health status is an important aspect of the ship's human resources and the main component that directly affects their professional activities.

Taking measures to protect the employees' health allows them to successfully address the physiological, psychological and social situation, improve their functional capabilities, and most importantly, to make better decisions in non-standard situations.

In the given context, to prevent accidents at sea, it is important to systematically monitor the crew members' health status in the work environment (before and after the shift) and to determine their suitability for the position with a comprehensive assessment of the results.

IV. PROBLEM SOLVING

The problem solution requires the solution of two sub-issues:

A. Systematic monitoring of employees and identification of psychological health conditions and deviations;

B. Assessment of the compatibility of the ship crew members with their positions comprehensively approaching the monitoring results.

A. Systematic monitoring of employees and identification of psychological health conditions and deviations

[27, 28] provides the methodological basis for systematic remote monitoring of employees based on the integration of IoT and artificial intelligence technologies, which are the key components of the Industry 4.0 concept, and [21] provides the application opportunities of monitoring system based on appropriate technology. It is possible to refer to various psychological tests for monitoring. [18] justifies the emphasis on the Cattell test to assess the professional qualities of seafarers in the recruitment process. Therefore, in this article, it is considered appropriate to refer to the Cattell test for the monitoring of a crew member performing a certain task. The Cattell test is the most popular multifactorial method to examine a person on 16 factors and determine his/her psychological state. Using the test results, it is necessary to use the quality levels of natural language to assess the ability of seafarers performing their duties, which makes the fuzziness inevitable. Therefore, a fuzzy mathematical logic apparatus is used to assess the seafarers' professional qualities [29]. Problem solution starts with:

- linguistic variables;
- term-sets of linguistic variables;
- determination of affiliation functions.

TABLE 1. LINGUISTIC VARIABLES OF THE CATTELL TEST AND THEIR TERM-SETS

Variables	**Names of linguistic variables**	**Term-sets**
L_1	unsociable/sociable	Unsociable, moderately sociable, sociable
L_2	intellect	Low intellect, intellectual development, high intellectual development
L_3	Emotionally intolerant/tolerant	Emotionally intolerant, somewhat emotionally intolerant, emotionally tolerant
L_4	subordinate/dominant	Subordinate, moderately authoritarian, authoritarian
L_5	restrained/emotional	Restrained, moderately emotional, emotional
L_6	sensitive/having high behavior standards	does not attempt to solve group problems, avoids responsibility, responsible
L_7	obedient/courageous	obedient, less courageous, brave
L_8	cruel/arrogant	Cruel, normal, arrogant
L_9	trusting/skeptical	trusting, less trusting, skeptical
L_{10}	practical/advanced imagination	Partly practical, with a creative imagination, with a very high creative imagination
L_{11}	outspoken/diplomatic	outspoken, partly diplomatic, diplomatic
L_{12}	confident/unconfident	confident, unconfident, anxious
L_{13}	conservative/radical	conservative, mediate, radical
L_{14}	conformism/nonconformism	not taking into account public opinion, sometimes taking it into account, always listening to public opinion
L_{15}	low self-control/high self-control	low self-control, moderate self-control, high self-control
L_{16}	relaxed/anxious	relaxed, moderately relaxed, anxious
y	Degree of compliance of the staff member with personal qualities	Not suitable, moderately compatible, compatible

The 16 personal quality factors in the Cattell test correspond to linguistic variables. For each linguistic variable, the lowest factor value (weak), the average factor value (medium), the highest factor value (strong) are determined according to a 3-level unified quality measurement scale (UQMS), which generate the term sets of linguistic variables (Table 1).

The term-sets are expressed by the affiliation function corresponding to the quality levels of UQMS. Therefore, fuzzy sets are allocated for term-set elements (Table 2).

TABLE 2. MATHEMATICAL DESCRIPTION OF LINGUISTIC VARIABLES BASED ON 3-DIMENSIONAL UQMS

Intensity levels of linguistic variable "unsociable/sociable"	Linguistic evaluation (UQMS)	Fuzzy set in the range [0, 1]	E1	E2	E3	Collective value (Levin)
unsociable	weak	[0,1-0,45]	0,45	0,40	0,35	0,40
less sociable	medium	[0,45-0,65]	0,55	0,60	0,65	0,60
sociable	strong	[0,65-0,99]	0,95	0,90	0,85	0,90

For each quality level, an individual fuzzy value is assigned from the set allocated within the interval [0.1]. For this purpose, the final fuzzy value is determined as a result of combining separate values set by individual experts into a single, collective value. For this, it was considered expedient to take the value occupying the "medium position" compared to external values in the set of individual values, as a collective value [30].

Figure 1 describes the affiliation function defined in the interval [0.1] for the mathematical description of the quality indicators in the Kettell test.

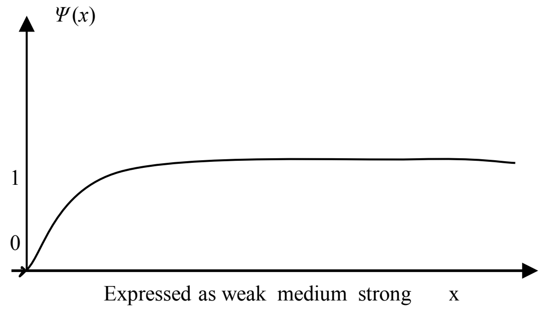

Fig.1. Graphical description of affiliation function

B. Assessment of compatibility of the ship crew members with their positions based on fuzzy patterns recognition

With the comprehensive approach to the monitoring results, the proposed approach for assessing the compatibility of professional ship crew members with their positions is brought to the pattern recognition issue [31]. For this, the patterns of the position, and then the staff member performing the task, are created based on their quality indicators in the Kettel test.

For example:

$V = \{V_g\}, g = \overline{1, n}$ is a set of duties on board;

$L = \{L_i\}, i = \overline{1,16}$ indicates the evaluation criteria in the Kettel test.

Then, based on these criteria, each position can be described as $V_g = |L_{gi}|, i = \overline{1,16}$, and a person holding this position as $S_g = |L_{gi}|, i = \overline{1,16}$.

According to the methodology developed in [32], the reference pattern of position can be described as a fuzzy pattern $\widetilde{V}_g = \{\mu_{L_{gi}}(y)/y, i = \overline{1,16}\}$, and the real pattern of employee holding this position can be described as a fuzzy pattern $\widetilde{S}_g = \{\mu_{L_{gi}}(y)/y, i = \overline{1,16}\}$.

Afterwards, the compatibility of the specialist with his/her position can be determined based on fuzzy similarity patterns. For this purpose, the degree of similarity of the reference and real fuzzy patterns is determined. For this, the degree of fuzzy inclusion into fuzzy situations is referenced. The similarity degree of fuzzy patterns $\theta(\widetilde{S}_g, \widetilde{V}_g)$ is calculated using the following formula [31]:

$$\theta(\widetilde{S}_g, \widetilde{V}_g) = \& \, \theta(\mu_{S_g L_i}(y), \mu_{V g L_i}(y)) = \underset{y \in Y}{\&} (\max(1 - \mu_{S_g L_i}(y), \mu_{V_g L_i}(y))) =$$
$$= \min_{y \in Y} (\max(1 - \mu_{S_g L_i}(y), \mu_{V_g L_i}(y)))$$

According to the degree of similarity of reference and real fuzzy patterns, the inclusion limit ψ is determined for making decision on the compatibility of the seafarer for his position.

Assume that, in accordance with the management terms, [0,8; 1] is accepted for the term set “corresponds to the position” and $\psi \in [0{,}5; 0{,}79]$ is accepted for the term “moderately corresponds to the position”. In this case, the following decision-making rules are included:

1. If $\theta(\widetilde{S}_g, \widetilde{V}_g) \geq \psi[0{,}8; 1]$, then the real fuzzy pattern $\widetilde{S}_g$ is completely similar to the reference fuzzy pattern $\widetilde{V}_i$ and the relevant specialist “corresponds to the position”;
2. If $\theta(\widetilde{S}_g, \widetilde{V}_g) \geq \psi[0{,}5; 0{,}79]$, then the real fuzzy pattern $\widetilde{S}_g$ is moderately similar to the reference fuzzy pattern $\widetilde{V}_i$ and the relevant specialist “moderately corresponds to the position”;
3. If $\theta(\widetilde{S}_g, \widetilde{V}_g) \leq \psi[0{,}1; 0{,}49]$, then the real fuzzy pattern $\widetilde{S}_g$ is not similar to the reference fuzzy pattern $\widetilde{V}_i$ and the relevant specialist “does not correspond to the position”, and he should be provided with medical support to perform this position.

When solving this issue, note that the requirements for meeting the criteria in the Kettel test may differ for each position (for example, the criterion sociable is rated as “strong” for the reference pattern for any position, whereas this criterion may be rated as “moderate” or even “weak” for another).

Based on the proposed approach, the establishment of a system for monitoring and assessing the health status of crew members involves the development of the following modules:

- testing the ship crew members based on the Kettel test;
- generating a reference fuzzy pattern of each position on the ship;
- generating a real fuzzy pattern of each ship crew member based on the test results;
- calculating the degree of similarity of reference and real fuzzy patterns;
- developing the decision-making unite;
- obtaining the result.

The proposed approach to assessing the psychological health of crew members can be considered as one of the solutions to the given problem. Thus, the following solutions to the problem stated are possible:

1. some of the 16 criteria in the Kettell test may be considered significant, while the rest may be considered desirable or even insignificant, in accordance with the conditions of personnel management on the ship. In this case, the issue under consideration can be solved by bringing it to fuzzy multi-scenario decision-making methods [33].
2. in accordance with the conditions of personnel management on board, it may be required to take into account the importance of their personal quality criteria in relation to each other. In this case, the problem can be solved by bringing it to the multi-criteria decision-making methods, taking into account the importance coefficients of the criteria [34].
3. Monitoring of the health status of the ship crew through IoT technologies [27, 28], etc.

The solution of these issues refers to the perspective research fields of the authors.

V. Conclusion

The problems of the human factor in transport logistics are difficult to assess, since the long-distance cruises and difficult living conditions in marine transport exacerbate these problems. The possibilities for studying human behavior in an accident are very limited, as such critical incidents occur very rarely, and on the other hand, it is impossible to predict and control their occurrence. Currently, the research is underway in this area based on the development of new technologies, especially IoT, sensor, cloud technologies, solutions and applications, situation modeling on board and innovative approaches to prevent undesirable situations.

The article highlighted the importance of the human factor in preventing ship accidents. It was substantiated that the psychological health condition of each crew member was important in making operational decisions, correctly understanding the situation faced by the crew on duty during the ship operation. In very this context, the issue of systematic monitoring of crew members on duty and the assessment of their compatibility with the position was raised. The proposed approach to problem solution was based on the Kettel test, a method of fuzzy pattern recognition.

The proposed approach can allow for the timely detection of undesirable situations in terms of the mental health of the crew member, to prevent wrong decisions and can be considered as one of the possible solutions to prevent ship accidents.

REFERENCES

[1] J. H. Bookbinder, and T. A. Matuk, “Logistics and Transportation in Global Supply Chains: Review, Critique and Prospects”. Chapter 9 in M. Oskoorouchi (ed.). Tutorials in Operations Research, 182-211, 2009. DOI: 10.1287/educ. 1090.0059.

[2] “Review of maritime transport 2020”, United Nations publication issued by the United Nations Conference on Trade and Development https://unctad.org/system/files/official-document/rmt2020_en.pdf

[3] Sea captains. Features of our time. 15.08.2018 http://www.morvesti.ru/analitika/1692/73303/

[4] “Connecting transport infrastructure networks in Asia and Europe in support of interregional sustainable transport connectivity”, Progress in Enhancing Transport Connectivity between Asia and Europe. Report, 2020. United Nations. 65 p. https://www.unescap.org/sites/default/d8files/knowledge-products/Euro-Asia%20Connectivity%20Report_2020_December%202020_FINAL%20corr.pdf

[5] “COVID-19 and MaritimeTransport”, Impact and Responses Transport and Trade Facilitation Series No.15. United Nations, Geneva, 2021. https://unctad.org/webflyer/covid-19-and-maritime-transport-impact-and-responses

[6] “The Impact of COVID-19 on Logistics”, İnternational Finance Corporation. June 2020. https://www.ifc.org/wps/wcm/connect/industry_ext_content/ifc_external_corporate_site/infrastructure/resources/the+impact+of+covid-19+on+logistics

[7] A. Rivera, “The impact of COVID-19 on transport and logistics connectivity in the landlocked countries of South America”, Project Documents (LC/TS.2020/155), Santiago, Economic Commission for Latin America and the Caribbean (ECLAC), 2020. https://www.cepal.org/sites/default/files/publication/files/46528/S2000768_en.pdf

[8] A. V. Faraonov, “Development of a situational model of the routing task when it is necessary to change the baseline plan based on a fuzzy situational network”, 12th All-Russian Meeting on Management Problems, VSPU-2014, Moscow, June 16-19, 2014, pp.5101-5113.

[9] I. B. Olenych, and A.F. Gukaliuk, “Application of the Fuzzy Modeling for Optimization of Transport Routes”, Universal Journal of Computational Mathematics 2017, Vol.5, no. 4, pp.87-92, http://www.hrpub.orgDOI: 10.13189/ujcmj.2017.050401

[10] A. Esmaeili1, R. A. Kahnali, R. Rostamzadeh, E. K. Zavadskas, and B. Ghoddami, “An application of fuzzy logic to assess service quality attributes in logistics industry”, Transport, 2015, Vol. 30, no.2, pp. 172–181 doi:10.3846/16484142.2015.1046402

[11] A. Sarkar, G. Sahoo, and U. C. Sahoo, “Application of fuzzy logic in transport planning”, International Journal on Soft Computing (IJSC), May 2012, Vol.3, No.2, pp.1-21.

[12] S. I. Nikishov, “Application of fuzzy composition for logistics flows modeling”, Voprosy innovatsionnoy ekonomiki, 2017, vol.7, no.3, pp. 247-256. doi: 10.18334/vinec.7.3.38197

[13] N. Yu. Barkova., D. D. Zherega, E. A. Popova, and V. P. Logacheva., “The use of the Internet of things in the supply chains of the pharmaceutical industry”, University Bulletin,2019, no. 9, pp.68-74.

[14] R. V. Kubasov, V. V. Lupacev, and M. V. Popov, “The living conditions of the crew on board of sea vessel (literature review)”, Bulletin of the State University of Marine and River Fleet named after Admiral S.O. Makarov, 2016, vol. 2, no.36, pp. 49–56.

[15] T. N. Rimina, and E. V. Pyatirova, “Peculiarities of the stress impact on shipboard personnel in working conditions at sea”, Health. Medical ecology”, Nauka, 2014, vol. 4, no. 58, pp. 103–105.

[16] R. Kari, and M. Steinert, “Human Factor Issues in Remote Ship Operations: Lesson Learned by Studying Different Domains”, Journal of Marine Science and Engineering, 2021, vol. 9, no. 4, pp.385-404. https://doi.org/10.3390/jmse9040385

[17] V. I. Zaytsev, and S. A. Vinogradov, “Some theoretical and practical aspects of the study of working conditions in the fleet”, Public health and habitat, 2014, vol.2, no 251, pp. 13–15.

[18] Ya. O. Ganina, and V. V. Laptev, “Fuzzy production model for assessing the professional qualities of marine specialists”, News of Astrakhan. state tech. uni. Ser. control, comput. tech. inform, 2016, No 3, pp.101–108

[19] L. I. Grigoriev, O. N. Chernysheva, and V. V. Kucheryavy, “Assessment of the professionally important psychological characteristics of the dispatcher in the human-machine systems of the process control system of oil and gas production”, Control problems, 2017, no. 1, pp.57 – 64.

[20] C. Harvey, N. Stanton, and P. Zheng, “Safety at sea: human factors aboard ship”, The Ergonomist, 2013, no. 517, July 2013. https://www.ergonomics.org.uk/Public/Resources/Publications/The_Ergonomist.aspx

[21] Online Platform for Seafarers. https://imeq-center.com/mental-health-assesment-for-seafarers

[22] O. P. Lomov, et al. “Physical factors of habitability of ships and vessels: monograph”, SPb .: Shipbuilding, 2014.

[23] A. E. Golovanov, L. P. Makarova, and G. G. Klimentenok, “Influence of the peculiarities of the human psyche on the processes of adaptation to motion sickness”, Young scientist, 2014, no 4, pp. 357–361.

[24] International Convention on the Training, Certification and Watchkeeping of Seafarers (ПДНВ-1978) http://seaman-sea.ru/stcw.html

[25] L. I. Grigoriev, O. N. Chernysheva, and V.V. Kucheryavii, “Estimation of professionally important psychological characteristics of the supervisor in human-machine control systems oil and gas production”, Management Problems, 2017, no. 1, pp.57-64.

[26] E. A. Koval, “The role of the human factor in transport security”, https://cyberleninka.ru/article/n/rol-chelovecheskogo-faktora-v-transportnoy-bezopasnosti/viewer

[27] M. H. Mammadova, and Z. G. Jabrayilova, “Conceptual approaches to intelligent human factor management on offshore oil and gas platforms”, ARCTIC Journal, Canada, Calgary, 2021, vol. 74, no.2, pp.19-40.

[28] M. H. Mammadova, and Z. G. Jabrayilova, “Conceptual approaches to IoT-based personnel health management in offshore oil and gas industry”, Proceedings of the 7th International Conference on Control and Optimization with Industrial Applications (COIA-2020), Volume 1, 26-28 August, 2020, Baku, Azerbaijan, pp.257-259.

[29] L. A. Zadeh, “The concept of a linguistic variable and its application to approximate reasoning”, Information Sciences, 1975, vol.8, no.3, pp.199–249.

[30] V. I. Levin, “A new generalization of the operation on fuzzy sets”, Moscow: Izvestiya RAN, Control theory and systems, 2001, no.1, pp.143-146.

[31] A. N. Melikhov, L. S. Bernshtein, and S. Ya. Korovin, “Situational advising systems with fuzzy logic”, Moscow: Nauka, 1990, 272 p.

[32] M. H. Mammadova, and Z. G. Jabrayilova, “Methods managing for matching of supply and demand on the IT Specialists”, Riga: Automatic Control and Computer Sciences, 2019, no. 2(53), pp.148-158.

[33] M. G. Mamedova, Z. Q. Jabrailova, and F. R. Mammadzada, “Fuzzy Multi-scenario Approach to Decision-Making Support in Human Resource Management”, Studies in Fuzziness and Soft Computing, Springer International Publishing Switzerland, 2016. Vol.342, pp.19-36.

[34] M. H. Mammadova, and Z. G. Jabrayilova, “Fuzzy multi-criteria method to support group decision making in human resource management”, Studies in Fuzziness and Soft Computing, Springer International Publishing Switzerland, 2018, vol.361, pp.223-232.

Expert System for Output Recommendations at Increased Loading of the Marshalling Station

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***Abstract*—The article is devoted to the development of an expert system for the output of recommendations with an increased workload of the Balajar station. A significant increase in the private wagon fleet has changed the system of organizing the work of the Azerbaijan Railways, the technology of the stations and the duration of station operations have changed. Problems arising from the uneven reception of trains have become more frequent. Due to this process of operation, the station load is increasingly exceeding the optimal value. Sometimes, with increased loading, the wrong dispatcer solution further complicates the operation of the station. In the article, to reduce the loading level of the station, it is proposed to use methods of structural technology. According to the loading rate of the station, an expert system for displaying recommendations has been developed to select the right solution.**

***Keywords*—marshalling station, workload, receiving yard, departure yard, tracks, expert system**

I. INTRODUCTION

In connection with the economic development of the republic in recent years, many enterprises have purchased private freight wagons. This led to a significant increase in the private wagon fleet of Azerbaijan Railways and changed the system of organizing their work. The technology of work of stations and the duration of station operations have changed, the number of low-tonnage cargoes has increased, a need occurred to send prefabricated group cargo to a large number of senders, and so on. All this significantly increased the volume of shunting operations, as well as the duration of ineffective downtime of freight wagons (waiting time for processing and loading and unloading operations) at the stations. To eliminate these shortcomings, the organization of train traffic is carried out according to the "firm schedule" (hard train lines of the train timetable). However, in many railway sections, the filling level of the "hard schedule" is 50%, which increases the duration of inefficient downtime of locomotives and reduces their productivity.

An increase in the duration of ineffective downtime and the volume of shunting operations, as well as a decrease in the productivity of locomotives, affect the uneven flow of trains to technical stations. Uneven reception of trains during freight traffic affects not only the quality of service for cargo owners, but also the efficiency and reliability of the station. Inequalities in the train reception interval lead to inefficient downtime of freight wagons between receiving, handling, sending, feeding to loading and unloading sites, etc., as well as uneven loading of shunting diesel locomotives, to the need to create extra reserves (throughput and processing capacity) and the need to attract additional personnel. All these negative factors reduce the power of stations. The power of stations can be increased by reconstructing the station tracks (construction of new roads, switches, etc.). But the reconstruction method requires a large capital cost [1, 2, 3].

II. PURPOSE OF THE RESEARCH

The problems arising from the uneven reception of trains are organizational in nature and related to the work technology of the stations. One of the solutions to these problems is “elastic (structural) technology”. Structural technologies are a set of technological techniques that allow you to control the properties of the structure of the station. Using these methods, it is possible to bring the structural properties of the station closer to the optimum in any mode of operation. Studies have shown that the introduction of "elastic technologies" in practice can increase the capacity of stations only in the short term. Since, a long-term increase in power with these methods then leads to a decrease in power. For this reason, such methods are not often used in practice. For greater efficiency in this direction, it is more advisable to use the method of structural technologies together with the gradual optimization of the track development of the station. It is proposed to carry out such optimization in 4 directions: parametric, functional, structural and systemic.

The feasibility of implementing all four directions is determined by the effectiveness of each of them. Actions in each direction are implemented sequentially. To increase the efficiency of the application considered optimization directions, it is necessary to use an additional method - the method of structural technologies. Experiments have shown that it is more expedient to apply this method together with parametric and functional directions of optimization [1, 4, 5].

III. SOLUTION OF THE PROBLEM

The regulation of the station work is based on a change in the distribution of power between the elements by changing the technology of work. Changing the power distribution of elements is carried out in two available technological ways: account of the transfer of throughput or track capacity.

The capacity of station tracks can be adjusted by changing the specialization of the tracks. This method is carried out by receiving and processing trains on tracks intended for other operations (cargo, wagons, destinations, etc.). A feature of the method is a gradual change in the specialization of tracks with the subsequent restoration of the existing station technology. The limitation of this method is the lack of free tracks for receiving trains. At large technical stations, if necessary, they change the specialization of yards to regulate train capacity. For example, depending on the situation, receiving trains to the departure yard, putting up trains ready to be sent to the receiving yard, etc.

During the operation of the station, there are cases when the load of the station exceeds the optimal value. Since such cases are non-standard, the methods of solving them are not specified in the instructions, the process of the station and other regulatory documents of the station. To overcome non-standard situations, it is necessary to standardize these types of cases. It is possible to classify situations that occur at stations by the amount of bandwidth utilization:

1. Station operation at low load (to 45 %);
2. Station operation at average load (46-80 %);
3. Station operation at full load (81-100 %).

The first case is standard. In this case, the station operates as usual, all operations are performed by the dispatcher in accordance with regulatory documents and instructions. No further action is required. Case 2 is considered partially non-standard, making the work of the station more difficult. In this case, some additional measures are required. In the third situation, the station utilization reaches its maximum value. In this case, in order to bring the station to its normal state, it is necessary to make optimization decisions based on structural technologies [6, 7]. In this case, in order to reduce the load level of the station, it is recommended to implement the following solutions:

a) Transfer mobile machinery (shunting locomotives, loading and unloading mechanisms, etc.) from one section of the station to another. By increasing the number of such vehicles, several operations of the transportation process can be performed simultaneously. This allows increasing the throughput and processing capacity of this section of the station;

b) Regulation of the distribution of teams and individual workers between work areas ("flexible use of staff"). When loading a specific section of the station, the problem can be eliminated by sending one of the work teams to the area. Also, with constant inefficient downtime of freight cars for technical and commercial inspections in parks, it is more expedient to create an additional mobile team. This measure will reduce inefficient downtime of trains waiting to be processed.

c) Changing the specialization of receiving and departure tracks. To increase the capacity of the station, it is possible to accept trains on free departure tracks or put ready-made trains on the tracks for receiving.

d) The possibility of occupying exhaust tracks and tracks for the movement of single locomotives. When receiving and departure tracks are busy, trains are allowed to be accepted to exhaust tracks and tracks for the movement of single locomotives. In some cases, stretch tracks (at dead-end stations), connecting tracks (on non-public tracks, tracks between the station and facilities, tracks between yards, etc.) can be used to park trains waiting for processing.

If the above solutions cannot reduce the load on the station, it is necessary to go to the following solutions:

e) Use of free ends of tracks. To maximize the use of station capacity, it is possible to divide the received trains into several groups and place them at the free ends of the tracks. This method will free up the track for the next train. However, to divide the train, additional shunting work will be required.

f) Changing the specialization of yards. If the configuration of the station and the location of the yards allow, then it is possible to reduce the load on the station by changing the specialization of receiving and departure yards. For example, the number of wagons accepted at the station at the same time can be increased by combining two yards (receiving and departure) and using them as one receiving-departure yard. It is also possible to receive trains in the departure yard or place trains ready for departure in the receiving yard.

g) Use of station loading and unloading tracks. If the station receives a large number of freight cars from all directions and all receiving and departure tracks are busy, it is possible to place trains in the loading and unloading tracks. Thanks to this method, the processing capacity of the station can be increased.

The implementation of the above measures will increase the throughput and processing capacity of the station. The station will return to normal. The dispatcher will then continue to operate the station in accordance with the instructions. If, after the implementation of all the above measures, the load of the station continues to increase and reaches its maximum value, then at the next stage the use of structural technology is not considered appropriate. In such cases, it is necessary to reduce the number of trains arriving at the station. To do this, the station dispatcher informs the dispatcher serving the railway section about this, which in turn temporarily stops approaching trains at neighboring stations. And also, the higher authorities are informed about the artificial delay of trains on the railway network.

Thus, non-standard situations arising during the operation of a dispatcher can be solved by applying the methods of structural technology and brought to a standard situation. Sometimes, with increased loading, the wrong dispatcer solution further complicates the operation of the station. An expert system should be developed to apply the above measures and their practical solutions. Using this system, according to the station load level, you can select a situation and make solutions for implementation.

In non-standard cases, the use of an expert system will allow the dispatcher to reduce the time for making management decisions, increase the performance of the station and increase throughput. In the first step, initial data is entered into the system. The initial data include the level of congestion of individual tracks and yards, the reserve capacity of the station, the number of shunting locomotives, loading and unloading machines and mechanisms, as well as the number of technical and commercial inspection teams, etc. In the second step, the station loading rate is estimated based on the preliminary data. In order to optimize the operation of the station, the congestion of tracks and parks is analyzed separately to determine a set of solutions. The third stage is the decision-making process. If the station load is equal to or less than 45%, the station operation in normal mode and no additional measures are required. In this case, the work is regulated by the standard solutions of the dispatcher. If the station load is more than 45%, then the expert system gives recommendations for reducing the station load [8, 9].

Expert system model on based on fuzzy logic, it is a set of production rules written in the natural language of qualitative concepts of specialists. Fuzzy expert systems allow not only to consider uncertainty, but also provide the opportunity to model reasoning based on the experience of specialists. The central control system of the station parameters (CCSSP) reads the data and provides this data to the dispatcher. Then the dispatcher enters the obtained data into the expert system and starts the processing mechanism. Fuzzification is the transformation of a clear set of input data into a fuzzy set, determined using the values of the membership functions. The purpose of the fuzzification step is to establish a correspondence between the specific numerical value of the individual input variable of the system and the value of the membership function of the corresponding term. For example: input variables as loading tracks or yards are expressed by linguistic terms: low, normal, high. Input {x1, x2,.... xi} where i - is the number of parameters, are values obtained from the central control system. Then happens linguistic evaluation of each parameter according to the set in the system membership functions. After that, the clear set of input parameters turns into a fuzzy set $\tilde{A}$ and is used as linguistic variables in the logical rules of the knowledge base. Defuzzification is the inverse transformation of a fuzzy set into a clear set B. Thus, the system values are the probabilities of conclusions of the recommendations $\{y_1, y_2, \ldots y_j\} \in Y$, where j - is the number of recommendations.

A fuzzy set represents a dependence of a $\mu(x) = \mu_{\tilde{A}\to B}$ (y) as a function from the output variable y. Thus, the conclusions of the recommendations are identified with a probability assessment. Such a logical output system is called Mamdani-Zade system. The choice of an odd model of the Mamdani type is due to the fact that that the rules of the knowledge base are transparent and intuitive, then as for Sugeno models, it is not always clear what linear dependencies "inputs - output "must be used and how to obtain them [10,11].

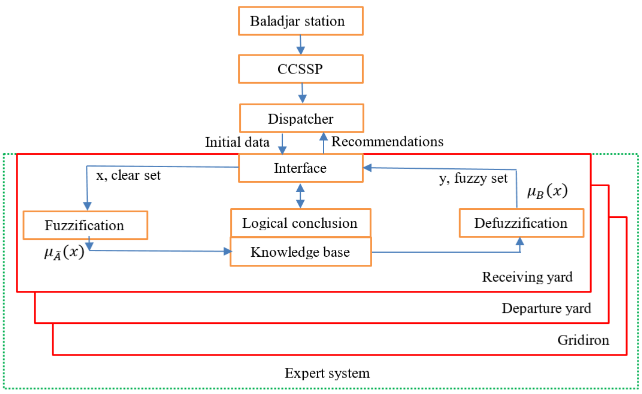

Fig. 1. Block diagram of the expert system of the Balajar station

In this work, the block diagram (Fig. 1) was implemented during the development of the expert system for the conclusions of recommendations using the example of the Balajar marshalling station. Balajar is the main marshalling station of Azerbaijan Railways and plays a key role in organizing train flows to the 3 main directions of the country.

The station has 3 yards (receiving, departure, gridiron) located parallel to each other. In the receiving yard 9, the departure yard 12, the gridiron 31 tracks. Loading and unloading operations are carried out in the freight yard of the station. The station serves 5 shunting locomotives. Technical and commercial inspections are carried out by 4 teams. The developed expert system will make it possible to make the right decision in non-standard cases.

Causal relationships between parameter values and malfunction are formalized in the form of a set of fuzzy logical rules. Format the base inference rule "if - then" is called fuzzy implication. For example, a snippet of recommendations when loading the receiving yard is as follows:

LOAD_YARD = (76-100% AND MORE)
TRAIN ARRIVAL INTENSITY = 6 TRAINS PER HOUR

....
LOADING_YARD = HIGH
TRAIN ARRIVAL INTENSITY = HIGH

....
THE NUMBER OF PROCESSING TEAMS BELOW THE NORM (NPT) - PROBABILITY 40%
OR THE NUMBER OF SHUNTING LOCOMOTIVES BELOW THE NORMAL (NSL) - PROBABILITY 30%
OR LACK OF TRACK FOR TRAIN RECEPTION (LTTR) - PROBABILITY 30%

....
IF THE NUMBER OF PROCESSING TEAMS = "BELOW NORMAL"
DISPLAY ("RECOMMENDATION: REMOVE THE PROCESSING TEAM FROM LESS LOADED YARD OR TEMPORARILY FORM AN ADDITIONAL")
SO_THAT, "TRAINS AWAIT PROCESSING "
IF NPT = NORMAL INQUIRY NSL

....
IF THE NUMBER OF SHUNTING LOCOMOTIVES = "BELOW NORMAL"
DISPLAY ("RECOMMENDATION: TRANSFER LOCOMOTIVE FROM LESS LOADED STATION SECTION")
SO_THAT, "TRAINS ARE WAITING FOR DELIVERY ON THE SORTING HUMP "
IF NSL = NORMAL INQUIRY LTTR

....
IF LACK OF TRACK FOR TRAIN RECEPTION = VERY HIGH
DISPLAY ("RECOMMENDATION: CHANGE THE SPECIALIZATION OF RECEIVING AND SENDING TRACKS")
SO_THAT, "THERE ARE FREE TRACKS IN THE DEPARTURE YARD"
IF LACK OF TRACK FOR TRAIN RECEPTION = VERY HIGH AND THERE ARE NO FREE TRACKS IN THE DEPARTURE PARK

DISPLAY ("RECOMMENDATION: TAKE A TRAIN ON THE TRACK TO MOVE SINGLE LOCOMOTIVES OR PUT ON THE EXTENSION TRACK")
SO_THAT, "EXTENSION TRACK AND TRAFFIC ROUTE FOR SINGLE LOCOMOTIVES ARE FREE"

IV. CONCLUSION

In terms of practical importance, the developed system will cope with the increase in workload, increase performance and to some extent increase the capacity of the station. Translate non-standard situations arising in the operation of the station into standard ones by implementing structural technology methods. The use of an expert system will make it possible to make the right decision, which will allow the dispatcher to reduce the time for making management decisions. It is also possible at an early stage to estimate the increasing probability of station loading when the input parameters change in real time.

From the point of view of scientific significance, the advantages of an expert system based on fuzzy logic are as follows:

- Maintaining the development of a quick prototype of an expert system with subsequent complexity of functionality;
- Fuzzy logical model is more user-friendly than similar mathematical model based on differential equations;
- The fuzzy set method allows you to include qualitative variables in the analysis, operate on fuzzy inputs and linguistic criteria;
- Fuzzy models are easier to implement than classic control algorithms.

REFERENCES

[1] Козаченко Д. Н., Горбова А. В. Определение расчетных объемов работы железнодорожных станций в условиях изменения структуры вагонопотоков /Сборник научных трудов Днепропетровского национального университета железнодорожного транспорта. Вып. 10. 2015 с. 50-56 [In Russian: Kozachenko D.N., Gorbova A.V. 2015. Determination of calculated volumes of work for railway stations in the condition of cars flow changing, Collection of scientific papers of the Dnipropetrovsk National University of Railway Transport. Issue 10, 50-56.

[2] Li Dong. 2015. Research on the passing capacity of Heavy Haul Railway Technical Station [D]. Southwest Jiao Tong University.

[3] Jaehn, F., Rieder, J., & Wiehl, A. 2015. Minimizing delays in a shunting yard. OR Spectrum, 37(2), 407–429.

[4] Guo, R., Guo, J., & Xie, . G. (2016). Optimizing model of a railroad yard's operations plan based on production scheduling theory. Transactions on The Built Environment, 162, 1743–3509.

[5] Gestrelius, S., Dahms, F., & Bohlin, M. (2013). Optimisation of simultaneous train formation and car sorting at marshalling yards *. In 5th International Seminar on Railway Operations Modelling and Analysis Rail Copenhagen Copenhagen.

[6] Sara Gestrelius, Martin Aronsson, Martin Joborn, Markus Bohlin. Towards a comprehensive model for track allocation and roll-time scheduling at marshalling yards /RailLille 2017 — 7th International Conference on Railway Operations Modelling and Analysis 1153-1172

[7] Boysen, N., Fliedner, M., Jaehn, F., and Pesch, E., 2012. "Shunting yard operations: Theoretical aspects and applications." European Journal of Operational Research, 220(1):1–14.

[8] Лаврухин, А. В. Формирование интеллектуальной модели функционирования железнодорожной станции при выполнении поездной работы / Наука и прогресс транспорта, Днепропетровский Национальный Университет железнодорожного транспорта – 2015. –№ 1(55). – С. 43-53 [In Russian: Lavrukhin A. V. 2015. Formation of an intelligent model of the functioning of the railway stations when performing train work/ Science and progress of transport, Dnepropetrovsk National University of Railway Transport, № 1 (55). 43-53.

[9] He, S., Song, R., & Chaudhry, S. S. (2000). Fuzzy dispatching model and genetic algorithms for railyards operations. European Journal of Operational Research, 124(2), 307–331.

[10] Jackson Peter. 1998. Introduction to expert systems. England, Harlow: Addison - Wesley. ISBN: 0-201-87686-8.

[11] Штовба С.Д. 2007. Проектирование нечетких систем средствами MATLAB. Москва: Горячая линия-Телеком. [In Russian: Shtovba S.D. 2007. Designing fuzzy systems with MATLAB. Moscow: Hotline-Telecom. ISBN 5-93517-359-X].

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An Econometric Assessment of the Dependence of Main Indicators of Transport Sector on Factors Affecting Them

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***Abstract*—In this research, the dependence of the main factors of the transport sector for the Azerbaijan economy on factors affecting themwas studied. For this purpose, firstly, to determine the share of key production factors in production, the production function for the transport sector was established based on the country's statistical indicators. The article also evaluates the impact of freight transportation on the value-added of the transport sector, and the impact of the number of vehicles and, separately, trucks on net profit.**

Keywords—transport, value-added, net profit, freight, the number of vehicles, trucks

I. Introduction

Transport is one of the main sectors of the economy. This sector is important for the production process to be happened by carrying necessary raw materials to factories and also, without this sector it would be impossible to supply finished goods to consumers. In this regard, the development of the transport sector is an important issue for each country. The transport sector is also one of the important areas in Azerbaijan. The chart below shows the share of transport in GDP.

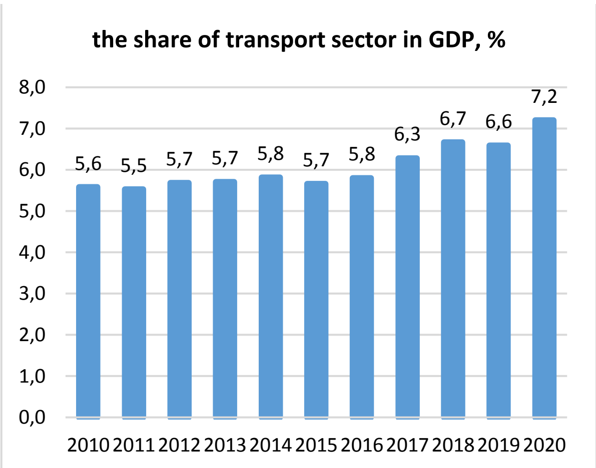

Fig. 1. The share of transport sector in GDP (%)

As can be seen from the Figure 1, the share of transport sector in GDP has mainly increased during the period, and in 2020, this share has been equal to 7,2% [8].

The oil and gas sector has been the main sector in Azerbaijan's economy after its independence. Oil products constitutes more than 90% of the country's export. During recent years, this sector has had a 33-50% share in the total GDP of Azerbaijan, depending on prices. Because the export of energy was the main source of revenue for the country, creating the system of transport corridors to export this energy was chosen as one of the basic policies [9]. Moreover, to reduce the dependence on the oil and gas sector, the development of the non-oil sector has been in the spotlight. Therefore, the country has been directing foreign direct investments from the oil and gas sector to the non-oil sector. For this, a number of sectors have been identified to support the sustainable development of the country, and due to its convenient position, one of these selected sectors is the transport sector. Creating the necessary infrastructure is an ongoing process. However, given the risk of being dependent on one sector, there is a need to diversify the national economy. In 2009-2019, the volume of investments in the transport sector of the country amounted to 20% of investments in all sectors of the economy [1]. However, to use these investments properly, it is relevant to research the efficiency of expenditures and to determine preferred areas to be developed. Therefore, this article evaluates the factors affecting the main indicators of the transport sector.

II. Methodology

A. *Production function analysis of transport sector*

Production is the process of transforming production factors into goods and services during a certain time. The relationship between the volume of products obtained at the end of a production process and the production factors used in that process is described through production functions. In other words, production functions reflect the relationship between the production of an enterprise, a production sector or the economy of a country as a whole, and production factors. Obviously, the most important condition for the economic growth of a country is to increase its production, and to achieve this, to use effectively existing production factors. In this regard, since economic development is the main economic goal of countries in the present as in the past, the rational use of production factors and therefore the importance of constructing production functions is one of the relevant topics to be studied. Because production functions can give important information about the production process for the economy or a sector of the economy [11].

Production functions mathematically express the relationship between production factors and the result of production. In general, we can write the production function as following [15]:

$$Y = F(X_1, X_2, ..., X_n), \quad (1)$$

One of the most common production functions is the Cobb-Douglas production function. In the Cobb-Douglas production function, the relationship between the volume of production and production factors that affect it is considered as follows:

$$Q = AK^{\alpha} L^{\beta}, \quad (2)$$

Here Q is the volume of production, K- is capital used to produce that volume of production, and L – is labour. α and β are the elasticity coefficients of K and L, respectively.

To evaluate this function, we will use least squares method in Eviews software [5]. For this, firstly having considered $\alpha + \beta = 1$, we can write equation (2) as following:

$$Q = AK^{\alpha} L^{1-\alpha}, \quad (3)$$

If we divide both side of this equation into L, we can get the following equation:

$$\frac{Q}{L} = A(\frac{K}{L})^{\alpha}, \quad (4)$$

In the equation (4), $\frac{Q}{L}$ – is the volume of production produced by one worker, and $\frac{K}{L}$-is the capital per worker. If we log both sides of this equation, we can write:

$$\log \frac{Q}{L} = \log A + \alpha \log \frac{K}{L} \quad , \quad (5)$$

And if we mark log(A)=c(1), and α =c(2), then we will can estimate the following equation in Eviews using least squares method [4]:

LOG(Q/L) = C(1) + C(2)*LOG(K/L), (6)

B. *Assesment of the dependence of value added and net profit of transport sector on factors affecting it*

To assess the dependence of value added and net profit of transport sector on the freight transportation and the number of vehicles we will estimate the following equation in Eviews, using least squares method:

Log(VA)=C(1)+C(2)*Log(FT), (7)

Log(NP)+c(1)+ C(2)*Log(NoV)+C(3)*log(NoT), (8)

Here, VA- is the value added of transport sector Np – net profit of transport sector, NoV – the number of vehicles, , FT-freight transportation, and NoT –the number of trucks in the country.

III. DATABASE OF THE RESEARCH AND ITS PROCESSING

Statistical indicators of The State Statistical Committee of the Republic of Azerbaijan (SSCRA) [8] related to the transport sector were used as the information base of the research. To analyze the transport sector with production functions, the Cobb-Douglas production function of this sector was established. For this purpose, (5) regression equation was evaluated in the eviews software package. In the study, we took the value-added of the transport sector as Q, the value of fixed assets of the transport sector as K, and the number of employees in this sector as L. It is known that the use of nominal indicators in the assessment is problematic. Therefore, the value-added of the transport sector and fixed assets were converted to real prices using the deflator, and all 3 input variables of the model were expressed as a percentage. So, the input data of the econometric model to construct the production function are obtained as in the table 1.

TABLE 1. VALUE ADDED, FIXED ASSETS AND LABOUR FORCE IN TRANSPORT SECTOR OF THE AZERBAIJAN ECONOMY

years	VA	K	L
1998	100	100	100
1999	95,1	101,6	92,7
2000	121,7	96,9	86,2
2001	114,2	98,7	82,5
2002	120,4	93,4	79,8
2003	134,8	94,5	90,5
2004	135,7	97,6	91,5
2005	127,5	101,5	92,7
2006	149,1	102,4	99,1
2007	227,1	99,2	105,9
2008	227,8	86,5	118,7
2009	331,3	121,2	121,8
2010	284,1	119,5	122,1
2011	260,3	112,7	123,4
2012	256,3	135,7	127,6
2013	243,5	148,4	133,1
2014	255,0	153,2	130,8
2015	341,7	189,8	138,5
2016	374,6	186,1	134,7
2017	373,2	171,5	137,2
2018	347,3	187,0	138,0
2019	343,9	193,9	142,3
2020	393,3	211,7	153,1

In addition, the article assesses the dependence of value-added and net profit of the transport sector on the main factors affecting these indicators. The impact of several indicators was assessed during the study, but only the results of adequate models were included in the article. These indicators are the volume of freight transportation, the number of vehicles, including the number of trucks. The input data of these established econometric models are shown in Table 2.

TABLE 2. THE VOLUME OF FREIGHT TRANSPORTATION, THE NUMBER OF VEHICLES AND TRUCKS FOR AZERBAIJAN

	VA	NP	FT	NoT	NoV
1998	324	131	55029	79934	392789
1999	315	105	67735	69685	409301
2000	453	229	80180	78566	438626
2001	436	224	92648	77142	451642
2002	474	250	98445	76928	457442
2003	563	287	110001	79019	511460
2004	614	268	117314	80918	554031
2005	670	275	128328	90852	612069
2006	872	394	145596	97395	690012
2007	1 607	908	167533	110391	773318
2008	2 060	1270	183093	113088	860047
2009	2 431	1541	190372	117378	925866
2010	2 369	1576	196452	118460	982553
2011	2 659	1813	203586	122182	1037626
2012	2 694	1724	210862	130019	1135936
2013	2 569	1466	217926	133637	1232678
2014	2 656	1386	221991	141126	1291008
2015	3 242	1860	222373	141273	1322610
2016	4 076	2162	222461	141525	1330551
2017	4 719	2935	226419	142857	1342324
2018	4 928	3137	230144	147343	1370574
2019	4 867	3055	235288	150547	1418404
2020	5 144	3229	188629	154659	1473563

IV. FINDINGS AND RESULTS

A. *Assessment of production function for Azerbaijan's transport sector*

The study evaluated the Cobb-Douglas production function of the transport sector based on the indicators of Table 1 using the equation (5). For this purpose, the least squares method was used in the eviews software package. As a result of the implementation of the model, the dependence of the value-added of the transport sector on capital and labor, which are the main factors of production, is obtained as follows:

LOG (VA / L) = 0.520698800487 + 0.543779053821 * LOG (K / L) + [AR (1) = 0.90502379848, UNCOND,

ESTSMPL = "1998 2020"], (9)

The main statistical characteristics of the model are given in Table 3.

In addition to these statistical characteristics, other important tests have been performed to test the Gaussian Markov conditions in Eviews, and the results suggest that this model is adequate [3]. By performing simple transformations using the model parameters, we can write the Cobb-Douglas production function for the Transport Sector as follows:

$$Q = 1{,}6K^{0{,}54}L^{0{,}46}, \quad (10)$$

It should be noted that, in general, the share of labor in production more than the share of capital, however, for Azerbaijan case the share of capital is higher. This can be considered normal for oil-rich countries [13]. Thus, in countries rich in natural resources, there is a rapid inflow of capital into the country using natural resource revenues. However, especially in developing countries, the existing workforce is not skilled enough to mobilize this capital [6,7].

TABLE 3. THE MAIN STATISTICAL CHARACTERISTICS OF THE MODEL (9)

Dependent Variable: LOG(VA/L)				
Method: ARMA Maximum Likelihood (OPG - BHHH)				
Sample: 1998 2020				
Included observations: 23				
Convergence achieved after 11 iterations				
Coefficient covariance computed using outer product of gradients				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.5206	0.241047	2.160153	0.0437
LOG(K/L)	0.5437	0.272272	1.997191	0.0603
AR(1)	0.905	0.114512	7.903313	0.0000
SIGMASQ	0.0195	0.005034	3.874793	0.0010
R-squared	0.7835	Mean dependent var		0.70523
Adjusted R-squared	0.7493	S.D. dependent var		0.30694
S.E. of regression	0.1536	Akaike info criterion		-0.6769
Sum squared resid	0.4487	Schwarz criterion		-0.4794
Log likelihood	11.785	Hannan-Quinn criter.		-0.6272
F-statistic	22.923	Durbin-Watson stat		1.61129
Prob(F-statistic)	0.0002			

B. *Assessment of the dependence of value-added and net profit of transport sector on factors affecting it*

The results of the eviews estimation of the dependence of value-added on the volume of freight were as follows:

LOG (VA) = -4.7222345876 + 0.847265836236 * LOG (FT) + [AR (1) = 0.691662196775, UNCOND, ESTSMPL = "1998 2020"], (11)

TABLE 4. THE MAIN STATISTICAL CHARACTERISTICS OF THE MODEL (11)

Dependent Variable: LOG(VA)				
Method: ARMA Maximum Likelihood (OPG - BHHH)				
Sample: 1998 2020				
Included observations: 23				
Convergence achieved after 20 iterations				
Coefficient covariance computed using outer product of gradients				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-4.722235	3.788891	-1.246337	0.2278
LOG(FT)	0.847266	0.319844	2.648996	0.0158
AR(1)	0.691662	0.232509	2.974770	0.0078
SIGMASQ	0.023402	0.009408	2.487346	0.0223
R-squared	0.895660	Mean dependent var		5.345884
Adjusted R-squared	0.879185	S.D. dependent var		0.484231
S.E. of regression	0.168311	Akaike info criterion		-0.540939
Sum squared resid	0.538242	Schwarz criterion		-0.343462
Log likelihood	10.22080	Hannan-Quinn criter.		-0.491274
F-statistic	54.36570	Durbin-Watson stat		1.776698
Prob(F-statistic)	0.000000			

The statistical characteristics and other relevant tests of the model show that the model is adequate.

According to the model, a 1% increase in freight transportation across the country increases the value-added of the transport sector by 0.8%.

The article then econometrically assessed the dependence of the transport sector's net profit on the number of vehicles. In this case, to consider the effect of the number of trucks on the net profit separately, the effect of both trucks and other vehicles other than trucks on the net profit was evaluated in the same regression equation. The results of the assessment were as follows:

LOG(NP) = -33.4018053347 + 0.875219456361*LOG(NoV-NoT) + 2.43953953068*LOG(NoT) + [AR(4)=-0.428306106271,AR(1)=0.447875709336,UNCOND], (12)

TABLE 4. THE MAIN STATISTICAL CHARACTERISTICS OF THE MODEL (12)

Dependent Variable: LOG(NP)				
Method: ARMA Maximum Likelihood (OPG - BHHH)				
Sample: 1998 2020				
Included observations: 23				
Convergence achieved after 28 iterations				
Coefficient covariance computed using outer product of gradients				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-33.40181	5.340561	-6.254363	0.0000
LOG(NoV-NoT)	0.875219	0.476068	1.838434	0.0835
LOG(NoT)	2.439540	0.985106	2.476424	0.0241
AR(4)	-0.428306	0.218950	-1.956179	0.0671
AR(1)	0.447876	0.194177	2.306535	0.0339
SIGMASQ	0.027345	0.009397	2.910143	0.0098
R-squared	0.9774	Mean dependent var		6.7052
Adjusted R-squared	0.9708	S.D. dependent var		1.12533
S.E. of regression	0.192345	Akaike info criterion		-0.1822
Sum squared resid	0.628945	Schwarz criterion		0.11405
Log likelihood	8.094804	Hannan-Quinn criter.		-0.10769
F-statistic	147.2102	Durbin-Watson stat		1.4438
Prob(F-statistic)	0.000000			

The statistical characteristics of the model (12) show that the model is adequate.

According to the model, a 1% increase in the number of trucks increases the net profit of the transport sector by 2.4%, and a 1% increase in the number of other vehicles increases the net profit of the transport sector by 0.87%. As can be seen, the increase in the number of any type of vehicle, in general has a positive effect on the net profit of the transport sector, but the effect of the increase in the number of trucks is higher than other vehicles.

V. CONCLUSIONS

The article evaluates the dependence of the main indicators of the transport sector of Azerbaijan on the factors affecting them econometrically. To this end, to determine the share of key production factors in production, the production function for the transport sector was first established based on the country's statistic indicators. It has been found that the share of capital in the value-added of this sector is predominant, and this is due to the inflow of high-value capital into the country using revenues from natural resources, however, at the same tim, the lack of skilled labor to mobilize this capital. In addition, the article provides an econometric assessment of the effect of the volume of freight transportation in the value-added and, the effect of the number of vehicles and, in particular, trucks in the net profit of the transport sector

It was found that the effects studied were positive. Also, when assessing the impact of the number of vehicles on the net profit indicator, it was found that an increase in the number of trucks increases profits more than that other vehicles increases it. Thus, as a result of the study, it can be said that the balance of factors of production should be taken into account when making decisions for the development of the transport sector, and increasing the skill of workers should be promoted.

REFERENCES

[1] Azerbaijan, B. (2021). Importance of investing in the development of transit and transport services in Azerbaijan.

[2] C.W.Cobb, P.H.Douglas, A theory of production. The American Economic Review, 18(1), 139-165, 1928.

[3] Dimitrios Asteriou, Stephen G.Hall, (2016), “Applied Econometrics”, Third edition, pp. 74-77, 275-286.

[4] Eviews 9, “User’s guide I” and “User’s guide II”.

[5] Hasanli, Y. & Hasanov, R. (2002). Application of Mathematical Methods in Economic Research. Baku: Elm.

[6] Hasanli, Y. (2013). The evaluation of mutual substitution elasticity of capital and labor factors by application CES function for economy of Azerbaijan. The Journal of Economic Sciences: Theory and Practice, 70(19), 77-96.

[7] Hasanli, Y., Musayev, T., Rahimli, G., & Ismayilova, S. (2021). Assessment of CES Function Parameters in Oil-Rich CIS Countries.

[8] http://www.stat.gov.az

[9] Ibrahimov, R. (2010). AZERBAIJAN ENERGY STRATEGY AND THE IMPORTANCE OF THE DIVERCIFICATION OF EXPORTED TRANSPORT ROUTES. *Journal of Qafqaz University*, (29).

[10] Ibrahimov, R. (2016). The Development of the Transport Sector in Azerbaijan: The Implementation and Challenges. *Human Development*, *5*(1), 45.

[11] Imanov, G. Hasanli, Y. (2001). Socio-economic models of Azerbaijan economy. Macroeconomic analysis. Baku, Azerbaijan: Elm.

[12] Kontorovich G.G., (2002), “Time Series Analysis”, Economic Journal, HSE, №1, pp.85-116.

[13] Lederman, D., & Maloney, W. F. (2007). Neither curse nor destiny: Introduction to natural resources and development. Natural Resources, 1, 1-396

[14] Magnus Y.R., Katyshev P.K., Peresetsky A.A., (2004), “Econometrics. The initial course.”, 6-th edition, Moscow, pp.32-112.

[15] Songu, M. & Sarac Elmas, F. (2017). Cobb-Duglas, CES, VES ve Translog Üretim Fonksiyonlarının Tahminleri Üzerine Genel bir Değerlendirme. Bulletin of Economic Theory and Analysis, 235-278

Technologies for Monitoring the Technical Condition of Tunnels by the Critical Values of the Noise and its Correlation with the Useful Signal

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***Abstract*—It is noted that at the moment of initiation of malfunctions in the structures of the tunnel, the noise of the noisy signal coming from the corresponding sensor takes on critical values that correlate with the useful signal. The authors develop the algorithms for calculating the probability of admissible and critical values of the noise of the noisy signal, the relay cross-correlation function and the correlation coefficient between the useful signal and the noise. Technologies are proposed for early monitoring of the technical condition of tunnels by critical values of the noise and for determining the dynamics of the development of defects by the value of the correlation coefficient between the useful signal and the noise of the noisy signal.**

Keywords*—useful signal, noise, noisy signal, probabilities of admissible and critical values of noise, correlation coefficient, tunnel, type of malfunction

I. Introduction

Tunnels are known to be an important part of modern transport communication networks with heavy traffic. Tunnels are typically built through both soft clay and hard rocks. Therefore, they are subject to rock pressure, groundwater, vibration shocks due to moving vehicles, etc. As a result, deformations, cracks, corrosion, wear, breakdowns and other malfunctions occur in the structures of the tunnels, which can lead to an emergency state. To avoid this, it is necessary to ensure its stability during construction of the tunnel and to adequately manage the risks of accidents during operation.

Geodetic monitoring systems are created for uninterrupted and safe operation of the tunnel. For this purpose, a system of sensors gauging pressure, displacement, load on reinforcement and anchors, crack opening sensors, inclinometers, etc. is installed to measure, collect and process initial information. Based on the results obtained, a conclusion is made on the technical condition of the tunnel, the presence of defects and the degree of their danger for the operation of vehicles, as well as recommendations are given on how to eliminate the malfunctions. [1-3].

However, the existing monitoring and control systems do not allow detecting the early period of malfunctions in the tunnels. This is especially important for countries of seismically active regions, when, after frequent weak earthquakes or minor repeated landslides, microscopic changes in the technical condition of the tunnel appear, which can subsequently lead to serious damage. [1-4].

It is shown in [5-10] that in the normal technical condition of the tunnel, the noisy signal that comes from the corresponding sensor contains only the noise caused by the influence of external factors. At the moment of formation of even the smallest damage, additional noise appears, which correlates with the useful component of the noisy signal.

Therefore, the problem arises of determining the early stage of the initiation of a defect in the tunnels and the dynamics of its development by calculating the probability of the values of the noise getting into a certain critical interval, as well as the characteristics of the correlation between the useful signal and the noise.

II. Problem Statement

It is known that in practice, real signals are the sum of useful signals $X(t)$ and noises $\mathrm{E}(t)$, i.e.,

$$G(t) = X(t) + \mathrm{E}(t). \qquad (1)$$

Because useful signals $X(t)$ are contaminated with noise $\mathrm{E}(t)$, tangible errors emerge in determining the estimates of their correlation functions $R_{XX}(\mu)$.

Here, as shown in [1, 5-10], the sum noise $\mathrm{E}(t)$ is made up of the noise $\mathrm{E}_1(t)$ caused by external factors and the noise $\mathrm{E}_2(t)$ caused by the initiation of a defect during the operation of objects, i.e.,

$$\mathrm{E}(t) = \mathrm{E}_1(t) + \mathrm{E}_2(t). \qquad (2)$$

Suppose that $G(t)$ is sampled stationary random signal with a normal distribution law, consisting of the useful signal $X(t)$ and the noise $\mathrm{E}(t)$ with a zero mathematical expectation m_{E}. Here, the formula for calculating the estimate D_G of the variance of the noisy signal $G(t)$ is written as [1,5-10]:

$$D_G = R_{GG}(0) = \frac{1}{N}\sum_{i=1}^{N} G^2(i\Delta t) =$$

$$= R_{XX}(0) + 2R_{X\mathrm{E}}(0) + R_{\mathrm{EE}}(0). \quad (3)$$

Therefore, the error of the obtained result is equal to

$$\lambda_{GG}(\mu = 0) = 2R_{X\mathrm{E}}(0) + R_{\mathrm{EE}}(0) = D_{\mathrm{E}},$$

where $R_{X\mathrm{E}}(0) = \frac{1}{N}\sum_{i=1}^{N} X(i\Delta t)\mathrm{E}(i\Delta t)$ is the cross-correlation function between the useful signal and the noise; $R_{\mathrm{EE}}(0) = \sum_{i=1}^{N} \mathrm{E}(i\Delta t)\mathrm{E}(i\Delta t)$ is the variance of the noise $\mathrm{E}(t)$.

The formula for calculating the estimate of the correlation function $R_{GG}(\mu)$ at $\mu \neq 0$ can also be written as [1,5-10]:

$$R_{GG}(\mu) = \frac{1}{N}\sum_{i=1}^{N} G(i\Delta t)G((i+\mu)\Delta t) =$$

$$= R_{XX}(\mu) + R_{\mathrm{E}X}(\mu) + R_{X\mathrm{E}}(\mu) + R_{\mathrm{EE}}(\mu). \quad (4)$$

Since $R_{\mathrm{EE}}(\mu)$=0 at $\mu \neq 0$, the sum noise will be equal to

$$\lambda_{GG}(\mu) \approx \begin{cases} 2R_{X\mathrm{E}}(0) + R_{\mathrm{EE}}(0) & \text{when } \mu = 0 \\ 2R_{X\mathrm{E}}(\mu) & \text{when } \mu \neq 0 \end{cases}. \quad (5)$$

Hence the obvious inequality

$$R_{XX}(\mu) \neq R_{GG}(\mu). \quad (6)$$

For this reason, in practice, it is often impossible to ensure the adequacy of the results of the problem being solved using the estimate of $R_{GG}(\mu)$, since in this case part of the valuable information contained in the noise $\mathrm{E}(t)$ of the signal $G(t)$ is lost. In this regard, it is obvious that it is necessary to create algorithms and technologies for determining the estimate of the noise variance D_{E} and the cross-correlation function $R_{X\mathrm{E}}(\mu)$ between the useful signal and the noise.

At the same time, it is obvious [1,5-10] that the correlation between $X(t)$ and $\mathrm{E}(t)$ arises when the values of the noise are a certain critical interval. It is known that the probability $P(\alpha \le \mathrm{E}(t) \le \beta)$ of the noise $\mathrm{E}(t)$ being in a certain interval $[\alpha, \beta]$ can be calculated from the expression:

$$P(\alpha \le \mathrm{E}(t) \le \beta) = \int_{\alpha}^{\beta} f(\varepsilon)d\varepsilon, \quad (7)$$

where $f(\varepsilon)$ is the density distribution function of the noise $\mathrm{E}(t)$.

Since in most cases the stationary ergodic noise obeys the normal distribution law $N(\varepsilon, m_{\mathrm{E}}, \sigma_{\mathrm{E}})$, and its mathematical expectation m_{E} =0:

$$N(\varepsilon) = \frac{1}{\sigma_{\mathrm{E}}\sqrt{2\pi}} e^{-\frac{(\varepsilon - m_{\mathrm{E}})^2}{2\sigma_{\mathrm{E}}^2}}, \quad (8)$$

then the probability $P(\alpha \le \mathrm{E}(t) \le \beta)$ can be calculated as follows:

$$P(\alpha \le \mathrm{E}(t) \le \beta) = \int_{\alpha}^{\beta} N(\varepsilon)d\varepsilon. \quad (9)$$

Below, we propose algorithms and technologies for determining the early stage of the initiation of a defect in a tunnel and the dynamics of its development as a result of calculating the probability of the noise being in a certain critical interval $[\alpha, \beta]$, as well as relay cross-correlation function and correlation coefficient between the useful signal and the noise.

III. Developing Algorithms for Calculating the Probability of Admissible and Critical Values of the Noise

From formula (7) it follows that to calculate the probability of the noise being in a given interval, it is necessary to determine the distribution density function $N(\varepsilon)$. Obviously, this requires calculating first of all the mean square deviation $\sigma_{\mathrm{E}} = \sqrt{D_{\mathrm{E}}}$ of the noise $\mathrm{E}(t)$. In works [1,15-10] it is shown that the estimate of the mean square deviation σ_{E}^* of the noise $\mathrm{E}(t)$ of the noisy signal $G(t)$ for real technical facilities can be calculated from the expression:

$$\sigma_{\mathrm{E}}^* = \sqrt{R_G(0) - 2R_G(\Delta t) + R_G(2\Delta t)}. \quad (10)$$

In addition, in [1, 15-10], a formula is derived for calculating the mean square deviation of the noise for the special case when the noise is white noise:

$$\sigma_{\mathrm{E}}^* = \sqrt{R_G(0) - R_G(\Delta t)}. \quad (11)$$

Then the density distribution function of the noise $\mathrm{E}(t)$, taking into account the fact that the mathematical expectation of the noise is $m_{\mathrm{E}} = 0$, will be determined from the expression:

$$N^*(\varepsilon) = \frac{1}{\sigma_E^* \sqrt{2\pi}} e^{-\frac{\varepsilon^2}{2(\sigma_E^*)^2}} \quad (12).$$

Obviously, the probability of the noise $E(t)$ being in some interval $[\alpha, \beta]$ can be determined from the expression:

$$P(\alpha \le E(t) \le \beta) = \int_\alpha^\beta N^*(\varepsilon) d\varepsilon . \quad (13)$$

Thus, knowing the probability with which the noise $E(t)$ takes admissible and critical values at different time instants, it is possible to determine the early latent period of the initiation of defects in a tunnel. The detection of the dynamics of malfunction development also requires calculating the value of the correlation coefficient between the critical values of the noise and the useful signal. This will allow determining the intensity of the emergency situation and prevent the occurrence of accidents in a timely manner.

IV. Algorithms and Technologies for Calculating the Relay Cross-Correlation Function and the Coefficient of Correlation Between the Useful Signal and the Noise

As shown above, during normal operation of the object, the noise $E(t) = E_1(t)$ emerges due to random external factors, which does not correlate with the useful signal $X(t)$. However, at the beginning of the latent period of changes in the technical condition of the object as a result of the initiation of various defects, the noise $E_2(t)$ emerges arises, whose critical values correlate with the useful signal. Therefore, from this moment on, the correlation between the useful signal $X(t)$ and the sum noise $X(t)$ is different from zero. Here, the initiation and development of malfunctions is essentially manifested in the estimates of the cross-correlation functions $R_{XE}(\mu)$ between $X(t)$ and $E(t)$ [1, 5-10]. Therefore, to control the beginning and dynamics of changes in the technical condition of tunnels, it is advisable to use the estimate of $R_{XE}(\mu)$.

It is known that the estimates of the relay correlation functions can be calculated from the formula [1]:

$$R_{XE}^r(\mu) = \frac{1}{N} \sum_{i=1}^N sgnX(i\Delta t) E((i+\mu)\Delta t) .$$

Obviously, to use this formula, it is necessary to determine the samples of the noise $E(i\Delta t)$ and the useful signal $X(i\Delta t)$, which cannot be measured directly or isolated from the noisy signal $G(t)$ [1].

In this regard, we will consider one of the possible options for the approximate calculation of estimates of the relay cross-correlation function $R_{XE}^{r*}(\mu)$ between the useful signal $X(t)$ and the noise $E(t)$ as a result of calculating the relay correlation function $R_{GG}^r(\mu)$ of the noisy signal $G(t)$.

For this, we first adopt the following notation and conditions [1]:

$$sgnG(i\Delta t) = \begin{cases} +1 & when \ G(i\Delta t) > 0 \\ 0 & when \ G(i\Delta t) = 0 \\ -1 & when \ G(i\Delta t) < 0 \end{cases} .$$

Then the relay correlation function $R_{GG}^r(\mu)$ of the noisy signal $G(t)$ will be calculated from the formula [1]:

$$R_{GG}^r(\mu) = \frac{1}{N} \sum_{i=1}^N sgn\, G(i\Delta t) G((i+\mu)\Delta t) .$$

Considering that [1]

$$\begin{cases} sgnG(i\Delta t) = sgnX(i\Delta t) \\ sgnG(i\Delta t) G(i\Delta t) = sgnX(i\Delta t) G(i\Delta t) \end{cases} \quad (14)$$

the expression for calculating the relay correlation function $R_{GG}^r(\mu)$ for $\mu = 0$ of the noisy signal $G(t)$ can be written as:

$$R_{GG}^{r*}(\mu = 0) = \frac{1}{N} \sum_{i=1}^N sgn\, G(i\Delta t) G(i\Delta t) =$$

$$\frac{1}{N} \sum_{i=1}^N sgn\, X(i\Delta t) X(i\Delta t) + \frac{1}{N} \sum_{i=1}^N sgn\, X(i\Delta t) E(i\Delta t)$$

$$= R_{XX}^r(0) + R_{XE}^r(0), \quad (15)$$

where $R_{XX}^r(\mu)$, $R_{XE}^r(\mu)$ are the relay correlation function of the useful signal and the cross-correlation function between the useful signal and the noise.

In the literature [1] it is shown that the estimates of the relay cross-correlation function $R_{XE}^{r*}(0)$ can be calculated from the expression

$$R_{XE}^{r*}(0) = R_{GG}^r(0) - 2R_{GG}^r(1) + R_{GG}^r(2) =$$

$$= \frac{1}{N} \sum_{i=1}^N sgnG(i\Delta t) G(i\Delta t) -$$

$$- \frac{1}{N} \sum_{i=1}^N 2\, sgn\, G(i\Delta t) G((i+1)\Delta t)$$

$$+ \frac{1}{N} \sum_{i=1}^N sgn\, G(i\Delta t) G((i+2)\Delta t) . \quad (16)$$

In this case, if the conditions of stationarity and normality of the distribution law of noisy signals are satisfied, then the following equalities will be valid for the controlled objects [1]

$$\begin{cases} R^{r*}_{XE}(0) \approx \frac{1}{N}\sum_{i=1}^{N} sgn\, X(i\Delta t)E(i\Delta t) \neq 0 \\ R^{r*}_{XX}(0) + R^{*}_{XX}(2\Delta t) - 2R^{*}_{XX}(\Delta t) \approx 0 \\ R^{r*}_{XE}(\Delta t) \approx \frac{1}{N}\sum_{i=1}^{N} sgn\, X(i\Delta t)E((i+1)\Delta t) \approx 0 \\ R^{r*}_{XE}(2\Delta t) \approx \frac{1}{N}\sum_{i=1}^{N} sgn\, X(i\Delta t)E((i+2)\Delta t) \approx 0 \end{cases} \quad (17)$$

and due to this, the right-hand side of expression (16) takes the form

$$R^{r*}_{XE}(\mu = 0) = R^{r}_{XE}(\mu = 0).$$

Thus, we can assume that the estimate obtained by formula (16) is an estimate of the relay cross-correlation function $R^{r*}_{XE}(\mu\Delta t)$ between the useful signal $X(t)$ and the noise $E(t)$.

The relationship between relay and normalized cross-correlation functions for normally distributed random processes $X(t)$, $E(t)$ here is expressed by the relationship [1]:

$$R^{r}_{XE}(\mu) = \sqrt{\frac{2}{\pi}}\rho_{XE}(\mu)\sigma_{E}, \quad (18)$$

where $\rho_{XE}(\mu)$ is the normalized cross-correlation function between the useful signal $X(t)$ and the noise $E(t)$, σ_E is the mean square deviation of the noise $E(t)$.

Hence the normalized cross-correlation function $\rho_{XE}(\mu)$ can be calculated from the expression [1]:

$$\rho_{XE}(\mu) = \frac{R^{r}_{XE}(\mu)}{\sqrt{\frac{2}{\pi}}\cdot\sigma_E}. \quad (19)$$

It follows from this formula that to calculate the normalized cross-correlation function $\rho_{XE}(\mu)$ between the useful signal $X(t)$ and the noise $E(t)$, we need to know the relay cross-correlation function $R^{r}_{XE}(\mu)$ and the mean square deviation σ_E of the noise. Obviously, using formula (16), it is possible to calculate the relay cross-correlation function $R^{r*}_{XE}(\mu)$. At the same time, the mean square deviation σ_E of the noise can be calculated from expression (10).

Therefore, the calculation of the normalized cross-correlation function can be reduced to the form:

$$\rho^{*}_{XE}(\mu) = \frac{R^{r*}_{XE}(\mu)}{\sqrt{\frac{2}{\pi}}\cdot\sigma^{*}_E}. \quad (20)$$

It is known here that the value of the normalized cross-correlation function $\rho_{XE}(0)$ at $\mu = 0$ is the correlation coefficient:

$$r_{XE} = \rho_{XE}(0) = \frac{R^{r}_{XE}(0)}{\sqrt{\frac{2}{\pi}}\cdot\sigma_E}. \quad (21)$$

Therefore, it is possible to calculate the value of the correlation coefficient r_{XE} between the useful signal $X(t)$ and the noise $E(t)$:

$$r^{*}_{XE} = \rho^{*}_{XE}(0) = \frac{R^{r*}_{XE}(0)}{\sqrt{\frac{2}{\pi}}\cdot\sigma^{*}_E}. \quad (22)$$

Thus, using formulas (10), (11), (16), (18)-(22) , we can calculate the correlation coefficient between the useful signal $X(t)$ and the noise $E(t)$.

V. Technologies for Monitoring the Technical Condition of Tunnels by Critical Values of the Noise and Its Correlation with the Useful Signal of the Noisy Signal

It is known that to prevent the risk of transport accidents in tunnels, it is necessary to carry out control of random signals that come from sensors gauging pressure, displacement, load on reinforcement and anchors, crack opening sensors, inclinometers, etc. in real time. Below we propose an algorithm for calculating the probability of development of tunnel defects, which makes it possible to significantly reduce the risk of transport accidents.

At the initial time period t_0, when the tunnel is in fully operational condition, the variance $D^{*}_{E,t0}$ of the noise $E(t)$ is calculated from the expressions:

$$D^{*}_{E,t0} = \frac{1}{N}\sum_{i=1}^{N} G(i\Delta t)G(i\Delta t) - 2\frac{1}{N}\sum_{i=1}^{N} G(i\Delta t)G((i+1)\Delta t) + \frac{1}{N}\sum_{i=1}^{N} G(i\Delta t)G((i+2)\Delta t).$$

Then we calculate the probabilities of the admissible values of the noise $E(t)$, i.e. the values of the noise, within the range of which the damage is considered inexistent, based on the condition $m_{\mathrm{E}} - k\sigma^*_{\mathrm{E},t0} \le \mathrm{E}(t) \le m_{\mathrm{E}} + k\sigma^*_{\mathrm{E},t0}$, where k is the selected coefficient. After that:

− taking into account the condition $m_{\mathrm{E}} = 0$, we calculate the minimum and maximum values of the noise $\mathrm{E}(t)$: $\varepsilon_{min} = -k\sigma^*_{\mathrm{E},t0}$; $\varepsilon_{max} = k\sigma^*_{\mathrm{E},t0}$;

− at a certain step $\Delta\varepsilon$ we set the values of the noise $\mathrm{E}(t)$ in ascending order from ε_{min} to ε_{max}:

$$\varepsilon(1) = \varepsilon_{min},\ \varepsilon(i+1) = \varepsilon(i) + \Delta\varepsilon,$$
$$\varepsilon(i+2) = \varepsilon(i+1) + \Delta\varepsilon,\ \ldots,\ \varepsilon(n) = \varepsilon_{max}, \tag{23}$$

and form a sequence of admissible values of the noise $\varepsilon(1)$, $\varepsilon(2)$, $\varepsilon(3)$, ..., $\varepsilon(n)$, for which the condition $\varepsilon(i-1) < \varepsilon(i)$ is satisfied.

The density function of the normal distribution is calculated:

$$N^*(\varepsilon(i))_{t0} = \frac{1}{\sigma^*_{\mathrm{E},t0}\sqrt{2\pi}} e^{-\frac{(\varepsilon(i))^2}{2(\sigma^*_{\mathrm{E},t0})^2}}.$$

After that, for the time instant t_0, we calculate the probabilities of the values of the noise $\mathrm{E}(t)$ with the mean square deviation $\sigma^*_{\mathrm{E},t_0}$ being in the admissible intervals $\varepsilon(1) \le \mathrm{E}(t) < \varepsilon(2)$, $\varepsilon(2) \le \mathrm{E}(t) < \varepsilon(3)$, ..., $\varepsilon(n-1) \le \mathrm{E}(t) \le \varepsilon(n)$:

$$P_{1,t0}(\varepsilon(1) \le \mathrm{E}(t) < \varepsilon(2)) = \int_{\varepsilon(1)}^{\varepsilon(2)} N^*(\varepsilon)_{t0} d\varepsilon,$$
$$P_{2,t0}(\varepsilon(2) \le \mathrm{E}(t) < \varepsilon(3)) = \int_{\varepsilon(2)}^{\varepsilon(3)} N^*(\varepsilon)_{t0} d\varepsilon, \ldots,$$
$$P_{(n-1),t0}(\varepsilon(n-1) \le \mathrm{E}(t) < \varepsilon(n)) = \int_{\varepsilon(n-1)}^{\varepsilon(n)} N^*(\varepsilon)_{t0} d\varepsilon. \tag{24}$$

The values of these probabilities are entered in the database of informative attributes as reference values corresponding to the fully operational condition of tunnels.

After a certain period of time at the instant t_1 at the points $\varepsilon(1)$, $\varepsilon(2)$, $\varepsilon(3)$, ..., $\varepsilon(n)$, we re-calculate the density distribution function $N^*(\varepsilon)_{t1}$ for the noise $\mathrm{E}(t)$ with the mean square deviation $\sigma^*_{\mathrm{E},t1}$:

$$N^*(\varepsilon(i))_{t1} = \frac{1}{\sigma^*_{\mathrm{E},t1}\sqrt{2\pi}} e^{-\frac{(\varepsilon(i))^2}{2(\sigma^*_{\mathrm{E},t1})^2}}.$$

Then, for the time instant t_1, we calculate the probabilities of the values of the noise $\mathrm{E}(t)$ with the mean square deviation $\sigma^*_{\mathrm{E},t_1}$ being in the admissible intervals $\varepsilon(1) \le \mathrm{E}(t) < \varepsilon(2)$, $\varepsilon(2) \le \mathrm{E}(t) < \varepsilon(3)$, ..., $\varepsilon(n-1) \le \mathrm{E}(t) \le \varepsilon(n)$:

$$P_{1,t1}(\varepsilon(1) \le \mathrm{E}(t) < \varepsilon(2)) = \int_{\varepsilon(1)}^{\varepsilon(2)} N^*(\varepsilon)_{t1} d\varepsilon,$$
$$P_{2,t1}(\varepsilon(2) \le \mathrm{E}(t) < \varepsilon(3)) = \int_{\varepsilon(2)}^{\varepsilon(3)} N^*(\varepsilon)_{t1} d\varepsilon, \ldots,$$
$$P_{(n-1),t1}(\varepsilon(n-1) \le \mathrm{E}(t) < \varepsilon(n)) = \int_{\varepsilon(n-1)}^{\varepsilon(n)} N^*(\varepsilon)_{t1} d\varepsilon. \tag{25}$$

After that, we calculate the difference of the probabilities of the noise $\mathrm{E}(t)$ being in the intervals $\varepsilon(1) \le \mathrm{E}(t) < \varepsilon(2)$, $\varepsilon(2) \le \mathrm{E}(t) < \varepsilon(3)$, ..., $\varepsilon(n-1) \le \mathrm{E}(t) \le \varepsilon(n)$ at the time instants t_1 and t_0:

$$P_{1,t1-t0}(\varepsilon(1) \le \mathrm{E}(t) < \varepsilon(2)) =$$
$$= P_{1,t1}(\varepsilon(1) \le \mathrm{E}(t) < \varepsilon(2)) - P_{1,t0}(\varepsilon(1) \le \mathrm{E}(t) < \varepsilon(2))$$
$$P_{2,t1-t0}(\varepsilon(2) \le \mathrm{E}(t) < \varepsilon(3)) =$$
$$P_{2,t1}(\varepsilon(2) \le \mathrm{E}(t) < \varepsilon(3)) - P_{2,t0}(\varepsilon(2) \le \mathrm{E}(t) < \varepsilon(3))$$
$$\ldots \tag{26}$$
$$P_{(n-1),t1-t0}(\varepsilon(n-1) \le \mathrm{E}(t) < \varepsilon(n)) =$$
$$P_{(n-1),t1}(\varepsilon(n-1) \le \mathrm{E}(t) < \varepsilon(n)) -$$
$$- P_{(n-1),t0}(\varepsilon(n-1) \le \mathrm{E}(t) < \varepsilon(n)).$$

The differences of the probabilities $P_{1,t1-t0}(\varepsilon(1) \le \mathrm{E}(t) < \varepsilon(2))$, $P_{2,t1-t0}(\varepsilon(2) \le \mathrm{E}(t) < \varepsilon(3))$, $P_{(n-1),t1-t0}(\varepsilon(n-1) \le \mathrm{E}(t) < \varepsilon(n))$ the informative attributes of the initiation of defects in tunnels.

Then work is performed to detect the defect, and the values of probabilities (25) and difference of probabilities (26) are saved as reference sets for the occurrence of this type of defect.

After the values of the probabilities have also been obtained at the time instants t_3, t_4, …, t_k, the database of informative attributes takes the form:

$$TS = \begin{bmatrix} \sigma^*_{E,t0} & N^*(\varepsilon(i))_{t0} & P_{1,t0} & P_{2,t0} & \cdots & P_{(n-1),t0} \\ \sigma^*_{E,t1} & N^*(\varepsilon(i))_{t1} & P_{1,t1} & P_{2,t1} & \cdots & P_{(n-1),t1} \\ \sigma^*_{E,t2} & N^*(\varepsilon(i))_{t2} & P_{1,t2} & P_{2,t2} & \cdots & P_{(n-1),t2} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \sigma^*_{E,tk} & N^*(\varepsilon(i))_{tk} & P_{1,tk} & P_{2,tk} & \cdots & P_{(n-1),tk} \end{bmatrix} \quad (27)$$

After the appropriate training, one of the possible technical states of the tunnel is assigned to each line. In this case, a new column with one of the possible states is added to matrix (27):

$$TS = \begin{bmatrix} \sigma^*_{E,t0} & N^*(\varepsilon(i))_{t0} & P_{1,t0} & P_{2,t0} & \cdots & P_{(n-1),t0} & 0 \\ \sigma^*_{E,t1} & N^*(\varepsilon(i))_{t1} & P_{1,t1} & P_{2,t1} & \cdots & P_{(n-1),t1} & 1 \\ \sigma^*_{E,t2} & N^*(\varepsilon(i))_{t2} & P_{1,t2} & P_{2,t2} & \cdots & P_{(n-1),t2} & 2 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \sigma^*_{E,tk} & N^*(\varepsilon(i))_{tk} & P_{1,tk} & P_{2,tk} & \cdots & P_{(n-1),tk} & k \end{bmatrix}, \quad (28)$$

where 0 is fully operational; 1 − operational without damage; 2 − partially operational with minor damage; 3 − limited operational, but the resulting minor damage develops intensively; 4 − non−operational; 5 − pre−emergency; 6 − emergency, etc. depending on the values of probabilities at a given time instant.

In addition to matrix of the technical condition (28), a matrix of the dynamics of damage development is also built, which consists of estimates of the correlation coefficients r^*_{XE} between the useful signal $X(t)$ and the noise $E(t)$ at the time instants t_0, t_1, t_2, t_3, …, t_k. After training, each value of the coefficient of correlation r^*_{XE-t0}, r^*_{XE-t1}, … r^*_{XE-tk} is associated with a certain degree of the dynamics of the failure development: no defect; defect exists but does not develop; defect develops insignificantly; defect develops; defect develops rapidly; defect quickly leads to a catastrophic situation, etc. As a result, we get the following matrix of the dynamics of damage development:

$$DR = \begin{bmatrix} P_{1,t1-t0} & P_{2,t1-t0} & \cdots & P_{(n-1),t1-t0} & r^*_{XE,t1-t0} \\ P_{1,t2-t1} & P_{2,t2-t1} & \cdots & P_{(n-1),t2-t1} & r^*_{XE,t2-t1} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ P_{1,tk-t(k1)} & P_{2,tk-t(k1)} & \cdots & P_{(n-1),tk-t(k1)} & r^*_{XE,tk-t(k1)} \end{bmatrix}. \quad (29)$$

Thus, using matrices (28), (29), it is possible to determine the probability of the initiation of defects in tunnels, as well as to determine the dynamics of the development of these defects over time, which is a prerequisite for determining the probability of transport accidents in tunnels.

VI. Conclusion

Studies have shown that one of the possibilities for identifying the initial latent period of the initiation of damage and defects in tunnels and determining the dynamics of their development is the calculation and analysis of the probabilities with which the nose takes admissible and critical values, as well as the values of the correlation coefficient between the useful signal and the noise. The algorithms and technologies proposed in the paper allow solving both of these problems. The use of the proposed technologies in monitoring and control systems will make it possible to identify damaged sections of tunnels at an early stage, which allows determining the probability of transport accidents.

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References

[1] Aliev T. A., Noise control of the Beginning and Development Dynamics of Accidents, Springer, 2019, 201 p. DOI:10.1007/978-3-030-12512-7

[2] Shvidkyi V.Ya., Gres A.A. Checkup of deformations when tunneling under the runways-in-use of Sheremetyevo airport. Transport construction, 2019, no. 3, pp. 23-25 (in Russian).

[3] Shevchenko A.A., Kobetskiy A.D., Boev A.O. Experience in application of automated systems for monitoring of metro tunnels. Transport construction, 2019, no. 2, pp. 26-28 (in Russian).

[4] Weihong (Grace) Guo, Jionghua (Judy) Jin, S. Jack Hu. Profile Monitoring and Fault Diagnosis Via Sensor Fusionfor Ultrasonic Welding // Journal of Manufacturing Science and Engineering. 2019. Vol. 141, Issue 8, pp. 081001-1- 81001-13. https://doi: 10.1115/1.4043731

[5] Aliev T.A., Musaeva N.F., Suleymanova M.T., Gazizade B.I., Journal of Automation and Information Scien¬ces. 2015, vol. 47(8), no 4, pp.24-40. //DOI: 10.1615/JAutomatInfScien.v47.i8.30

[6] Aliev T.A., Musaeva N.F., Gazizade B.I., Journal of Automation and Information Sciences, 2018, vol. 50, no 6, pp.1-13. DOI: 10.1615/JAutomatInfScien.v50.i6.10

[7] Aliev, T.A. & Musaeva, N.F. & Suleymanova, M.T., Automatic Control and Computer Science. 2018, vol. 52, issue 3, pp. 231–242. DOI: 10.3103/S0146411618030021

[8] Aliev T.A., Musaeva N.F., Journal of Automation and Information Sciences. 2019, vol.51, no.9, pp. 12-23. doi: 10.1615/JAutomatInfScien.v51.i9.20

[9] Aliyev T. A., Musaeva N.F., Rzayeva N.E., Mammadova A.I., Measurement Techniques, Springer, 2020, no 6, pp. 421-430. DOI: 10.32446/0368-1025it.2020-6-9-16

[10] Aliev, T.A., Musaeva, N.F., Rzayeva, N.E., Mamedova, A.I., Journal of Automation and Information Sciences, 2020, vol. 52, no 5, pp. 1-12. DOI: 10.1615/JAutomatInfScien.v52.i5.10

The Perturbed Markov Random Walk Described by the Autoregressive Process AR(1) with Finance Application

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***Abstract*—In this paper, we consider a perturbed Markov random walk described by an autoregressive process AR(1) with finance application. The solution of many management problems is brought to autoregressive process.**

Keywords—autoregressive process, AR(1), Markov walk, finance, R programming language

I. INTRODUCTION

Frequently, the values of a time series are highly correlated with the values that precede and succeed them. This type of correlation is called autocorrelation. Autoregressive modeling is a technique used to forecast time series with autocorrelation. A first-order autocorrelation refers to the association between consecutive values in a time series. A second-order autocorrelation refers to the relationship between values that are two periods apart. A pth-order autocorrelation refers to the correlation between values in a time series that are p periods apart. You can take into account the autocorrelation in data by using autoregressive modeling methods.

II. FORMULATION AND PROOF OF THE MAIN RESULTS

Let $\xi_n, n \geq 1$ be a sequence of independent and identically distributed random variables defined on the some probability space $(\Omega, \mathcal{F}, P)$. It is well known (see, for example, Melfi (1992), Novikov (2008), Zhang and Yang (2010), Saadatmand et al (2016)) that the first-order autoregressive process $(AR(1))$ is defined using a recurrent relation of the form

$$X_n = \beta X_{n-1} + \xi_n, \ \ n \geq 1,$$

where $\beta \in R = (-\infty, +\infty)$ is some fixed number and it is assumed that the initial value X_0 does not depend on the innovation $\{\xi_n\}$.

III. PREPARE YOUR PAPER BEFORE STYLING

Defination **(**Melfi (1992)**).** Let a sequence of random variables $Y_0, Y_1, \ldots$ form a Markov chain in R, a sequence of random variables $Z_1, Z_2, \ldots$ has the property that the conditional distribution of the random variable Z_k for each fixed k, provided that (relatively). $\{Y_i, i \geq 0\}$ and $\{Z_i, i \neq k\}$ depends only on Y_k and Y_{k-1}. In this case the sequence of sums $L_n = Z_1 + \cdots + Z_n, n \geq 1$ is called a Markov random walk.

In particular, from this definition it follows that for any Borel function $f: R \times R \to R$ the sum of random variables $Z_k = f(Y_{k-1}, Y_k)$, $L_n = \sum_{k=1}^{n} Z_k$ is a Markov random walk. Note that the usual random walk described by the sums of independent random variables $\xi_n, n \geq 1$ is a Markov random walk. To make sure of this, it is enough to take $f(x_1, x_2) = x_1 - x_2$ and $Y_k = \sum_{i=1}^{k} \xi_i, (Y_0 = 0)$.

It is known that important problems in the theory of nonlinear renewal for an ordinary random walk were studied in the works of Lai and Siegmund (1977), Lallay (1982), Zhang (1988), Woodroofe (1982), (1990) etc. Internal development of renewal theory and the theory of boundary value problems for random walk, as well as new statistical applications indicate the need to study general concepts (the case of dependent cases of random variables, the case of nonlinear boundaries).

Some aspects of Markov renewal and renewal-reward processes also consider in papers Rahimov et al. (2019), (2020), Aliyev and Khaniyev (2013), Aliyev et al (2015), Aliyev and Bayramov (2017).

Recently, much attention has been paid to the study of nonlinear boundary value problems for Markov random walks described by $AR(1)$ processes (see, for example, Novikov (2008), Rahimov et al. (2015), (2019)). It should be noted that the nonlinear boundary value problems for the Markov random walk have been studied much less than for the ordinary random walk described by sums of independent random variables.

Table 1. Descriptive analyses of S&P and NASDAQ

	Highest:	**Lowest:**	**Difference:**	**Average:**	**Change %:**
S&P500	4,544	2,191.6	2,352.72	3,047	92.73
NASDAQ	15,288	5,398	9,890.10	8,852	183.5

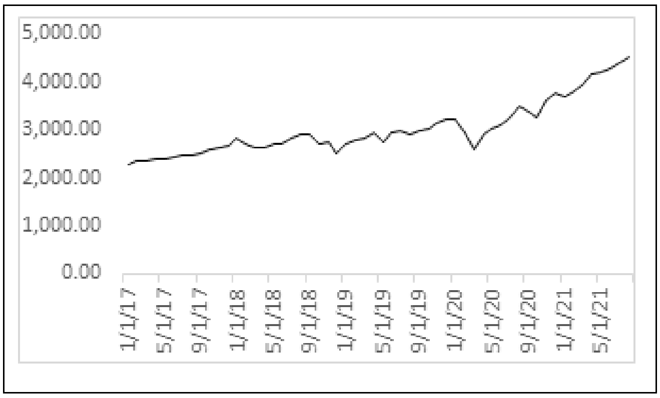

Fig. 1. Price of S&P500 index beetween 01/01/2017-01/08/2021.

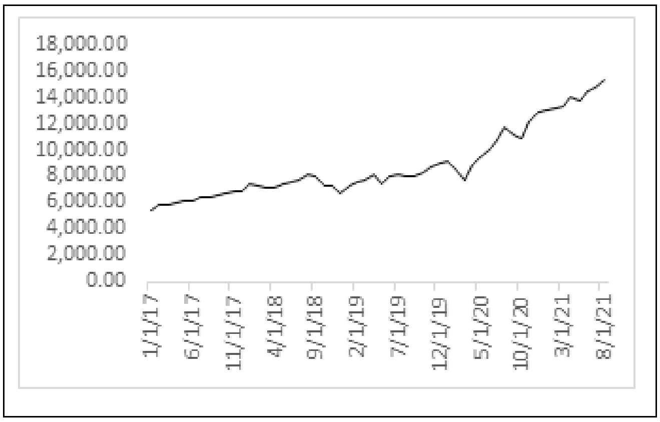

Fig. 2. Price of NASDAQ index beetween 01/01/2017-01/08/2021.

In this paper, we consider a family of moments of the first crossing of a parabolic boundary by a perturbed Markov random walk described by an autoregressive process. The central limit theorem is proved for a perturbed Markov random walk, and the limit behavior of this family of moments of intersection of the parabolic boundary by this walk is studied. The proved Theorem 3 can be used to test the statistical hypothesis for the relationally unknown parameter β of the autoregressive process in a sequential repeated significance test.

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REFERENCES

[1] Aliyev, R., Khaniyev, T. (2013) On the Moments of a Semi-Markovian Random Walk with Gaussian Distribution of Summands. Communications in Statistics - Theory and Methods, 43(1): 90–104.

[2] Aliyev, R., Ardic, O., Khaniyev, T. (2015) Asymptotic approach for a renewal-reward process with a general interference of chance. Communications in Statistics - Theory and Methods, 45(14): 4237–4248.

[3] Aliyev, R., Bayramov, V. (2017). On the asymptotic behaviour of the covariance function of the rewards of a multivariate renewal–reward process. Statistics and Probability Letters, 127: 138–149.

[4] Athreya, K.B., McDonald, D., Ney, P. (1978) Limit theorems for semi-Markov processes and renewal theory for chains. Ann. Probability, 6: 788–797.

[5] Gut, A. (1988) Stopped random walks. Limit theorems and applications. Springe, New York.

[6] Kesten, H. (1974) Renewal Theory for Functionals of a Markov Chain with General State Space. The Annals of Probability, 2, 3: 355–386.

[7] Lai, T. Siegmund, D. (1977) A non-linear renewal theory with applications to sequential analysis I. Ann. Statist, 5: 946–954.

[8] Lalley, S. (1982) Non-linear renewal theory for lattice random walks. Seq. Anal. 1: 193–205.

[9] Melfi, V.F. (1992) Nonlinear Markov renewal theory with statistical applications. The Annals of Probability, 20 (2): 753–771.

[10] Melfi, V.F. (1994) Nonlinear renewal theory for Markov random walks. Stochastic Processes and their Applications, 54: 71–93.

[11] Novikov, A.A. (2008) Some remarks on distribution of the first passage time and optimal stop of AR (1)-sequences. Theoriya veroyatn i ee primen. 53 (3): 458–471.

[12] Rahimov, F.H., Ibadova, I.A., Khalilov, V.S. (2019) Limit theorems for a family of the first passage times of a parabola by the sums of the squares autoregression process of order one (AR (1)). Uzbek Mathematical Journal, №2: 81–88.

[13] Rahimov, F.H., Ibadova, I.A., Hashimova, T.E. (2020) Limit theorem for first passage times in the random walk described by the generalization of the autoregression process. Uzbek Mathematical Journal, 4: 102–110.

[14] Saadatmand, A., Nematollahi, A. R., Sadooghi-Alvandi, S. M. (2016) On the estimation of missing values in AR(1) model with exponential innovations. Communications in Statistics - Theory and Methods, 46(7): 3393–3400.

[15] Shiryaev, A.N. (1996) Probability. Springer.

[16] Shiryaev, A.N. Essentials of Stochastic Finance: Facts, Models, Theory. Word Scientific, 2003, 843 p.

[17] Woodroofe, M. (1982) Nonlinear renewal theory in sequential analysis. SIAM. Philadelphia.

[18] Zhang, C.H. (1988) A Nonlinear Renewal Theory. Annals of Probability, 16(2): 793–824.

[19] Zhang, Y., Yang, X. (2010) Limit Theory for Random Coefficient First-Order Autoregressive Process. Communications in Statistics - Theory and Methods, 39(11): 1922–1931.

[20] G. Eason, B. Noble, and I. N. Sneddon, “On certain integrals of Lipschitz-Hankel type involving products of Bessel functions,” Phil. Trans. Roy. Soc. London, vol. A247, pp. 529–551, April 1955. *(references)*

[21] J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73.

[22] I. S. Jacobs and C. P. Bean, “Fine particles, thin films and exchange anisotropy,” in Magnetism, vol. III, G. T. Rado and H. Suhl, Eds. New York: Academic, 1963, pp. 271–350.

[23] K. Elissa, “Title of paper if known,” unpublished.

[24] R. Nicole, “Title of paper with only first word capitalized,” J. Name Stand. Abbrev., in press.

[25] Y. Yorozu, M. Hirano, K. Oka, and Y. Tagawa, “Electron spectroscopy studies on magneto-optical media and plastic substrate interface,” IEEE Transl. J. Magn. Japan, vol. 2, pp. 740–741, August 1987 [Digests 9th Annual Conf. Magnetics Japan, p. 301, 1982].

[26] M. Young, The Technical Writer’s Handbook. Mill Valley, CA: University Science, 1989.

Navigation Issues Based on Images

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***Abstract*—Unmanned aerial vehicles are effectively used to monitor the transport corridor. The research is dedicated to the provision of autonomous movement during the flight of unmanned aerial vehicles in the transport corridor. For this purpose, some issues of autonomous navigation of unmaned aerial vehicle are considered.he research is dedicated to ensuring the autonomous navigation of unmanned aerial vehicles. To ensure this navigation without the use of GPS, the method of navigation by reference objects encountered in the video is considered. In the research work, the main object of reference is non-dividing, non-intersecting roads in the transport corridor.**

Keywords—unmanned aerial vehicle, navigation, autonomous, invariant, image recognition, transport corridor monitoring

I. INTRODUCTİON

In modern times, unmanned aerial vehicles have a wide range of uses, both in military and civilian conditions. Examples include monitoring of transport corridors, transportation, and so on. The use of unmanned aerial vehicles is one of the most effective methods of monitoring transport corridors. Any transport corridor can change due to both man-made and natural influences. Monitoring of this transport corridor is one of the conditions for safe and effective use of the corridor. One of the such issue is the location, tracking and control of unmanned aerial vehicles. These devices have different navigation methods. Currently, one of the main approaches in this direction is the application of GPS technology. GPS - global positioning system allows to determine the coordinates of the device with high accuracy by receiving electromagnetic signals from the satellite network, working in continuous mode. This technology, which is applied to unmanned aerial vehicles, determines the location of the device and regulates its movement [1].

For autonom navigation of unmanned aerial vehicle (UAV) investigates in [2]. An UAV receives current coordinates from a GPS receiver via a Bluetooth connection with a navigator computer without human intervention. With this point, the optimal trajectory is drawn to the next destination. During the flight, the navigator computer provides information on which direction and how far to turn. This information is used in the servos of unmanned aerial vehicles.

To date, unmanned aerial vehicle navigation techniques have been proposed in three main categories. 1) inertial navigation; 2) satellite navigation; 3) vision-based navigation. Visual-based navigation from these methods provides richer information about the earth's surface and objects than others [3].

It is possible for unmanned aerial vehicles to navigate with GPS in the open air, at an altitude without any obstacles. However, at lower altitudes, where obstacles may be present, this approach is not appropriate. [4] proposed optical flow navigation for autonomous movement of unmanned aerial vehicles in such areas.

During the flight of drones in a given corridor, navigation is carried out mainly by GPS technology. However, in case of any problems with the use of GPS, it is effective to apply the method of navigation based on videoimages. In the presented paper it is proposed a method of navigation based on the images displayed by the camera.

II. PROBLEM STATEMENT

The main disadvantage of the widely used GPS method is that the performance of unmanned aerial vehicles is completely dependent on GPS. Where there is no GPS, there are obstacles to the movement and control of these devices. For this reason, a system is required for unmanned aerial vehicles to navigate autonomously which is not depend on GPS.

Various methods have been proposed to regulate the autonomous navigation of unmanned aerial vehicles without the use of GPS. Some of the methods are shown in the introduction. Other one of such method is vision-based navigation. The main approach in this method is to determine current location of UAV based on observed objects by the device and their coordinates. Observed objects include power plants, roads, bridges, road crossings, buildings and other infrastructure facilities, as well as single trees, steep cliffs, rivers, lakes and other natural objects. The device recognizes these objects and determines its current coordinates and location based on their coordinates. The images and coordinates of the objects must be known in advance. To store this information, a database is created and the parameters of the objects are processed and placed in the database. The image obtained by the device must also be processed. The results obtained are compared with the data in the database to determine which of these objects corresponds to the database. The location of the device is determined based on the coordinates of the image object. It is known that there are always roads in the transport corridor. The problem statement is to develop an algorithm identification of roads - curves, windings in the transport corridor based on vision.

III. PROBLEM SOLVİNG

As noted, important infrastructure, such as reference objects, is used to find location of the device. Roads in the transport corridor are taken such as infrastructure in the research. Thus, the device must take a photo of the earth's surface during flying without GPS. Depending on the road in the image, it must determine its approximate location.

The following approach has been proposed to solve the problem.

To solve the problem, firstly must be known the images and coordinates of all the roads that the device can observe. Certain characteristics are determined by processing these images. These characteristics are placed in the database as a factor indicating the appropriate road. The unmanned aerial vehicle captures video of the earth's surface during the flight, if there are paths in these images, finds them. Relevant features are also determined from the images received by the device, as well as certain features determined from the processing of the images placed in the database. These features are compared with those in the database and the appropriate one is selected.

Through the application of this method, drones can provide autonomous movement on the trajectory without GPS. There are a number of problems here. Images from unmanned aerial vehicles have a number of features. Thus, the device can capture images in different forms: at different distances, at different angles, in different directions and scales. With this in mind, it is necessary to find characteristics that allow to eliminate these problems.

Each of the part of roads can be identified as a curve, because the research is focused curved roads. There are different methods for identifying curves: interpolation polynomials, Bezier curves, etc. However, the B-spline model is chosen to identify the curves in the study. The main reason for choosing this method is that the B-spline is stable invariant to operations such as rotation and scaling. Application of the B-spline method provides invariant identification of curves [5,6,7].

A. *Application of B-spline method*

In this method the given continuous connected curve is divided into several segments. Each segment includes the same number of control points. The displacement of any control point affects only the segment into which this point enters. The procedure for constructing curves with a B-spline is given in (1).

$$Q(u) = \sum_{i=0}^{n} P_i N_{i,k}(u) \quad (1)$$

In this equation:
u is a parameter of the function representing the curve parametri, $u=n-k+2$
n is defined as number of control points -1,
$P_i(x_i, y_i)$ – control points,
$N_{i,k}(u)$ – basis function,
k is the number of points per segment on which the curve is divided and $2 \leq k \leq n+1$ is true for k.

The construction of the B-spline is based on the structure of the basis function $N_{i,k}(u)$. The procedure for setting up basis functions is given in (2).

$$N_{i,k}(u) = \frac{u-t_i}{t_{i+k}-t_i} N_{i,k-1}(u) + \frac{t_{i+k+1}-u}{t_{i+k+1}-t_{i+1}} N_{i+1,k-1}(u) \quad (2)$$

$$t_i = 0,1,2, \dots n+k$$

As can be seen from the structure of the base functions, these functions do not depend on the control points. For this reason, both the road images placed on the base and the curves of the road images received by the device are approximated by the B-spline and control points are determined. The base characteristics of the B-spline are its control points. Control points are placed in the database as a characteristic.

B. *Image processing*

As mentioned, the placement of previously known roads (curves) in the database means the determination and placement of certain characteristics (control points) from these roads. A comparison between curves also means a comparison of their corresponding characteristics. In order to obtain these characteristics from the images and to construct a suitable spline, the image must be processed and separated from the image as a road curve.

As known, the images taken will not consist only of roads. The image will contain unnecessary objects and pixels. Therefore, firstly the images must be cleaned of "dirty" data. Non-informative pixels are discarded by image processing, as it is more efficient to work with images that have only the required number of dots. When it comes to image processing, there are a few steps involved. The steps and sequence of these are shown below.

1) Converting the image to a grayscale image.

Images are given us in color RGB format. Instead of working with different colors, it is better to make the image a single color. The conversion method is given below:

$$0.3R + 0.59G + 0.11B \quad (3)$$

Here, R, G, B represent the red, green, and blue color distribution in the image pixel, respectively [8].

2) Smoothing.

Each image may contain random, unnecessary pixels and a collection of pixels. For example, a shadow, a small object flying outside, and so on. Working with images means working with pixels and their colors. Therefore, these factors are affected and it is advisable to discard them during processing. Using the smoothing algorithm, the image is cleared of "adventitious" pixels.

3) Edges detection of objects on the image.

Defining the edges of objects in the image brings the image to black and white. At this stage, the Canny Edge Detection algorithm is applied. Only black (or white) pixels play an informative role after the application of the edge detection algorithm [9, 10].

4) Extracting object from image.

At this stage, it is required extract the road-curve from the various objects in the image. To do this, using the Connected Component Labeling algorithm, each object in the image is extracted as a separate set of pixels [11]. Of these sets, it is assumed that it represents the required curve which have the most pixels.

C. *Thinning*

At the end of the processing, the image should be in black and white, consisting only of a curve. Despite the processing of the image, the curve in the final image will not be at the desired thinness. It is necessary to thin the thickness of this curve to 1 pixel. After the thinning operation, the number of black dots in the image decreases again. It is important to apply this algorithm. In the last step, the curve in the image should be taken as a sequence of pixels instead of a set of pixels. The construction of this sequence is done by checking the adjacent pixels of each pixel. To build this sequence is

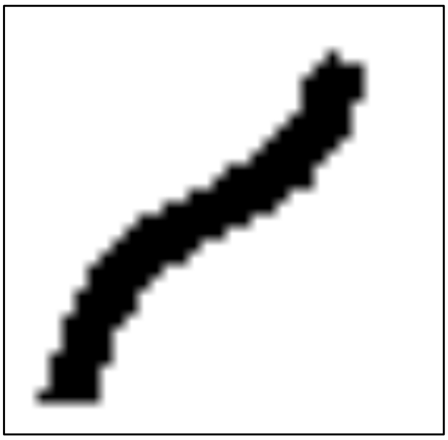

Fig. 2. Given curve

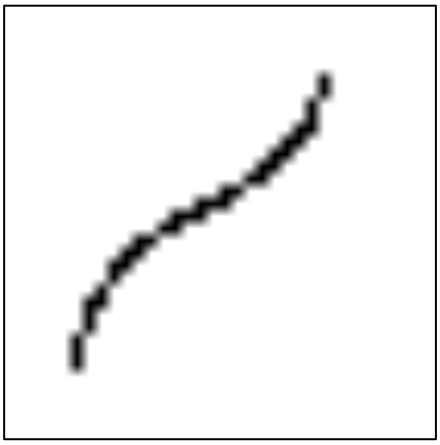

Fig. 1. Curve after thinning algorithm

more difficult and impossible for thicker curves. In the research, Zhang-suen Thinning algorithm is applied to the images [12]. The essence of this algorithm is to study the black neighbours pixels of each black pixel. As a result, the object in the image - the curve is thinned to 1 pixel, and the number of black pixels is sharply reduced. Fig. 1 shows any curve taken. The result obtained after applying the thinning to this curve is given in Fig. 2.

With the adjacent pixel approach, the set of black pixels representing the curve is brought to the pixels sequence. It should be noted that the number of black pixels may be slightly reduced when assembling the sequence. Certain characteristics must be determined in a certain method from the sequence of points obtained. For the B-spline, these characteristics are the control points. Each of these steps applies to known images and the image captured by the drone. The characteristics of the known images are placed in the database and the characteristics of the image received by the device are compared with those in the database. The one that matches the known images is determined. The current position of the unmanned aerial vehicle is determined based on the coordinates and position of this route [13].

IV. CONCLUSION

The proposed method can be used as one of the alternative methods for autonomous navigation during the monitoring of transport corridors by unmanned aerial vehicles.

The advantage of the proposed method is that the device can determine its location without the use of GPS.

There is the long processing of images is the disadvantage side of this method here.

REFERENCES

[1] https://en.wikipedia.org/wiki/Global_Positioning_System

[2] Tae Hyun Kim & Denny Toazza, Navigation Control of an Unmanned Aerial Vehicle (UAV), Bachelor Thesis in Computer and Electrical Engineering, November 2009.

[3] Yuncheng Lu, Zhucun Xue, Gui-Song Xia, Liangpei Zhang, A survey on vision-based UAV navigation, Geo-spatial Information Science, volume-21,2018.

[4] Aasish C, Ranjitha E., Razeen Ridhwan U, Bharath Raj S, Angelin Jemi L., Navigation of UAV without GPS, 2015 International Conference on Robotics, Automation, Control and Embedded Systems.

[5] F.S. Cohen, Zhaohui Huang, Zhengwei Yang, Invariant matching and identification of curves using B-splines curve representation, February 1995, IEEE Transactions on Image Processing 4(1):1 – 10.

[6] Sandeep Pande, Manna Chetty, Position Invariant Spline Curve Based Image Retrieval Using Control Points, August 2019, International Journal of Intelligent Engineering and Systems 12(4):177-191.

[7] Zhaohui Huang and Fernand S. Cohen "Affine-invariant moments and B-splines for object recognition from image curves", Proc. SPIE 1964, Applications of Artificial Intelligence 1993: Machine Vision and Robotics, (11 March 1993).

[8] https://www.dynamsoft.com/blog/insights/image-processing/image-processing-101-color-space-conversion/

[9] J.R.Parker, Alghorithms for Image Processing and Computer Vision, second edition, Wiley Publishing,Inc, pp.21-251.

[10] Reinhard Klette, Concise Computer Vision, An Introduction into Theory and Algorithms, springer –Verlag London 2014, pp. 43-121.

[11] Costantino Grana, Daniele Borghesani, Rita Cucchiara, Connected Component Labeling Techniques on Modern Architectures, Image Analysis and Processing - ICIAP 2009, 15th International Conference Vietri sul Mare, Italy, September 8-11, 2009.

[12] https://rosettacode.org/wiki/Zhang-Suen_thinning_algorithm

[13] Sabziev E.N, Determining the location of an unmanned arial vehicle based on video camera images, Advanced Information Systems, -2021, Vol.5, № 1, - p.136-139.

[14] Tarik Abu-Ain, Siti Norul Huda Sheikh Abdullah, Bilal Bataineh, Khairuddin Omar, A Fast and Efficient Thinning Algorithm for Binary Images, December 2013, Journal of ICT Research and Applications 7(3):205-216.

[15] Lynda Ben Boudaoud, Abderrahmane Sider, Abdelkamel A Kamel Tari, A new thinning algorithm for binary images, Conference: 2015 3rd International Conference on Control, Engineering & Information Technology (CEIT).

[16] Yumin Tan ,Yunxin Li, UAV Photogrammetry- Based 3D Road Distress Detection, International Journal of Geo-Information, 12 september 2019.

[17] Jinqiang Cui, Shupeng Lai, Xiangxu Dong, Ben M Chen, Autonomous Navigation of UAV in Foliage Environment, December 2016, Journal of Intelligent & Robotic Systems 84(1-4).

[18] Muthukrishnan.R, M.Radha , Edge Detection Techniques For Image Segmentation, International Journal Of Computer Science & Information Technology (Ijcsit) Vol 3, No 6, Dec 2011.

[19] Chenfan Sun, Wei Zhan, Jinhiu She, and Yangyang Zhang, Object Detection from the Video Taken by Drone via Convolutional Neural Networks, Mathematical Problems in Engineering, Volume 2020,13 October 2020.

Poster papers

Innovative Information Technologies in the Development of the Transport Industry Education

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***Abstract*—The state of the transport industry education system is considered in the article. It is shown that the training of specialized professionals is one of the objectives of the transport industry education system aimed at increasing the country's competitiveness in the transport service market. This can be achieved by introducing modern innovative information technologies into the transport industry education system.**

Keywords—transport industry education system, innovative information technologies, transport service market, distance learning, network education conglomerates

I. INTRODUCTION

The transport industry education system has proven the relevance and high potential for possible development since its inception and throughout its existence. Transport educational institutions retain their leading positions in the field of industry-specific professional education all over the world.

The transport industry education system requires the need to introduce modern innovative information technologies into its educational process in order to comply with the modern trends, which would allow creating a modernized system for training transport industry personnel. Training of highly qualified specialized professionals in the transport industry education system is one of the main objectives at all levels of professional training of transport educational institutions, which, in turn, leads to an increase in the country's competitiveness in the transport service market.

II. PROBLEM STATEMENT

As noted above, training of highly qualified personnel, who keep up with the times, possess the necessary theoretical knowledge in their field and apply it in practice using modern innovative information technologies, is one of the main objectives of transport industry education.

Modern transport educational institutions produce a large number of specialists, however, various studies [1, 2, 3] show that there is still a shortage of highly qualified personnel in the transport service market. The motivational components for attracting prospective students to this particular area of transport industry education should be:

1. Quality education.

In transport industry educational institutions, appropriate resources should be available in the form of modernized educational and laboratory classrooms equipped with the necessary innovative information technologies in the form of various equipment for training transport service workers. It should be noted here that this should apply to all levels of professional education: secondary, higher, postgraduate and continuing education. Thus, we would get specialized professionals who would be able to work with modern innovative information technologies upon graduation from a transport educational institution, and already working specialized professionals with advanced training or retraining.

2. Subsequent employment.

Transport educational institutions should have statistical data on requests to offer graduates places of possible employment corresponding to their knowledge level, both in the public sector and in the private sector in the transport service market. That is, there should be an interdependent employer ↔ graduate scheme. Studies show that the demand for specialized transport professionals in the transport service market will grow in the future. Graduates of transport educational institutions will always be able to find work in the transport infrastructure: as design engineers for various transport equipment, as design engineers in mechanics, hydraulics, electrical engineering, in logistics companies of various levels, in marketing and freight forwarding services, in the logistical system of wholesale and retail transport equipment and components trade, etc.

III. PROBLEM SOLUTION

Looking at the experience of developed countries, we can see that any upgrade of the transport industry education system today is impossible without introducing modern innovative information technologies [3]. For instance, in the People's Republic of China, the leader in high-speed railway traffic (over 16,000 km of high-speed railway lines are operated in the PRC today), with more than 70 universities producing transport specialists, 37 of them producing railway specialists, the focus is on specialized modernized training centers. These centers provide both training and retraining for transport infrastructure professionals. The Beijing Jiaotong University, one of the leading technological universities of the People's Republic of China, has a center (Fig. 1) with all the necessary innovative information technologies for training various profile specialists in the field of high-speed railways. An electronic library containing materials on the development of high-speed transport in the world was built at the university in 2006.

Fig. 1 The high-speed railway control training center of the Beijing Jiaotong University

As we can see, the modern educational process, in particular, in the transport industry education system discussed in this article, at all its levels is open to the introduction of innovative information technologies—hardware and software designed for processing, storing and transmitting information [4,5,6]. These technologies include computers and telecommunication networks, video and audio tools, various multimedia systems, the use of which in the education system is aimed at supporting the educational process.

One of the new forms of the combined application of these Internet-based innovative information technologies has given rise to the currently widespread distance learning.

The best-known definitions of "distance learning" are as follows:

"distance learning" as a learning process in which "teacher" and "student(s)" are geographically separated and therefore rely on electronic and printed materials to organize the learning process (the definition of the United States Distance Learning Association (USDLA)) [7, p.11];

"distance learning" is a remote education technology, in which teachers and students are physically in different places and use case, TV and network technologies (group of MESI specialists) [7, p.17].

From the definitions, we can conclude that the distinctive feature of distance learning is the possibility of learning remotely, which has become possible today because of the Internet.

The purpose of using distance learning is to increase the availability and quality of education through the use of modern Internet-based information and communication technologies.

The prospects of the development of distance learning are especially clear if we study the indicators of the global market in this area. According to the data and forecast published by Forbes [8, 9], the volume of the world distance learning market reached $107 billion in 2015, and it is expected to rise to $325 billion by 2025.

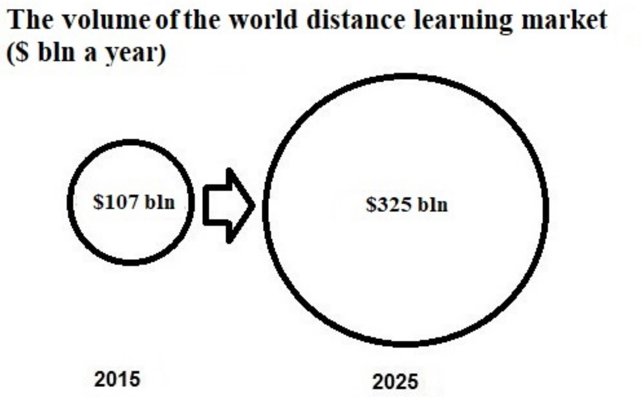

Fig. 2 The estimated volume of the world distance learning market (2015-2025)

The volume of the global distance learning market shown in Fig. 2 is estimated with positive dynamics, indicating a growing demand and prospects for the development of this form of education in the future.

In the transport industry education system considered in this article, distance learning can be used at all levels of professional education: secondary, higher, postgraduate, and continuing education.

Internet-based distance learning in the system of higher transport industry education is designed to improve the performance of the two main motivational components described in the previous section, for the subsequent increase in the number of prospective students in this particular area of industry education:

1. improving the quality of professional education in transport educational institutions;

2. providing professional personnel for the transport service labor market.

Let us single out two advantages of distance learning in the transport industry education system [10]:

1. since distance learning based on modern innovative information technologies connected by the Internet is large-scale, this form of education can be implemented not only within a separate transport industry educational institution, but also within a region, city, country or even between countries of the world, which consequently leads to further integration of national transport industry educational systems into a world system of transport industry education;
2. with distance learning in the transport industry education system, communication can be established not only with other transport educational institutions, but also with any corporate unit of the transport infrastructure, creating the education ↔ production industry cooperation.

These two advantages contribute to the intensive circulation of industry knowledge flows in a single industry information and educational space, which is very important today, given the speed at which information today is created, processed and shared.

This is essentially how distance learning industry network interactions are formed—network education conglomerates, which are classified, in particular, by geographical scope [10]:

- A regional distance learning industry network brings together participants within one region;
- A national distance learning industry network brings together participants in the territory of one country;
- An international distance learning industry network brings together participants in different countries.

Since a distance learning industry network is an open structure, it can be expanded by including new elements in it. A regional distance learning industry network can get the status of an international distance learning industry network by including foreign educational institutions. An example of such a network education conglomerate in the transport industry education system is the Network University for Transport and Logistics of the International Association of Transport Universities of Asian Pacific Countries (IASTU APC) [11].

IASTU APC was established in 2009 and already included 12 transport universities and organizations from Australia, Kazakhstan, PRC, Republic of Korea, Mongolia, Russia, Japan in 2014 [12]. At the moment, the official website of the association lists 31 transport universities from Australia, Vietnam, Indonesia, Kazakhstan, RPC, Republic of Korea, Mongolia, Russia, Uzbekistan, Ukraine [11]. The geography of the members continues to expand every year. The main objective of the association is to work out directions and projects of cooperation in the field of science and education in transportation that meet the current demands of the world community, individual countries and regions, to create and implement intellectual products and services that provide training and retraining of personnel [12].

The Network University for Transport and Logistics of Asian-Pacific Countries operates on the basis of an equal partnership of all universities and organizations that are members of IASTU APC, while the coordinator university carries out the coordination work. The main goals of the network university are: training of highly qualified specialists at Bachelor's, Master's, postgraduate and doctoral levels in transport and logistics; search for and organization of new forms of inter-university cooperation. The Network University makes it possible today to implement a model of open distance learning in the IASTU APC member countries and thereby significantly reduce the cost of educational programs.

The activities of the Network University for Transport and Logistics of Asian-Pacific Countries are carried out in the following order in several main online steps [13]:

- Member universities of the Network University submit educational programs to be included in the integrated database, providing them to the coordinator university in electronic form.
- The coordinator university processes the information provided by the member universities, updating the integrated database of the Network University on the IASTU APC website, placing the programs on the IASTU APC web-site, handling information distribution and maintaining the records related to the activities of the Network University.
- A member university of the Network University interested in the implementation of a joint educational program searches the integrated database to select the appropriate program.
- For the further implementation of the joint educational program, the interested member university contacts the partner university that submits this program for discussion, approval and launching.
- The information on the launched joint educational program is communicated within the Network University by member universities to the coordinator university.

The advantages of the Network University for Transport and Logistics of the Asian Pacific Countries are as follows: a wide range of offered educational programs; the possibility of issuing more than one diploma; production of highly qualified personnel who will be able to work across the entire territory of Eurasia; the opportunity to use the information and communication base of member universities; access to the electronic libraries of member universities; the opportunity to publish research articles and papers in specialized printed publications of member universities [13].

CONCLUSION

Training of highly qualified personnel is one of the main objectives of transport educational institutions aimed at increasing the country's competitiveness in the transport service market. The problem can be solved only if the transport industry education system meets modern professional quality standards. Modern innovative information technologies should be introduced into transport industry educational institutions to provide the educational process with the necessary technical conditions for training, advanced training and retraining of highly qualified specialized professionals in the transport industry. One of these technologies is distance learning, which allows raising the education level through the use of modern Internet-based information and communication technologies.

REFERENCES

[1] Klimenkov A.N. Transport education: problems and development prospects, Vestnik SSTU, 2013. No. 2 (71), pp. 280-282 (in Russian)

[2] Panychev A.Yu. Conditions, prospects and economics of quality of transport education, Vestnik Rostovskogo Gosudarstvennogo Ekonomicheskogo Universiteta, 2015. No. 3 (51), pp. 90-96 (in Russian)

[3] Blazhko L.S., Kiselev I.P. International program of continuing professional education in high-speed railway transport, Transport Rossiyskoy Federatsii, 2015. No. 2 (57), pp. 19-25 (in Russian)

[4] Abdullayeva S.A. Application of innovations in education as an imperative of the times, ANI: Pedagogika i Psikhologiya. 2016. Vol.5 No. 3 (16), pp. 11-12 (in Russian)

[5] Agaev T.A., Jabrailov Z.G., Mamedova M.G. Training of specialists in the field of information technologies in Azerbaijan, Otkrytoye Obrazovaniye, 2010. No. 1, pp. 85-96 (in Russian)

[6] Goreva O.M., Osipova L.B. Prospects for the development of distance learning, Sovremennie Problemy Nauki i Obrazovaniya, 2015 (in Russian)

[7] Polat Ye.S., Bukharkina M.Yu., Moiseyeva M.V. Theory and practice of distance learning, Textbook, Moscow, 2004, 416 p. (in Russian)

[8] Pushnova V.V. Distance learning: current state and prospects for development, Vestnik Astraxanskogo Gosudarstvennogo Texnicheskogo Universiteta, 2020. No. 2 (70), pp. 33-39 (in Russian)

[9] E-learning climbing to $325 billion by 2025 // [Electronic resource], Access mode: www.forbes.com

[10] Mitsuk I.V., Khabarov V.I., Volegzhanina I.S. Management of industry knowledge in the "industry-industry educational institution"

system, Obrazovatel'nyye Tekhnologii i Obshchestvo, 2016. No. 3 (19), pp. 473-491 (in Russian)
[11] International Association of Transport Universities of Asian Pacific Countries (IASTU APC) // [Electronic resource], Access mode: http://iastu-ap.org/network-university/
[12] Guruleva T.A. Single educational space in the APR, Vyssheye Obrazovaniye v Rossii, 2014. No. 12, pp. 134-140 (in Russian)
[13] International Association of Transport Universities of Asian Pacific Countries // [Electronic resource], Access mode: http://en.dvgups.ru/index.php/international-activities/63-international-activities/125-international-association-for-transport-universities-in-asia-pacific-countries

Innovative Development in the Context of Digitalization of the National Economy

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***Abstract*—The article analyzes the development of innovative entrepreneurship in order to ensure the strengthening of market positions in modern competitive conditions, to achieve competitiveness and its sustainable maintenance. Issues of development of innovation entrepreneurship in the Republic of Azerbaijan are considered in the article. Global experience shows that support of innovation development of the economy in developed countries gives positive results. The article analyzes the existing problems in the application of modern innovations in economics and presents suggestions and recommendations for their elimination.**

Keywords—innovation development, investment, technology parks, industry, economy

The processes of globalization accelerated by the development and spread of information and communication technologies at the beginning of the 21th century has a serious impact on the socio-economic life of countries. In the globalized world, the pace of development of economic processes, the spread and application of innovations in the field of production are accelerating. This gives a positive impetus to the impact of globalization and, in turn, allows a country to adopt more advanced technical standards and new management practices.

As a result of vital socio-economic reforms in our country and legal measures taken in parallel to make these reforms sustainable, the effects of the global economic crisis have been reduced to a minimum. The socio-economic policy successfully pursued in recent years in Azerbaijan to ensure sustainable development, as well as the process of diversification of the national economy, which is one of the priorities of this policy, are instrumental in this context. The planned economic programs and investment projects have been and are being successfully implemented. All these processes are closely observed by a number of influential economic centers around the world, and the level of economic development of our state is valued highly. It should be noted that one of the main objectives of the Strategic Road Map, approved by the decree of President Ilham Aliyev on December 6, 2016, is to ensure the innovative development of the non-oil sector. The global financial crises and the decline in world crude oil prices over the past three years, and the growing global pressure on the nature of economic development as a whole have accelerated the development and implementation of several strategic road maps. Thus, the Strategic Road Map for ensuring the promising areas of the national economy covers the years up to 2020, 2025 and beyond 2025 (9).

It should be noted that the successful implementation of the Strategic Road Maps is aimed at ensuring macroeconomic stability, increasing the non-oil sector and export, improving trade and fiscal balance, creating a favorable business environment and attracting investment in economic sectors, continuously improving infrastructure, creating innovative new industries and improving the social wellbeing of the population, as well as at strengthening the position of our country in international rankings.

An analysis of the scientific and technical policy of developed countries in recent years shows that strengthening the interrelation of science, production and social life is the main objective of public policy for these countries, as well as the basis of a new type of economy. This is considered innovative economy. It should be noted that innovative economy has been successfully developing in the European Union for the last 25-30 years. The role of innovative entrepreneurship in these processes is also significant. Innovative economy does not mean only the economic processes that systematically use the achievements and results of constantly evolving science. This is essentially a system of economic relations in which scientific and intellectual capital consists of a large and significant part of the available funds of the economic system, corporate entities and economic entities. In general, the main "center of gravity" in an innovative economy is scientific knowledge, intellectual capital, engineering processes, as well as innovation infrastructure. It should be borne in mind that these are the main components of ultimately ensuring economic growth (1, p.254).

According to the Global Center for Digital Business Transformation, "if the digital revolution does not undergo digital transformation in the next five years, 40% of the world's leading companies in the field will be driven out of the market." In order to effectively adapt to the ongoing changes, it is expedient to study them in depth and identify new global challenges, and adequately address them in the future. Otherwise, they can lead to irreversible consequences for businesses, the labor market and society as a whole. Taking these changes into account, experts estimate that about 50% of the professions that exist today may disappear in 2025-2030. The professions of the future will require from people more innovation, agility, mobility and more advanced social skills (2).

As a result of changes in the external environment in modern times, the areas of the digital economy that are important for business play a more important role. First, ways must be explored to remove barriers to company's entry into one market or another. As we know, globalization is intensifying competition, and as a result, physical distances are no longer considered an obstacle. Second, the company dictate has been replaced by the consumer dictate, and companies have fewer opportunities to manipulate consumers. Even the most professional marketing cannot neutralize negative feedback about the product on the internet, and the business becomes forced to restructure its strategy in the light of these new realities. Third, if in the past the decision on the location of the project implementation was often determined by geographical distance: the idea, as a rule, was developed at the place of origin, and then implemented. In the setting of digitalization of the economy, the idea is usually implemented where there are more favorable conditions for innovation activity. Fourth, the digitalization of the economy requires forming and adopting new managerial decisions: new methods of assessing economic efficiency, as well as the value of organizations that produce material products or provide intellectual services, create intellectual products, and so on.

The efficiency of production is the main category of market economy, which is directly related to the achievement of the end goal of social production, the development of each enterprise as a whole. The essence of improving the economic efficiency of production is improving the economic results per item of expenditure in the process of using available resources. At present, one of the main functions of the socio-economic development program of our country is to increase its global competitiveness, which is an integral condition for the transition of the economy to innovative development.

Evaluation of economic efficiency of business activity as part of economic analysis is an indicator of the most important aspects of the economic activity of an organization. When analyzing the evaluation of the efficiency of an enterprise in our country, in most cases, financial indicators are taken as the only benchmark of its activity. Most economists believe that it is necessary to measure efficiency with a comprehensive indicator, but there is currently no generally accepted system of indicators for evaluating efficiency. For this reason, the criteria may vary from enterprise to enterprise.

To achieve and maintain competitiveness, an organization must be constantly seeking and implementing innovations, while retaining the advantages it has gained. Only this factor will strengthen its market positions in the current conditions of growing competition. Thus, the role of innovation in the modern world is growing significantly, because it is impossible to produce competitive highly science-intensive and innovative products without it.

To evaluate the efficiency of innovation, it is advisable to apply an integrated approach to modernization. Modernization creates conditions for the production of new products, opens opportunities for the unhindered production of innovative products. Modernization also helps to improve the quality of finished products using more modern technologies. The complex mechanism of innovation activity within the modernization program affects all elements of modernization, i.e., the formation of a team authorized to implement the program, reconstruct, develop and apply new technologies and the formation of financial resources. The efficiency of this mechanism is that the formation of competitiveness is carried out independently at each stage (3).

One of the methods of increasing efficiency that combines all the results is the development of innovation activities. Creating innovative products and technologies, equipment upgrades will allow many enterprises not only to build a modern range of products, but also to improve the quality and presentation of products. This will increase the competitiveness of the country's products in both domestic and foreign markets.

In the context of the growing role of modern knowledge and information, the integration of Azerbaijan into the world economic community, the strengthening of interaction between capital markets and new technologies makes the transition of the country's economy to innovative development, expansion of innovative entrepreneurship even more important.

The directions and methods of transition of the national economy to innovative development can be formulated only taking into account the key specific features of the country, including its unique natural resources, production and scientific and technological potential. Strategic and tactical measures in the field of innovation can be developed only scientifically. Therefore, it is first and foremost necessary to study scientific theoretical and conceptual approaches to ensuring the institutional directions of innovation-oriented economic development. Modern ICT, various innovation systems including key innovations, have recently become one of the important conditions for the socio-economic, cultural and intellectual growth of any state, indicating the overall level of development and potential. We should bear in mind that by formulating economic development strategies on the basis of science and technology, the states that consider innovative development to be an important guarantee of the state-building process occupy leading positions in the world (4, p.140).

President of the Republic of Azerbaijan Mr. Ilham Aliyev continues the socio-economic development of the country at the level that meets modern standards. The purposeful policy pursued by Mr. President to ensure that most of the proceeds from the sale of oil and gas products for export to international markets is directed to human capital is being successfully continued. In the example of Japan, Singapore, Malaysia, South Korea, it is safe to say that science and education, the potential of highly qualified personnel are the main guarantee of sustainable socio-economic, cultural and intellectual development of any country. It should be noted that due to the importance of intellectual potential and the dividends it brings, it now surpasses even the richest natural resources. In order to continue economic competition compared to developed countries, it is important to focus primarily on education, extensive knowledge, information technology, innovation economy, as well as the successful innovative entrepreneurship (5).

If we analyze the number of industrial enterprises specializing in the application of innovations across all types of property in the Republic of Azerbaijan on the basis of annual statistics, we can see that there have been significant changes in this area recently (Fig. 1). For instance, if in 2015 the number of industrial enterprises operating in our country on all types of property was 2,583, in 2018 and 2019 the figure grew to 2,837 and 3,169, respectively (8). All this growth process is due to the continuous development of enterprises in the non-oil sector in our country, the increased investment in industry, the expansion of export opportunities of industrial enterprises and private innovative entrepreneurship.

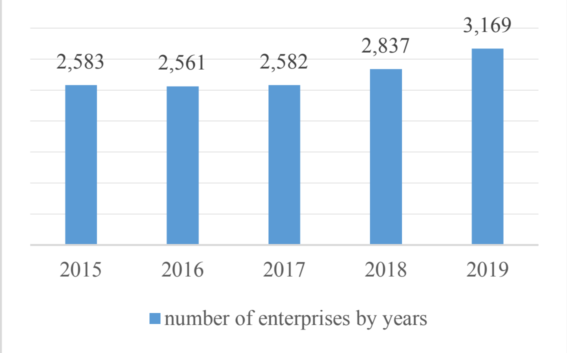

Fig. 1. Number of industrial enterprises operating in the Republic of Azerbaijan across all types of property (by types of property)

TABLE I. VOLUME OF INNOVATION PRODUCTS ACROSS ALL INDUSTRIES, BY LEVEL OF INNOVATION AND TYPE OF ECONOMIC ACTIVITY, THOUSAND MANATS

Year	2016	2017	2018	2019
A product that has undergone significant changes and is newly introduced	35,746.9	14,676.7	28,952.2	21,698.1
Improved product	540.9	383.8	855.3	3,905.9

An analysis of statistical data shows that there have been significant changes in the level of innovation in recent years in Azerbaijan in all industries and the volume of innovative products produced by innovative entrepreneurs by type of economic activity (Table 1). For instance, if the volume of newly introduced products that have undergone significant changes in industrial enterprises in 2016 was 35,746.9 thousand manat, in 2018 and 2019 this figure decreased to 28,952.2 and 21,698.1 thousand manat, respectively. The main reason for the decline is the decrease in the production of innovative products by innovative industrial enterprises in the regions, including the decrease in the exports of manufactured products. In 2016, the manufacture of innovative and improved products by industrial enterprises amounted to 540.9 thousand manat, whereas in 2019 this figure increased several times and amounted to 3,905.9 thousand manat (8). The main reason for this is the growing demand for innovative products in domestic and foreign markets.

Due to the rapid development of science and technology in the recent years, as well as the ever-increasing demand of society for these innovations, the application of modern innovation processes in economy is becoming a key priority for more innovative entrepreneurship. The experience of developed countries shows that the need to develop innovative entrepreneurship is determined by a number of factors, including: the defining role of science in improving the efficiency of the development and application of modern technologies; the need to significantly reduce the time of the formation and adoption of modern innovative technologies, to increase the technical level of production; the increase of expenses of enterprises during the development of new products by innovative entrepreneurs; rapid obsolescence of equipment and technology; the need for rapid introduction of new innovative technologies, etc. The experience of post-Soviet countries shows that innovative entrepreneurship as a process can be divided into four main components. These include: the search for modern ideas, innovative discoveries and their application in the production process; organization of efficient business plans for the developed idea; search for the required capital resources; implementation of management and control processes, etc. (6, p. 541).

In modern times, transport connects the two separate sectors of the national economy, agriculture and industry, making the country's economy a single whole.

An economy of the 21st century requires every country to produce competitive, specialized products for the world market, while the transport sector requires vehicles with high load capacity and intensive movement capacity. From this point of view, competition in all spheres of transport in the world is based on the implementation of transportation of heavy cargo over long distances in a short period of time.

The development of transport in the world not only involves the transportation of goods and passengers, but is also of great economic importance in terms of the employment of hundreds of millions of people in the transport sector, the inclusion of rich natural resources on land and in water basins in the production cycle, settlement of the population, the formation of cities, towns and villages, and in the development of industrial and transport hubs, including ports.

From this point of view, a successful economic policy that ensures the rapid development of the economy in our republic, leading to sustainable stability, progress and growth, has launched a qualitatively new stage in the development of road infrastructure of our country by creating favorable conditions for the development of the transport sector, as in all other areas. In this context, efficient regulation in the transport system has become an important necessity to ensure the rapid, safe and quality implementation of the rapidly developing national economy and dynamically growing transportation needs of the society in our country.

The transport sector, which occupies a special place in the rapid and all-round development of the national economy, covers the activities in the production, distribution and consumption of goods and services, and plays an undeniable role in all economic activities. According to the latest World Bank reports, the share of transportation costs in the initial price of the product is currently 5% in developed countries, 4.25% in developing countries, and an average of 4.8% worldwide. In particular, the annual volume of the Asian transport market alone is about $200 billion. Thus, the reduction of transportation costs and the consequent reduction of the cost of delivery of manufactured goods to consumer markets results in increased competitiveness and development of other sectors of economy, including industry and the national economy.

In this regard, it is very important to coordinate and analyze the transport areas from a modern point of view in order to determine the place of the Republic of Azerbaijan in the world economy and integration processes with other countries. Azerbaijan, who occupies a central position among the Eurasian countries, has a favorable transport system, which creates a favorable basis for the implementation of efficient economic relations, meeting the global interests. At the same time, the restoration of the historic Silk Road is vital for the implementation of the TACIS (Technical Assistance to the Commonwealth of Independent States) and TRACECA (Transport Corridor Europe-Caucasus-Asia) programs. (7)

Taking into account the important role of Azerbaijan's transport system in international integration, by establishing the economic efficiency of rail, sea, road, pipeline, air and river transport, the characteristics and capacity of transport hubs in modern conditions are studied, the transport system of the republic is analyzed by economic regions, specific features of each economic region are determined, the efficiency and potential of transport in domestic and foreign cargo transportation are evaluated. The transport system entering a new stage of development after gaining independence, the completion of reforms in the transport sector has created a favorable stimulus for the formation of a uniform transport policy.

In order to attract transit cargo to the Middle Corridor in the competitive environment created by neighboring transit corridors, it is important to improve the efficiency of the corridor, regularity of transportation, optimization of tariffs and, most importantly, simplification and harmonization of regulatory and customs procedures. Digitalization of the Middle Corridor is the most important tool to ensure transparency in transit traffic and equal conditions between participants in the transport process.

As a result of the liberation of our lands by the Azerbaijani Army as a result of the 44-day civil war under the leadership of President, Supreme Commander-in-Chief Ilham Aliyev, ample opportunities have opened up for the successful promotion of transport corridors through the country's territory. Azerbaijan is the initiator of a number of important international projects in the region, including the Baku-Tbilisi-Kars railway. Our country plays an active role in the development of international transport corridors, which have a significant impact on international transport and the expansion of multimodal infrastructure.

Innovative small business has significant opportunities for the effective application and development of innovative technologies. In this regard, small businesses have the ability to adapt to changes in the market environment, so they can use innovative technologies for a long time. Innovations in small-scale production processes do not require large financial investments and operating costs. That is why the operational efficiency of management by small business structures allows for the rapid improvement and application of new technologies. The risk of losses in the process of transition to new production areas is also relatively low because of the small volume of production in the activities of innovative businesses.

It should be taken into account that innovative business entities ensure the commercialization of the creative activities of innovators. From this point of view, innovative entrepreneurship also carries out activities for the development and application of new technologies, equipment, goods and services in order to make a profit. In the conditions of modern market economy, small innovative enterprises are the most efficient subject of economic activity of innovative entrepreneurship. These enterprises play an important role in the introduction of new innovative technologies (7).

When introducing modern innovations, it is important to study and evaluate the scientific-technical, organizational-managerial, financial, legal, political, socio-psychological and cultural factors that accelerate the innovation process. Although innovative small businesses have unlimited resources, they have traditionally played an important role in the implementation of various areas of scientific and technological progress. In general, the main results obtained from the application of the mechanism of development of innovative entrepreneurship can be shown as follows: increased number of innovative small enterprises; new jobs; increased innovation potential of the regions; increased share of budget revenues from the export of innovative products; increased indicators of the output of innovative products; rapid renovation of fixed production assets of small innovative entrepreneurship entities, etc.

CONCLUSION

In order to achieve competitiveness and maintain it, in addition to maintaining the advantages, an organization also has to strengthen its market positions in the modern context of growing competition in the process of continuous search and introduction of innovations. Using an integrated approach to modernization in order to assess the efficiency of innovation, it is possible to achieve the introduction of modern technologies, improved quality of finished products and, consequently, competitiveness.

Expansion of innovative entrepreneurship in our country is one of the important components of the economic policy being pursued. It is in this direction that extensive measures should be taken, such as the development of state-entrepreneur relations, improvement of the state regulation system, legislation and administrative procedures related to the business environment, the development of innovative entrepreneurship in the regions, further improvement of state support mechanisms for such entrepreneurship.

State support to the development of innovative entrepreneurship in Azerbaijan, along with other measures, should serve to attract young entrepreneurs to this field, to create favorable conditions for the implementation of business opportunities, to meet the needs for financial resources of small and medium entrepreneurs.

REFERENCES

[1] Shakaraliyev A.S. Economic policy of the state: A triumph of sustainable and continuous development, Baku. University of Economics, 2011, 365 p. (in Azerbaijani)

[2] Dovydova O.G. Innovations as a factor of increasing the efficiency of industrial enterprises in the context of the digitalization of the economy. UO "Belorusskiy Gosudarstvennyy Ekonomicheskiy Universitet", Republic of Belarus, Minsk (in Russian)

[3] Nekhorosheva, L.N. Changing the innovation landscape in the context of the formation of Industry 4.0: new threats and priorities / (in Russian)

[4] Digital transformation of economy and industry: problems and prospects. Monograph. Ed. Prof. A.V. Babkin, Doctor of Economics.-SPb: Izdatel'stvo Politekhnicheskogo universiteta, 2017, pp. 29-50. (in Russian)

[5] Babashkina A.M. State regulation of the national economy. Moscow: Finansy i Statistika, 2017, 254 p. (in Russian)

[6] Aliyeva A.A. Increasing the competitiveness of industrial enterprises in a market economy. Transactions of ANAS (Economics series), Baku: Elm və Bilik, 2019, No. 1, pp. 101-108 (in Azerbaijani)

[7] H.V. Isakov. Participation of the Republic of Azerbaijan in the restoration of the “Great Silk Road”, Baku, Şərq-Qərb, 2011, 284 p. (in Azerbaijani)

[8] World Economy (edited by A.S. Bulatov) Moscow: Yurist, 2018, 734 p. (in Russian)

[9] Abdullayev K.N. The main characteristics of innovative development of the national economy // Tikintinin Iqtisadiyyatı və Menecment (Scientific-practical journal), Azerbaijan University of Architecture and Construction, Baku, No. 1, 2020, pp. 159-162. (in Azerbaijani)

[10] https://www.stat.gov.az/source/industry/?lang=en

[11] https://static.president.az/pdf/38542.pdf (in Azerbaijani)

Corrosion Inhibition of Carbon Steel in Formation Water Imitate by Electrochemical Method

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***Abstract*—For the first time the effect of the inhibitor "MARZA-1" on the corrosion rate of steel in the MI water formation imitate was studied. Corrosion rate is measured by taking polarization curves. It was found that the investigated inhibitor "MARZA-1" effectively slows down both cathode and anode reactions in the presence of hydrogen sulfide in the model formation water MI.**

Keywords—potentiostat, electrode potentials, corrosion rate, inhibitor, formation water, hydrogen sulfide, steel

I. Introduction

Metal corrosion causes enormous harm to many industries, primarily to oil and gas production and processing enterprises. This is explained by the aggressive properties of corrosive environments while oil producing, which are conditioned with the presence of a large amount of mineralized water, hydrogen sulfide and sulfate-reducing bacteria, as well as carbon dioxide in them.

One of the most economical and effective methods of protecting metals is associated with the use of corrosion inhibitors [1].

Inhibitors are used at all stages of processing, transportation of oil, gas and petrochemical products in these industries. The protection of metals from corrosion by inhibitors is based on the property of certain specific chemical compounds or their mixtures to reduce the rate of the corrosion process or completely suppress when they are introduced in insignificant concentrations into a corrosive environment. In this regard, the problems of studying corrosion processes and measuring the corrosion rate by taking polarization curves become urgent. An increase in the reliability of equipment can be achieved by carrying out anti-corrosion treatment of pipeline systems [2].

Electrochemical methods for studying the process of corrosion of steel samples, which consist of the removal of polarization curves on a potentiostat are known. Curves graphically reflecting the dependence of the anode and cathode currents on the potential are called polarization curves [3]. The stationary state of the system corresponds to the value of the potential at which the condition of equality of the anode and cathode potentials is satisfied.

The assessment of the fundamental possibility of electrochemical corrosion is made by the magnitude of the corrosion element EMF, which is equal to the difference in the equilibrium potentials of the conjugated electrochemical reactions. It is convenient to represent the kinetic characteristics of corrosion processes graphically in the form of a set of polarization curves of cathode and anode processes. At the same time, the potentials of anode and cathode processes are plotted along the abscissa axis, the voltage of the corresponding anode and cathode currents is plotted along the ordinate axis, or a semi -logarithmic dependence is plotted in the coordinates "potential-lg current density".

Judgment about the real rate of the corrosion process can be obtained from the kinetic dependences of the anode and cathode reactions. Cathode and anode polarization curves are recorded directly on the sample, the corrosion of which is being studied. The intersection point of the anode and cathode polarization curves determines the corrosion rate on the abscissa axis, and the stationary potential on the ordinate axis. Since near the stationary potential the polarization data cease to fit into a semi- logarithmic dependence, the corrosion rate is usually found from the intersection point of the extrapolated rectilinear curves [4]. The value of the stationary (corrosion) potential always lies between the values of the equilibrium potentials of coupled reactions. The general corrosion rate is expressed by the current per unit area of the entire metal surface (current density) without dividing it into cathode and anode sections. The corrosion rate depends, inter alia, on the mechanism of anodic dissolution of the metal and the cathode reduction of the oxidant, and thus can be calculated depending on the relative position of the polarization curves [5].

The graphical method for calculating the corrosion rate allows, in contrast to the analytical method, to calculate the corrosion rate for complex cases corresponding to the real conditions of the corrosion process.

The aim of this work is to measure the corrosion rate by taking polarization curves.

II. Experimental Technique

To study inhibitor action mechanism of the hydrogen sulfide corrosion of steel MARZA-1, a potentiostatic method for measuring polarization curves was used.

Polarization measurements were carried out on a stationary electrode reinforced with epoxy resin cured by polyethylene polyamine, having a working area of 0.36 cm2 in a potentiostatic mode (potentiostat P-5827 m) in a three-electrode cell with separate cathode and anode spaces. Electrode from comparise in is auxiliary silver chloride - smooth platinum. The potentials are recalculated according to the normal hydrogen scale (NHS) atmosphere - air.

The inhibition coefficients of the anode (γ_a) and cathode (γ_k) electrode reactions were calculated at a shift from E_{cor} by 20 mV according to the formula (1).

$$\gamma_j = \frac{i_j^0}{i_j} \qquad (1)$$

where, i_j^0 and i_j - are the densities of the anode or cathode current in the absence and presence of an inhibitor, respectively. Polarization was carried out from the cathode to the anode region with a holding time of 30 s at each potential.

A simulated formation water MI was used as a background solution to perform corrosion tests. Before testing, the samples were washed with distilled water, then placed in a 500 ml beaker so that the selected area was completely immersed in the MI formation water imitator.

III. Experimental part

Analysis of potentiostatic curves showed, the MARZA-1 inhibitor predominantly slows down the anode process that in the presence of low concentrations of H_2S (50 and 100 mg / l) (Fig. 1).

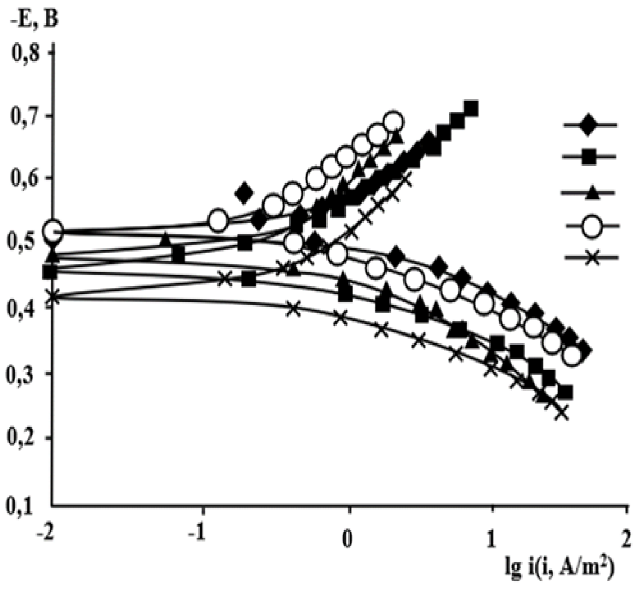

Fig. 1. Potentiostatic polarization curves on S_T3 steel in imitation of MI formation waters, with the addition of hydrogen sulfide (50 mg / l), without (1) and in the presence of the inhibitor MARZA-1 mg / l; 3.0 (2); 5.0 (3); 7.0 (4); 10.0 (5)

Increase in hydrogen sulfide concentration up to 400 mg / l leads to the fact that, at a concentration of 5.0, 7.0 and 10.0 mg / l, MARZA-1 inhibits both electrode reactions, and at a concentration of 3 mg / l, only anodic, in the absence of influence at the cathode (Figure 2).

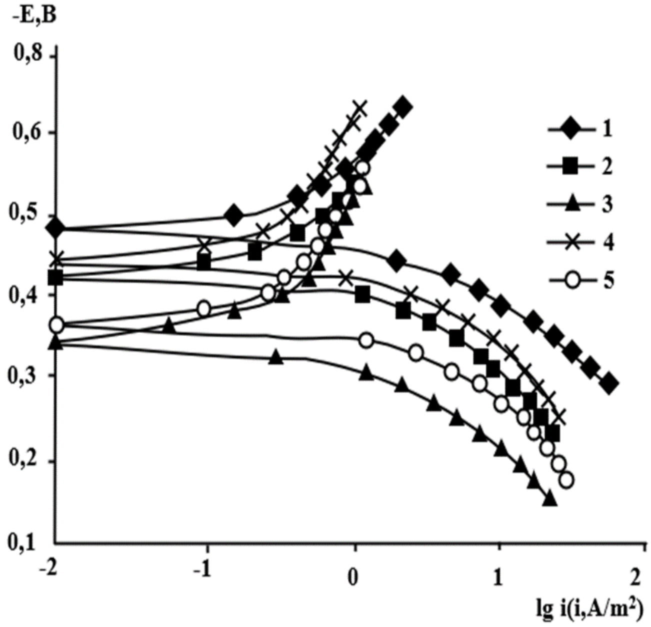

Fig. 2. Potentiostatic polarization curves on S_T3 steel in imitation of MI formation waters, with the addition of hydrogen sulfide (400 mg / l), without (1) and in the presence of the inhibitor MARZA-1 mg / l; 3.0 (2); 5.0 (3); 7.0 (4); 10.0 (5)

The introduction of CO_2 does not significantly change the picture, and the nature of the dependence remains the same (Fig. 3)

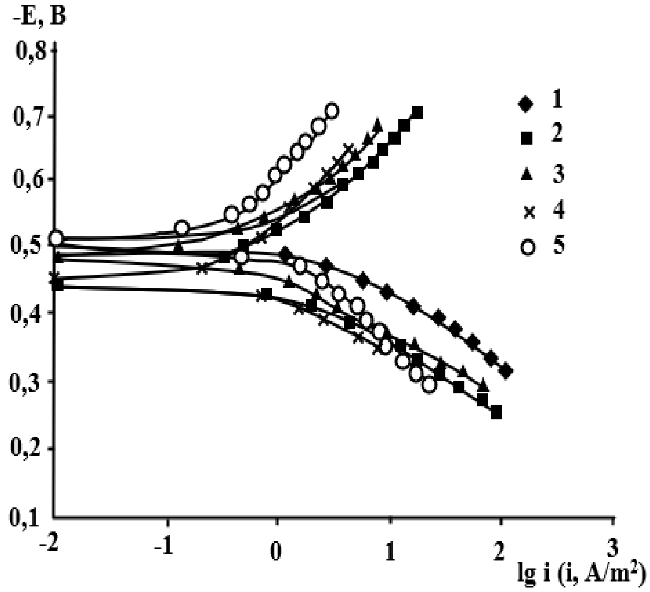

Fig. 3. Potentiostatic polarization curves on S_T3 steel in imitation of MI formation waters, with the addition of hydrogen sulfide (400 mg / l) and carbon dioxide (1 atm.), without (1) and in the presence of the MARZA-1 inhibitor mg / l; 3.0 (2); 5.0 (3); 7.0 (4); 10.0 (5)

IV. Conclusion

1. The inhibiting efficiency of a reagent called "MARZA-1" in relation to hydrogen sulfide corrosion of steel in model formation water MI was studied by electrochemical methods (by taking polarization curves).

2. It was found that the investigated inhibitor "MARZA-1" effectively slows down both cathode and anode reactions at the electrode in the presence of hydrogen sulfide in the model formation water MI.

References

[1] *Damaskin B.B., Petriy O.A., Tsirlina G.A. Electrochemistry. Moscow: Chemistry, Kolos, 2006.672 p.*

[2] Baranov A.N., Mikhailov B.N. Protection of metals from corrosion. Irkutsk: ISTU Publishing House, 2012, 152 p.

[3] Yanyushkin A.S., Arkhipov P.V. Atomic-molecular processes in the ion of the diamond wheel and the processed material. Metal technology. 2010. No. 1, p.25-33.

[4] Baranov A.B., Yudin A.N., Yanyushkin A.S., Rychkov D.A. A method of obtaining a combined chrome coating: US Pat. 2459018. Rus. Federation publ. 08/20/15. Bul. No. 23.

[5] Anufriev I.G. Accelerated method for assessing the corrosivity of acid solutions in relation to low-carbon steel // Corrosion: materials, protection, 2010, No. 1, pp. 44-48.

The Mathematical Descriptions of the Natural Gas Phase State in Nozzle Separator System

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***Abstract*—The article presents the mathematical descriptions of liquid –gas phase ratios in the nozzle separator systems at the primary gas treatment unit. When compiling the mathematical descriptions, the following conditions shall be met: double-phase gas passing through the separator unit; unchanged amount of gas at all points of the gas treatment unit; stability of pressure decrease on technological lines; solution of material balance equation of gas and liquid phases; the heat on the walls of the pipes and equipment is taken into account. A formula is given to determine the quantity and the density of the liquid phase separated from the gas phase.**

Keywords—nozzle, separator, liquid-gas flow, equilibrium, temperature, pressure, mathematical recording, gas consumption, humidity, material balance, heat balance

I. INTRODUCTION

Determining the effectiveness of the process of separation of gas is of great importance. The efficiency of the separation process depends on many factors, as well as on the structure of the gas-liquid flow into the separator, the phase ratio, the speed, the amount and temperature of free liquid so on. In this regard, the study of the mathematical description of gas-liquid systems is of practical importance. Currently, the mathematical descriptions of gas-liquid systems are well developed. However, it shall be noted that before entering the gas treatment facilities, the gas passes through the regulating nozzles, where the temperature decreases due to the pressure drop, and the vapor liquid components in the gas phase become condensed. This liquid is separated from gas in collectors and pipes upstream of the separator. At present, this is not taken into account when calculating the separate devices in the process of designing gas treatment units. This is proved by our research to determine the effectiveness of technological equipment operating systems at gas-condensate fields[2].

II. EXPERIMENTAL TECHNIQUE

The article considers the mathematical recording of the liquid-gas ratio in the nozzle separator system in primary gas treatment units for the processing of gas produced from the fields.

The following conditions have been considered for the purpose of mathematical recording:

- the two-phase gas-liquid state of gas passing through the separator unit;
- unchanged amount of gas consumption in all facilities of gas distribution unit;
- Stability of pressure drop along the technological line of gas distribution unit;
- solution of equation of material balance in case of theoretical equilibrium of liquid and gas phase;
- not considering the heat accumulated on the walls of pipes and equipment.

Effective operation of a nozzle separator system depends on gas pressure and temperature drop.

The principle of operation of the separation process is mainly based on the phase change of the gas-condensate mixture depending on the change of system parameters (p, t). As a result of lowering the gas temperature at a constant pressure, some of the heavy hydrocarbons enter the liquid phase. Thus, the condensation rates of the components are inversely proportional to their equilibrium constant.

It is known that the equilibrium constant of the gas mixture and the separate components depends on the pressure [1-3].

When the natural gas flow enters the nozzle separator system, liquid phase contains pentane and hydrocarbons of higher molecular weight $q_{C_{5+}}$), water in gas flow q_{H_2O} , inhibitors (metanol) q_{me} injected to the gas flow for prevention the formation of hydrates.

As it is known, after the natural gas passes throttle, the phase equilibrium changes, resulting in passing some components in the gas phase into the liquid phase, allowing additional fluid separation in the separator [4].

III. EXPERIMENTAL PART

Suppose that the composition of the gas entering the nozzle separator is known, then the molecular density of the 1st hydrocarbon component in the liquid is determined by the following equation:

$$x_i = \frac{x_{0i}}{k_i - (k_i - 1)L} \qquad (1)$$

Where x_i -is the molar portion of component *i* in the liquid phase; x_{0i} — molar portion of component *i* before gas parameter values change; k_i- equilibrium constant of component *i* in case of equilibrium; L-molar portion of the fluid phase.

Equilibrium coefficient k_i is defined by the following expression :

$$k_i = f(p_s, t_s, x_1, x_2, \dots x_n) \qquad (2)$$

Here, p_s, t_s - are the values of pressure and temperature in the separator.

Then, the molar density of the component *i* of hydrocarbons in the liquid phase will be as follows:

$$q_{im} = x_i GL = \frac{x_{0i} GL}{k_i - (k_i - 1)L} \qquad (3)$$

Here, G is the mass of liquid hydrocarbons.

The expression (3) will be written for the density of hydrocarbon components

$$q_m = \sum_{i=1}^{n} q_{im} \qquad (4)$$

The expressions (3) and (4) are for the weight density

$$q_q = \sum_{i=1}^{n} q_{im} M_i \qquad (5)$$

Very few of the hydrocarbon components of the gas contained in the water as a component of gas do not damage its total volume V_1, and this is not considered in the calculations. However, since some of the hydrocarbon components in the gas have passed into the liquid phase, the amount of gas V_2 entering the separator is calculated by the following formula:

Here M_i — is the molar mass of *i* component.

$$V_2 = V_1 - \Delta V \qquad (6)$$

Here, ΔV is the volume of hydrocarbons that pass from the total gas volume to the liquid phase, and is defined by the following expression:

$$\Delta V = N_A \sum_{i=1}^{n} q_{im} \qquad (7)$$

Here, N_A - is Avogadro number.

q_2'–the density in the unit volume of hydrocarbons that pass from the first volume of gas to the V_i fluid phase is calculated as follows:

$$q_2' = \frac{\sum_{i=1}^{n} q_{im}}{V_1} \qquad (8)$$

The density q_2'' of separated liquid phase hydrocarbons is determined by the following expression:

$$q_2'' = \frac{\sum_{i=1}^{n} q_{im}}{V_2} \qquad (9)$$

In addition to liquid hydrocarbons, which are separated from gas, the composition of the total liquid also contains methanol solution injected into the gas to prevent water and hydration. The moisture content in natural gas is expressed in the following equation:

$$W = W_1 - W_2 = \frac{A}{p_1} + B_1 - \frac{A}{p_2} + B_2 \qquad (10)$$

Here *W* - is the amount of moisture released from natural gas; W_1, W_2- gas humidity at the input and output of the separator; *A* -moisture content in ideal gas; B_1, B_2- are empirical ratios and are derived from reference books; p_1, p_2 - is the pressure of the gas at the input and output of the separator, respectively.

Then the moisture content in the liquid phase in natural gas at the separator input will be determined by the following formula:

$$W' = \frac{W_1}{W_2} \qquad (11)$$

The amount of moisture content in the liquid phase separated out of separators will be *W"*

$$W" = \frac{W}{W_2} \qquad (12)$$

If the density of hydrocarbons in the liquid phase separated out of total gas is equal to the density of hydrocarbons in the liquid phase separated out of separators$q_{C_{5+}} = q'_{C_{5+}}$, then the total ratio of fluid at the input of separator is calculated by the following expression:

$$q_{sg} = \frac{q_m}{V_1} + \frac{W_1}{V_2} + \frac{WC_2}{C_1 - C_2} \qquad (13)$$

The total density of liquid separated out of separator during the unit time will be:

$$q_{sm} = \frac{q_m}{V_2} + \frac{W}{V_2} + \frac{WC_2}{C_1 - C_2} \qquad (14)$$

Part of the fluid released in the nozzle separator system is transported to the main gas pipeline. The density of the liquid phase in the gas flow at the output of the separator is as follows:

$$q_{sç} = q_{sm} k_{ef} \qquad (15)$$

Here, k_{ef}- the efficiency of the separator depends on the size of the equipment in the nozzle separator system:

for separators with the horizontal tangential nozzle

$$k_{ef} = f\left(\frac{I_s}{D_s}\right) \qquad (16)$$

for vertical gravity separators

$$k_{ef} = f(h_s) \qquad (17)$$

Here, I_s, D_s, h_s - are the separator's length, diameter, and height, respectively.

Using the expressions (14) and (15), we can calculate the density of liquid $dq_m/d\tau_s$ separated from natural gas.

$$\frac{dq_m}{d\tau_s} = \frac{dq_{sm}}{d\tau_s} - \frac{dq_{AG}}{d\tau_s} \qquad (18)$$

Here, q_m - is the density of the liquid phase separated from natural gas.

The expression $dq_m/d\tau_s$ – - characterizes the quality of the natural gas processing in the nozzle separator unit and at the same time shows the degree of dependence rate of liquid phase absorption on the phases relation.

Considering the above, the material balance of the nozzle separator system can be written as follows.

The amount of fluid in the total gas V_1 injected into the unit during the unit time is as follows:

$$G_1 = V_1 \frac{dq_{mq}}{d\tau_s} \qquad (19)$$

At this moment, the amount of fluid transported by the separator gas and flowing into the main gas pipeline will be

$$G_2 = V_2 \frac{dq_{mq}}{d\tau_s} \qquad (20)$$

The amount of separated fluid will be

$$G_3 = V_3 \frac{dq_m}{d\tau_s} \qquad (21)$$

Then the material balance of the separators according to the liquids is as follows:

$$G_3 = G_1 - G_2 \qquad (22)$$

Thus, expressions (18) and (22) together reflect the general mathematical description of the nozzle separator unit.

IV. CONCLUSION

1.Mathematical notation of accumulation of fluid and liquid-gas phases correlation of hydrocarbon gas is provided in choke-separator systems.

2.Double-phase hydrocarbon gases passing through separators, stability of pressure drop along process lines, solution to equation of material balance of gas and liquid phase in equilibrium, and the heat accumulated on the walls of pipelines and units have been taken into account.

3.A formula is provided for determining the quantity and concentration of the liquid phase in the gas phase in the considered condition.

REFERENCES

[1] Lutoshkin G.S., 1983. Collection and treatment of oil, gas and water. M.Nedra, p. 189-206.

[2] Bekirov T.M., Shatalov A.T., 1986. Collection and processing of natural gases for the transportation. M.Nedra, p. 135-138.

[3] Gritsenko A. I., 1977. Scientific principles of field processing of hydrocarbon raw materials. - M.Nedra, p. 67 - 69; 113 -115.

[4] Seyfiyev F.G., BAKU-2020, Mono propylene glycol testing for gas drying in gas producing businesses of OGPC "28 MAY" HERALD of the Azerbaijan Engineering Academy The international science-technical journal Vol.12. № 3, pp. 45-49

Synthesis of Sulfocationites Based on Filled Polymer Mixtures

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***Abstract*—The purpose of the scientific publication is to consider the issue of the synthesis of sulfo-cationites with improved physical and mechanical properties on a polymer basis. Firstly, to achieve this task, the mechanical and chemical modification of polystyrene and polyvinyl chloride wastes was carried out with the introduction of a filler – red sludge. The optimal conditions of the process of mechanical and chemical modification, i.e. temperature and time, were determined. Further, sulfocationites were synthesized based on a polymer mixture filled with sludge by sulfonation. The main properties of ionites were studied and it was shown that they have satisfactory characteristics.**

***Keywords*—polystyrene waste, polyvinyl chloride, red sludge, mechanical and chemical modification, sulfonation, static and dynamic exchange capacity, swelling coefficient, density, mechanical strength**

I. Introduction

One of the promising directions in the chemistry of high-molecular compounds is the preparation, synthesis and application of new ion-exchange materials with a complex of properties that solve important scientific and technical problems in various industries.

İon-exchange materials are of paramount importance in chemical technology, in particular in the technology of obtaining biological products and medicinal substances. Ionites have found their application in the production of antibiotics, vitamins, insulin, blood preservation, extraction of toxic substances from the blood, softening and purification of water, in the production of iodine and bromine, as well as in the food industry for the purification of glucose, gelatin, glycerin, etc.

A large number of studies conducted for the synthesis of insoluble ionites have shown that it is possible to achieve high degrees of chemical transformations when introducing various ionogenic groups into polymers and copolymers with a mesh structure of macromolecules. The transfer of the results of these studies to the chemical transformations of linear polymers and copolymers requires, in each individual case, the selection of conditions that determine the nature of the intermolecular interaction in the polymer.

II Experimental part

We have conducted research in the field of synthesis of ion-exchange materials, in particular, the production of sulfocationites based on a polymer frame using household waste and a polymer containing a functional group [1-3]. Binary mixtures based on waste polystyrene and polyvinyl chloride were obtained by the method of mechanical and chemical modification (OPS:PVC) taken in different ratios. Further, on the basis of these mixtures, sulfocationites were obtained by sulfonation. The main characteristics of sulfocationites were studied, such as static and dynamic exchange capacity (SEC and DEC), swelling coefficient in water, mechanical strength, chemical resistance, density, etc. It was found that the density of the obtained ion-exchange materials is 906 kg/cm^3. Sulfocationites having a relatively low density compared to water create some difficulties when conducting tests to determine the dynamic exchange capacity, since ionites float to the surface of the test solution. In order to improve a number of properties of synthesized sulfocationites, in particular, to increase the density of ion-exchange materials, we proposed the idea of adding a mineral filler with a small specific surface area to their composition. Fillers are introduced into ion-exchange materials in order to improve their mechanical and operational characteristics, such as strength, stiffness, heat and heat resistance, as well as to increase their density and bulk volume. These indicators are directly related to the technology of operation of ion-exchange materials. In particular, the low density of polymer sulfocationites does not contribute to the effective use of industrial ion exchange devices. There, in order to increase the efficiency of industrial ion exchange plants, sulfocationites should have a density greater than, for example, the density of the treated water. As a filler to increase the density of the sulfocationites synthesized by us, we used a six-fold washing sludge-the residue of processing alunite from the Ganja Azeraluminium combine, with the following characteristics.

pH (water suspension)…………….…………7
Density, kg/m^3 3960
Specific surface area, m^2/g ....32 Particle
Size shape, microns.....................................3-12
Particle shape...round

The sludge has the following composition, %: SiO_2 – 82; Al_2O_3 – 10; Fe_2O_3 – 5,4; K_2O – 0,30; Na_2O – 0,30, etc.

III Results and discussion

As mentioned earlier, the introduction of a filler into the polymer frame, in addition to changing the mechanical parameters of the obtained mixtures and giving them some special properties, for example, chemical resistance, also reduces the cost of the obtained ion-exchange materials, since fillers, as a rule, have a low cost, and in our case it is a waste of production. The introduction of the filler into the polymer frame was carried out during mechanical and chemical modification. Polystyrene waste, PVC and filler were mixed mechanically in the molten state and then loaded into a laboratory extruder for further modification and for uniform dispersion of the mixture components. The filled polymer mixtures were obtained at a temperature of 140-150^{0}C for 5 minutes. The filler was introduced in an amount of 2÷10% (wt.) from the mass of the polymer mixture of OPS:PVC. To obtain sulfocationites, polymer mixtures filled with sludge were sulfonated with concentrated sulfuric acid in the presence of anhydrous as a catalyst. Sulfonation was carried out for 4 hours at a temperature of 40-50^{0}C. After the end of the reaction, the sulfonated product was transferred to a glass filter and washed with sulfuric acid with a gradual decrease in the acid concentration from 75% to 5%. Then the sulfonated product was washed with distilled water to a neutral reaction and left in distilled water for 24 hours. The granules of sulfocationites washed in this way were filtered and dried in air, and then in a vacuum cabinet at a temperature of 40°C to a constant mass. The main characteristics of sulfocationites obtained on the basis of a mixture of OPS were determined:PVC filled with sludge (Table 1).

№	Composition of sulfocationite, %(wt)		$K_{наб}$ in the water	SEC according NaOH, meq / g	SEC according $CaCl_2$, meq / g	DEC according $CaCl_2$, meq / g	Mechanical strength after 10 hours of shaking, %
	OPS:PVC	Sludge					
1	100	-	1,22	6,0	5,8	0,82	100
2	98	2	1,23	6,34	5,9	0,80	100
3	96	4	1,22	6,67	6,0	0,80	100
4	94	6	1,20	6,67	5,9	0,80	100
5	92	8	1,15	6,32	5,4	0,78	98
6	90	10	1,14	5,99	5,1	0,75	98

TABLE 1. THE MAIN CHARACTERISTICS OF SULFOCATIONITES BASED ON A MIXTURE OF OPS:PVC FILLED WITH SLUDGE

As can be seen from Table 1 with the introduction of into the mixture OPS:PVC sludge, in an amount from 2 to 10% (wt.) the swelling coefficient of sulfocationites in water decreases slightly, and the static exchange capacity increases, although the indicators of DEC worsen compared to a sample that does not contain a filler.

Analyzing the data in Table 1, it can be concluded that in sulfocationites obtained on the basis of a polymer mixture filled with sludge in an amount of 4-6% (wt), the static exchange capacity indicator has better results compared to a sample that does not contain a filler. It is shown that with such an amount of introduced filler, the SOE index of cationites increases from 6.0 to 6.67 mg-eq/g (0,1N each), and at the same time, the indicator of the dynamic exchange capacity of this sample is better than that of others. By introducing sludge in an amount of more than 6%(by weight) into the polymer mixture, a more rigid system is formed, the filler blocks the sulfogroups to a greater extent, the swelling coefficient decreases, as a result of which the sorption parameters of sulfocationites obtained on their basis deteriorate.

There, the optimal amount of filler in the composition of sulfocationite is 4-6% (by weight). The improvement of the properties of cationites occurs, apparently, for two reasons. Firstly, sludge is a mineral filler, the particles of which are metal oxides that shield individual sections of the macromolecule and reduce the destructive effect of sulfuric acid on polystyrene. Secondly, we believe that the metal oxides that are part of the filler, such as, SiO_2, Al_2O_3 and Fe_2O_3 increase the rate of diffusion of sulfuric acid into the mass of the mixture.

IV Conclusions

Polymer mixtures of were obtained by the method of mechanical and chemical modification OPS:PVC:sludge. The mechanical and chemical modification was carried out on a laboratory extruder at a temperature of 140-150^{0}C for 5 minutes. The filler was introduced in an amount of 2 to 10% (wt.).

Further, sulfocationites were obtained based on a modified polymer mixture filled with sludge by sulfonation with concentrated sulfuric acid for 4 hours at a temperature of 40-50^{0}C.

The main indicators of ion-exchange materials filled with sludge were studied, such as SEC (according $NaOH$ and $CaCl_2$), DEC (according $CaCl_2$), swelling coefficient, etc. It is shown that sulfocationites with a sludge content in the amount of 4-6% (wt.) the indicators of static and dynamic exchange capacity have the best results.

REFERENCES

[1] F.A. Amirov, G.A. Aliyeva, F.R. Rahimova, G.F.Rustamova. Fuzzy C-Means Based Synthesis of Ion –Exchange Materials. 11 th Word Conference on " İntelligent systems for İn dustrrial Automation -WCIS, 2020, Tashkent , Üzbekistan. 17 March 2021. Pages 487-495. http://wcis2020.uz/ DOI:10.1007/978-3-030-68004-6_64

[2] G.A.Aliyeva, F.R.Rahimova, G.F.Rustamova. Investigation of the properties of sulfocationites based on polymer composition. 9th Rostocker International Conference: "Technical Thermodynamics: Thermophysical Properties and Energy Systems", October, 2020, University of Rostock, Germany. THERMAM 2020, p.62

[3] G.Aliyeva, J.Safarov, F.Rahimova, V.Khalilov. Mechano-Chemical Modification of Wastes of Polystyrene with Polyvinyl Chloride. 6th International Conference: "Thermophysical and Mechanical Properties of advanced materials", 8th Rostocker International Conference: "Thermophysical Properties for Technical thermodynamics", 22-24 september 2019,Çeşme, Izmir, Turkey. THERMAM 2019 s.61 1G. Eason, B. Noble, and I. N. Sneddon, "On certain integrals of Lipschitz-Hankel type involving products of Bessel functions," Phil. Trans. Roy. Soc. London, vol. A247, pp. 529–551, April 1955. *(references)*

Water Treatment by Mechanical Methods

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***Abstract*— In today`s era, tossing of exhaut gasses is one of the major ecological problem. These gases also have detrimental effects on water resorces. According to the investigations, we determined that, applying of graphen oxide and zeolite as mechanical treater can be solution to the treatment of water sources which are contaminated with exhaust gases. According to the obtained results, graphene oxide has better results than zeolite.**

Keywords—graphene oxide, zeolite, water treatment, SEM

I. Introduction

In a world of gradually developing technologies the demand for new new scientific breakthroughs in order to improve these technologies becomes more indispensable. The synthesis of multifunctional compounds and drugs is considered as one of the possible solutions to this issue. Such kind of compound is the graphene oxide, as nowadays it's derivatives and their chemical production issue become more relevant among the the chemists and also characterization of the products require novel analytical methods which in order creates a new research possibilities [1-4]. And the question is, in which way the synthetic chemistry could take a part in graphene and graphene oxide topic and could it push this area further by any new developments? In last 20 years we observed the inordinate improvement in chemical characterization, reactivity principles, application properties and complex formation with other various compounds of synthetic allotropes of carbon, like fullerenes and carbon nanotubes.

Rapid growth of world population and industrial development aggravates the problem of clean water scarcity and as an result, enhancing the demand for highly beneficial and eco-friendly water treatment technologies. The main research goal of this direction is preparation of semipermeable nanostructurized membranes and graphene oxide with ensembles derived from it posses a great potential for replacing the polymer membranes due to their relative accessibility and mechanical and chemical durability.

The current research strategy in this area is the synthesis of more efficient graphene oxide membranes for water treatment by modifying carbon oxygen ratio and analyzing the functional groups [5-7]. The main goal of our laboratory work is to obtain new derivatives of graphene oxide and analyze their efficacy in water treatment. The experiment will be carried out by Hummers method, and obtained graphene oxide ensemble will be applied in filtering of water in order to measure the amount of ions in filtered water [8-11].

II. Experimental part

The experiment first was carried out at room temperature and then was heated to higher temperatures(90 °C). The used equipment is listed below:
Filter paper; 250 ml cylindrical flask; cold bath, electric heater;
The measurement of the a mount of reactants by titration is depicted in image below:

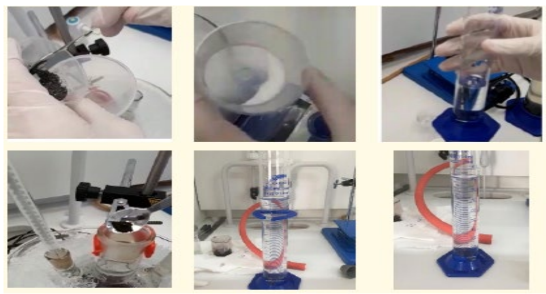

Fig. 1. Laboratory equipment used in the synthesis of graphene oxide

In recent years modified and improved Hummers method become widespread and the most beneficial and our experiment was based on that method in order to obtain more better results. The step-by-step sequence of procedures during our laboratory work was proceeded according to NCR documentation [23] due to its efficiency in our other research projects. As reactants we took 2gr of graphite, 1gr of $NaNO_3$ and 6gr of $KMnO_4$. 46 ml of 95-98% sulfuric acid were prepared in advance. During reaction cold bath was used to keep temperature low as required. According to theoretical part it advisable to carry out reaction twice. After preparing the samples three and two necked thermometers were chosen. Then graphite, $NaNO_3$ and H_2SO_4 were added to flask and the obtained mixture was stirred for a some period. After, during 20 minutes the temperature was plummeted till 200 °C. By heating again till 20 °C, $KMnO_4$ was added gradually for 2 hours. As the reaction was exothermic we retained the temperature around 20-25 °C using cold bath. Then we heated it up to 35 °C stirred it for 30 minutes. After we put the mixture again into the cold bath, added to the sample 92 ml of distilled water and temperature rised to the 90°C, followed by decrease to the 70 °C. Then we used electric heater to keep temperature at 70-70 °C for 15 minutes. After we poured the reaction mixture into 1 L Erlenmeyer flask and washed it with distilled water to enhance dispersion and decrease the loss of adduct. For this reason 500 ml of 3% percent H_2O_2 solution was prepared. After keeping adduct at temperature for 12 hours, we washed it with distilled water by filtration method. For the complete removal the sulfuric acid we washed the adduct again with NaCl solution with 12 gr/l concentration. Then, in the Buncher system we added 100 ml of thickened water into our newly obtained composition.

In further proceedings we applied the zeolite nanoparticles and graphene oxide which we obtained from our experiment in order to studed their exact roles in water treatment. We used clinoptilolite as the zeolite nanoparticles. Elements within the clinoptilolite were given in the table below:

- Table 1. Components of clinoptilotite zeolite

Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	FeO	MnO	Fe_2O_3
1.37	0.99	12.13	65.95	1.95	3.63	0.07	0.02	1.22

Table 2. Components of clinoptilolite zeolite

Element	Mass %	Number of atoms %	Consistency %	Formula
Na	3.09	2.78	4.17	Na_2O
Mg	2.03	1.72	3.37	MgO
Al	7.61	5.82	14.38	Al_2O_3
Si	33.41	24.55	71.48	SiO_2
K	2.39	1.26	2.88	K_2O
Ca	0.65	0.34	0.91	CaO
Fe	2.18	0.81	2.81	FeO
O	48.63	62.72		
Sum	100			

After all these processes we applied the FTIR spectrophotometer for characterizing the functional groups in the powder samples of hybrid nanostructures. As a spectrum we picked the interval of 4000 - 400 cm^{-1}.

III. Conclusion

After experiments, we revealed the some amount of Cl ions by titration method at central Azersu laboratory. For determining the effect of obtained graphene oxide on the amount of Cl^- during water treatment we passed the simple water through filter consist of graphene oxide and then analyzed it for the number of Cl^- ions.

As a consequence of the research, the number of Cl ions was considerably reduced by ~20% using a filter that consisting of GO. According to the obtained results number of Cl^- ions before the filteration was 7472, but this amount reduced to 5958 after filteration. If water purification membranes and other devices could be used during the experiment, the indicators could be even better. Experiments on the investigation of functional groups in the produced graphene oxide are now underway.

REFERENCES

[1]. K. S. Novoselov, A. K. Geim, S. V. Morozov, D. Jiang, Y. Zhang, S. V. Bubonos, I. V. Grigorieva, A. A. Firsov, Science 2004, 306, 666;

[2]. D. R. Dreyer, R. S. Ruoff, C. W. Bielawski, Angew. Chem. 2010, 122, 9524

[3]. K. S. Novoselov, A. K. Geim, S. V. Morozov, D. Jiang, M. I. Katsnelson, I. V. Grigorieva, S. V. Dubonos, A. A. Firsov, Nature 2005, 438, 197;

[4]. R. S. Edwards, K. S. Coleman, Nanoscale 2013, 5, 38;

[5]. A. Hirsch, M. Brettreich, Fullerenes, Chemistry and Reactions, Wiley-VCH, Weinheim, Germany, 2005

[6]. S. Eigler, Y. Hu, Y. Ishii, A. Hirsch, Nanoscale 2013, 5, 12136.

[7]. You S.; Yu J.; Sundqvist B.; Belyaeva, L. A.; Avramenko, N. V.; Korobov, M. V.; Talyzin, A. V. (2013). "Selective Intercalation of Graphine Oxide by Methanol in Water/Methanol Mixtures". The Journal of Physical Chemistry C. 117 (4): 1963. doi:10.1021/jp312756w

[8]. Nonlinear optical properties of graphene oxide in nanosecond and picosecond regimes". Zhibo Liu. January 12, 2009. doi:10.1063/1.3068498.

[9]. Zheng, Xiaorui; Jia, Baohua; Chen, Xi; Gu, Min (May 7, 2014). "In Situ Third-Order Non-linear Responses During Laser Reduction of Graphene Oxide Thin Films Towards On-Chip Non-linear Photonic Devices". Xiaorui Zheng. 26 (17): 2699 2703 . doi:10.1002/adma.201304681.

[10]. Gómez-Navarro, C.; Weitz, R. T.; Bittner, A. M.; Scolari, M.; Mews, A.; Burghard, M.; Kern, K. (2007). "Electronic Transport Properties of Individual Chemically Reduced Graphene Oxide Sheets". Nano Letters. 7 (11): 3499–3503

[11]. Jung, Inhwa (November 1, 2008). "Tunable Electrical Conductivity of Individual Graphene Oxide Sheets Reduced at "Low" Temperatures". Nano Letters. 8 (12): 4283–4287. doi:10.1021/nl8019938. PMID 19367929.

AI-Based Processing of Seismic Signals During Oil Exploration

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***Abstract*—Preprosessing of seismic data is one of the most widely used methods in oil and gas exploration which is providing comprehensive information about various layers and rock properties underneath the Earth without any expensive drilling operations. The accuracy and efficiency of the seismic data analysis mainly depend on the quality and the quantity the seismic receivers - geophones or hydrophones located on the Earth or marine surface. Furthermore, the choice of the seismic source energy is also important factor in the reliability of the acquired seismic data. Unfortunately, such seismic data analysis usually appears with an excessive amount of noise generated by various sources and erratically missing information due to inaccessible points in the field. The attenuation or suppression of random noise is of great importance for geologists to achieve high quality and precise seismic data in oil and gas exploration. According to this data, the potential oil or gas resources can be found out, even an approximate capacity of the reservoir can be estimated by expert geoscientists and engineers. Many methods have been investigated for random noise attenuation and each of them has certain advantages and disadvantages. The selection of the appropriate method depends upon the preferred criteria on the acquired results in the seismic data analysis. In this paper is considered the application of Artificial Neural Network in seismic data analysis using MATLAB. As result Artificial Neural Network (ANN) filter is designed. While comparing with other classical filters this method has showed his efficiency.**

Keywords—seismic data, preprocessing, Artificial Neural Network, root-mean-square error, seismic signals, filter, signal-to-noise ratio

I. INTRODUCTION

In recent years, major improvements and innovations have been developed in energy exploration. Oil and gas exploration is one of the most expensive processes in fuel energy acquisition. Millions of dollars are being spent to find out if there is a potential petroleum reservoir to continue drilling and complete the well. Seismic surveys have become one of the most efficient methods applied in energy exploration providing huge return on investment. Seismic technique is a remarkable option to analyze the subsurface structure in advance of drilling and to determine the design of the well trajectories in order to achieve the reservoir in the safest and most effective way. Obtaining a detailed record of the geological formations, which is known as well logging, allows the geologists to gather comprehensive information about different layers of rock formations. This contributes greater certainty about whether or not the hydrocarbons exist beneath Earth's surface. If there is not any latent petroleum reservoir, the drilling process needs to be stopped and the well should be abandoned to prevent incurring higher costs of completing a well. In consequence, seismic data analysis leads to a more profitable hydrocarbon extraction with fewer wells drilling.

Seismic data with high quality is very crucial in seismic exploration to accurately analyze the subsurface structure. However, in real industrial experiments, the seismic signals are usually obtained with high frequency noise which could cause losing useful information about the rock formations underneath the Earth. So that, noise attenuation is one of the important stages in seismic signal analysis. Although a number of methods have been suggested to attenuate the seismic noise signal, the efficiency of these methods is evaluated with the preservation of the original signal amplitude. Traditional attenuation algorithms, such as transform domain algorithms [1], [2], [3], spatial domain algorithms [4], curvelet transform [5], comprehensive types denoising algorithms [6], [7] can manage to eliminate the noise to some extent, they usually appear with some drawbacks such as inaccurate design assumptions and problems in estimating parameter values ([8]-[11]). Furthermore, a comprehensive experience and knowledge about the noise are required before the traditional methods applied in seismic noise attenuation. As the random noise is obscure in the real exploration process, it needs to be tested at different variances which contributes to time-consuming and inefficient process. Considering the drawbacks of the traditional methods. contemporary science and industry demand more effective and intelligent denoising methods. In recent years, deep learning or ANN has rapidly and extensively developed, consequently it has also applied in seismic exploration field.

II. DESIGN OF NEURAL NETWORK FOR RPOCESSING OF SEISMIC DATA

The suggested method for preprocessing of raw seismic signal learns the difference between noisy and clean data. The data representation and noise cancellation will be performed using Matlab software. Matlab has a range of features for filtering the noisy signal and its Neural Network Toolbox – "$nntool$" enables to design an Artificial Neural Network structure with desired number of layers and flexible parameters. There are mainly five steps in the method described in this paper:

1. Generate a clean - ideal output signal using traditional filtering methods.
2. Design a neural network framework.
3. Train the network and test the network performance.
4. Compare the denoising results of neural network and traditional methods.
5. Calculate the signal-to-noise ratio to check the efficiency of the result.

The input data is represented as a tabular data which shows the measurements of seismic sensors on 513 traces of the Earth. When the seismic sources – air guns are fired and send acoustic waves to the lower layers of the Earth surface, seismic receivers or hydrophones towed behind the seismic ship collect the depth values of the rocks according to the time duration between sent and received signals. As a result of multitude bombing actions from air guns, a table of data in the size of 886 x 513 is obtained. Each column in the table depicts one trace or layer in the Earth subsurface and each raw shows a time at which the sample is acquired from the sensors. Considering the acoustic signal speed (v_s) in the water and two sequential depth samples (s_1, s_2) the data parameters are initialized in Table 1 below:

Table 1. Acoustic Signal Parameters

v_s	$1500\ m/s$
$s1$	$-2.385\ m$
$s2$	$-1.803\ m$

Using the known signal parameters represented above, the sampling time ($T_{samplig}$) and sampling frequency ($F_{sampling}$) parameters can also be easily calculated as shown below:

$$T_{sampling} = \frac{|s2 - s1|}{v_S} = 0.388\ ms \quad (1)$$

$$F_{sampling} = \frac{1}{T_{sampling}} = 2.577\ kHz \quad (2)$$

Each trace – column consists of error measurements due to sensor accuracy or environmental noises. Therefore, the experimental raw data obtained directly from hydrophones or geophones is not helpful for geologists and geoscientists to predict the potential of hydrocarbon resource.

The noise interference on the pure signal is apparently observed in the 2D representation of the original experimental data in time and frequency domains (Figure 1):

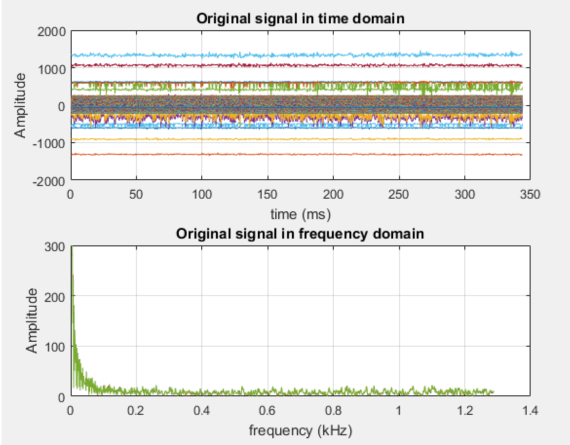

Fig.1. 2D representation of raw seismic data

Due to neural network design, we need a target data to train the network. This target data can be obtained by applying traditional filters on the input data. As the random noise signals are generally high frequency signals, we need a lowpass filter to vanish the noise from the signal.

While designing the low-pass filter, the choice of cutoff frequency at which the signal is sufficiently cleaned is very important. Based on the noisy signal frequency response, the cutoff frequency has been chosen 0.02 kHz approximately in order to minimize the amplitude of the noise on the seismic signal. Furthermore, the passband and stopband frequencies should be less than Nyquist frequency, which is half of sampling frequency. The low-pass Butterworth filter with minimum order was designed using Matlab FFtool (Figure 2):

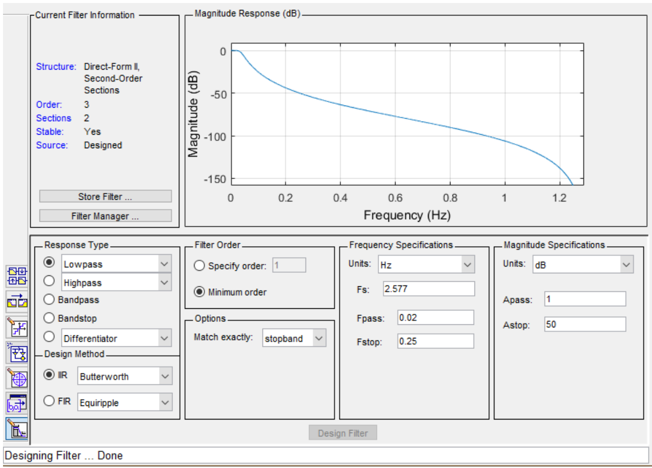

Fig.2.Lowpass Filter Design

After applying the designed low-pass Butterworth filter on the original noisy seismic signal, the noise was attenuated and an ideal – noise-free signal was obtained (Figure 3 & Figure 4):

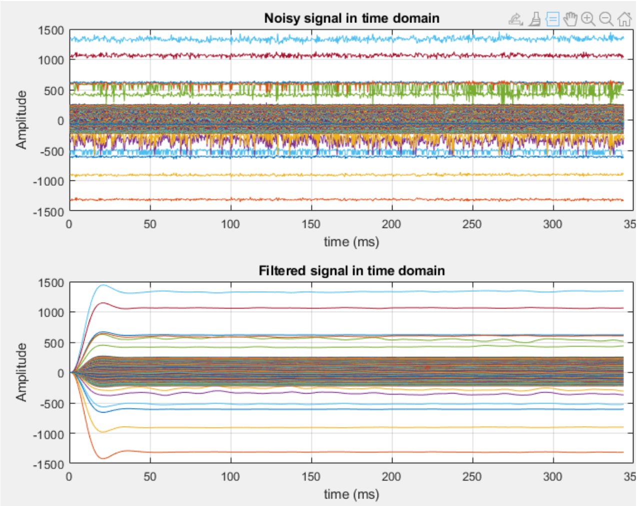

Fig.3.Raw and filtered data in time domain

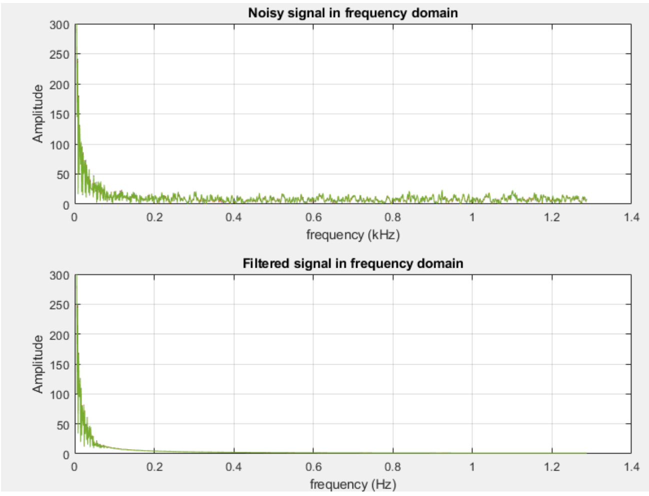

Fig.4.Raw and filtered data in frequency domain

Comparing with original noisy signals, the acquired results are much smoother and ideal both in time and frequency domain representation. There are some ripples in time domain as demonstrated in Figure 3, this is because of the allowable passband attenuation indicated in magnitude specifications of the filter. The obtained signal will be the target data for the neural network to learn the system and will be used to validate the acquired results.

ANN learns how ideally the system performs and implements it on the other samples in the same manner, afterwards. As discussed in the previous subsection, the input data was filtered using traditional low-pass filter firstly. The input signal together with the ideal filtered signal are two main inputs of the neural network to be able to calculate the respective weights of the hidden layers. Since the provided seismic signal data is quite big, only some portion of the data is used to train the system. In this instance, 200 samples of traces obtained in 100 ms time were used for learning purpose of the neural network and the next 200 samples were used to test and validate the results. Matlab has NNTool function which opens Neural Network/Data Manager window in order to import the input data, create a neural network with desired parameters and to export the neural network results.

After input and target data were imported, a neural network structure is designed. The neural network design used in this work is a 7 layers (6 hidden, 1 output) network with 10 neurons at each hidden layer. The hidden layers have a hyperbolic tangent activation function which is more successful than sigmoid function and is applied in many neural network problems. As it is regression type prediction problem, Linear activation function has been selected for the output layer. After creating the neural network, it needs to be trained with the imported input and target data. Training parameters are specified as represented in Figure 5:

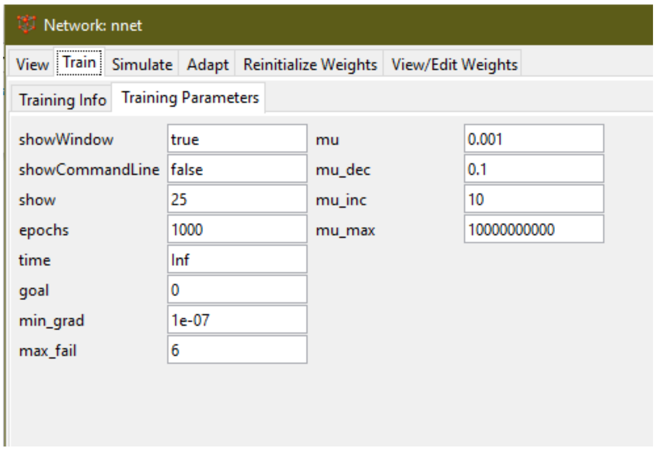

Fig.5.Trainning parameters of neural network

The training process lasted for 13 minutes approximately, and after 57 iterations the goal was achieved (Figure 6):

Fig.6.Neural network structure and obtained parameters

The performance of the training and error histogram as represented in Figure 7, also validates the neural network successful results:

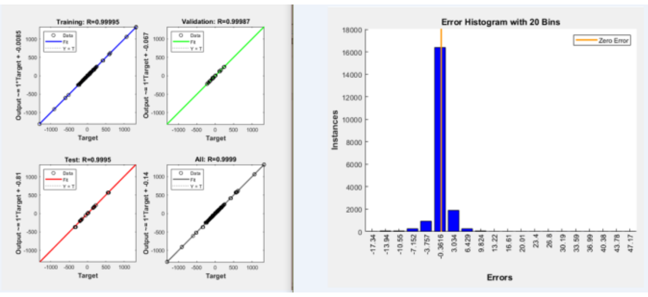

Fig.7. Regression performance and Error histogram of the neural network

As mentioned above, 200 samples different from the trained data were used to check and validate the neural network performance. When the testing data was initiated as an input to the trained network model the obtained result was compared with the desired output in time (Figure 8) and frequency domain (Figure 9):

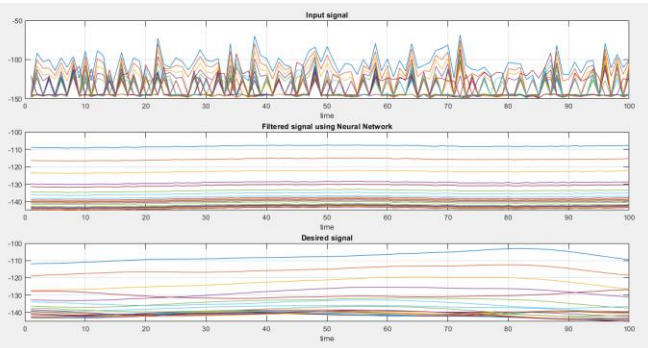

Fig.8.Neural network's output and target signals in time domain

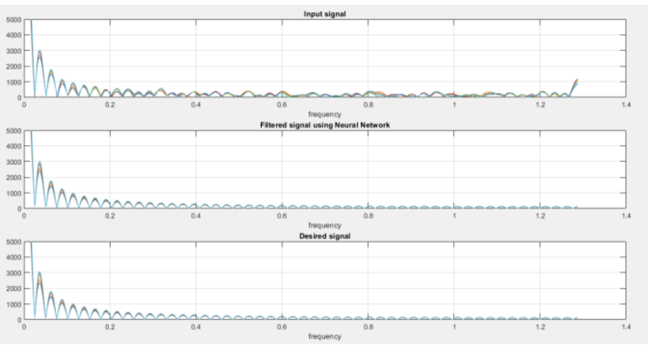

Fig.9.Neural network's output and target signals in frequency domain

As can be seen from the figures above, the results are very close to the desired ones and the noise on the signal has considerably been attenuated. Different sets of data were tested with the designed network and all results were the satisfying as represented in Figure 8 and Figure 9.

Furthermore, the statistical properties of the input and output signals were also calculated to verify the model efficiency (Table 2):

Table 2.Statistical properties of Neural network

$mean\ (input)$	-81.1607
$mean\ (output)$	-82.3470
$variance\ (input)$	275.7967
$variance\ (output)$	0.1800
$RMSE\ (training)$	0.2050
$RMSE\ (testing)$	0.4444
$SNR\ (input)$	0.9054
$SNR\ (output)$	8.8955

The derived values show that the signal has been cleaned from the noise successfully as its $mean$ and $variance$ have decreased as expected. Another important parameter, root-mean-square-error ($RMSE$) is almost the same for the training and testing data. Finally, the most essential parameter to confirm the noise attenuation in the signal is the Signal-to-noise ratio (SNR). A significant increase in the signal-to-noise ratio value also implies the noise reduction in the output signal.

III. Conclusion

As implemented in many areas of industry, a neural network can successfully be applied in oil and gas exploration to achieve a desired result in a more efficient and eco-friendly way. A detailed and systematic analysis of seismic data can guide the geologists to decide the potential capability of the reservoir and can save millions of dollars for oil and gas companies if the well does not worth to drill. Moreover, a careful preprocessing and interpretation of seismic signals can result in an accurate drilling direction and depth due to precise assumptions about rock formations. Although the preprocessing of seismic signals using ANN model is time consuming, it can deal with the seismic signal without requiring any prior knowledge or comprehensive analysis of the signal. Despite the fact that the traditional methods are more accurate and reliable, Artificial Intelligence (AI) or Machine Learning has become main focus of industry due to its convenience and flexibility.

This paper mainly discusses the AI application in noise cancellation in seismic signals which is known as preprocessing of seismic signals. A future work could be to apply a CNN in seismic signal processing and improve the processing of seismic signals in order to make a judgement about reservoir capability and to identify the rock properties. Certainly, it requires a deep knowledge about various rock formations and their characteristics, afterwards, a neural network can be trained to be implemented in seismic signal processing.

References

[1] Oropeza and M.Sacchi. Simultaneous seismic de-noising and reconstruction via multichannel singular spectrum analysis (MSSA), Geophysics, vol. 76, No. 3, pp. v25–v32, 2011

[2] W. Chen, M. Bai, and H. Song. Seismic noise attenuation based on waveform classification, J. Appl. Geophys., vol. 167, pp. 118–127, Aug. 2019.

[3] Y. Chen, H. Chen, K. Xiang, and X. Chen. Preserving the discontinuities in least-squares reverse time migration of simultaneous-source data, Geophysics, vol. 82, no. 3, pp. S185–S196, May 2017.

[4] Stumpf, N. Lachiche, J.-P. Malet, N. Kerle, and A. Puissant. Active learning in the spatial domain for remote sensing image classification, IEEE Trans. Geosci. Remote Sens., vol. 52, no. 5, pp. 2492–2507, May 2014
[5] H. Zhang, S. Diao, H. Yang, G. Huang, X. Chen, and L. Li. Reconstruction of 3D non-uniformly sampled seismic data along two spatial coordinates using non-equispaced curvelet transform, Explor. Geophys., vol. 49, no. 6, pp. 906–921, Nov. 2018.
[6] Y. Chen and S. Fomel. Random noise attenuation using local signaland-noise orthogonalization, Geophysics, vol. 80, no. 6, pp. WD1–WD9, Nov. 2015.
[7] Q. Zhao, Q. Du, X. Gong, and Y. Chen. Signal-preserving erratic noise attenuation via iterative robust sparsity-promoting filter, IEEE Trans. Geosci. Remote Sens., vol. 56, no. 6, pp. 3547–3560, Jun. 2018.
[8] W. Liu, S. Cao, Z. Jin, Z. Wang, and Y. Chen. A novel hydrocarbon detection approach via high-resolution frequency-dependent AVO inversion based on variational mode decomposition, IEEE Trans. Geosci. Remote Sens., vol. 56, no. 4, pp. 2007–2024, Apr. 2018
[9] W. Huang, D. Feng, and Y. Chen. De-aliased and de-noise Cadzow filtering for seismic data reconstruction, Geophys. Prospecting, vol. 68, pp. 553–571, 2018.
[10] D. Zhang, D. J. Verschuur, S. Qu, and Y. Chen. Surface-related multiple leakage extraction using local primary-and-multiple orthogonalization, Geophysics, vol. 85, no. 1, pp. V81–V97, Jan. 2020.
[11] R. Anvari, A. R. Kahoo, M. Mohammadi, N. A. Khan, and Y. Chen. Seismic random noise attenuation using sparse low-rank estimation of the signal in the time–frequency domain, IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens., vol. 12, no. 5, pp. 1612–1618, Apr. 2019.

Development of Diagnostic and Control System for SMART Home

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***Abstract*—The fire parameters studied, a fire signalization and extinguish control system proposed. Given system makes it easy to manage any event in house by distance control. If a gas leakage or fire occurs in apartment or at home, an alarm is triggered and a notification is sent to the mobile phone. At the same time, changes occurred in the apartment "under the control" of the system can be tracked in special monitor mode that it is possible to prevent of the fire and without increasing its scale.**

Keywords—control system, fire, extinguisher, temperature sensor, smoke sensor, automatic mode

I. INTRODUCTION

Fire alarm and warning systems are electronics based systems that detect fires that may occur in buildings, homes and facilities, help to prevent injuries to people working and living in these areas, and to take the necessary measures to minimize losses. For this reason, such systems are one of the most important automatic control systems in smart buildings.

Fire extinguishing systems are the common (group name) name of the systems used to stop or reduce the effects of a fire. This system group includes irrigation systems, dry dust and gas extinguishing systems. The purpose of fire extinguishing systems is to cool combustible materials and lower the temperature of these substances below the combustion temperature. In addition, some fire extinguishing systems reduce the level of oxygen in the air with heavy and non-combustible gases to reduce the fire. In the event of a fire, fire extinguishing systems are activated manually or automatically. Chemical gases such as water, foam, dry chemical dust, CO2 and Fm200, and Novec are used as extinguishing agents in automatic fire extinguishing systems. However, the most commonly used are water, foam and CO2. Water is widely used as a fire extinguisher in fires due to its low cost and high heat absorption, which lowers of the combustion temperature [2,6].

At the moment, the demand for motor fuels and lubricants is increasing due to the increase in oil production. However, it is already obvious that such a resource as crude oil is exhaustible (1-3). It is with the aim of solving this problem that the process of development of oil refining has been going on for several decades in the direction of:

– deepening and chemicalization of the process;
– increasing efficiency and achieving optimization of the quality of the resulting finished product, reducing its consumption;
– options for the creation and use of alternative fuels.

The first direction is the most high-tech and intensively developed at the moment branch of the oil refining industry, with the creation of flexible technological schemes and all kinds of catalytic and hydrogenation processes for deep processing of oil and oil residues (5). In this regard, when considering catalytic technological schemes, the most interesting is the catalytic cracking of petroleum feedstock, which is capable of producing high-quality fuel components for internal combustion engines with an octane rating of 85-95 from low-quality, low-value and cheap heavy feedstock. In addition, this technological process is associated with by-products such as mixed gases, which are propane-propylene and butane-butylene gases in composition, which, in turn, are feedstock for the production of various hydrocarbons, such as ethers, alkylates, etc (4, 6). With the help of catalytic cracking units, such valuable components in chemical products as soot feedstock and naphthalene, expensive types of coke are obtained.

As catalytic cracking process is one of the most important processes for deep oil refining, the control of this process is also very essential.

There are many parameters affecting catalytic cracking process. However, the main parameter is temperature. Certain temperatures should be maintained during conduction of this process in order to make system operate in its most efficient regime.

II. PROBLEM STATEMENT

Combustion is the rapid oxidation of combustible substances and gases, when produces heat and light. During the meeting of a substance is heated to ignition temperature with oxygen exothermic chain reaction is occurred. The following three components must be present in order for combustion to begin:

1. Flammable substance (Fuel), 2. Oxygen, 3. Heat (Igniter).

Products that arise after a fire are used to detect a fire. Smoke, heat, and flames are the most important combustion products used in fire detection. The fire detectors are response to physical size of combustion products (Figure 1).

Figure 1. Fire detector

- Smoke control systems are used in high-rise buildings, shopping malls, business centers, factories, airports and in other buildings. Installation of this system in high-rise buildings is more important than in other places. Because people suffer more from smoke in fires over there. Many skyscrapers have been built according to the smart building concept, which includes automatic systems for control and manage of regarding processes in such objects. For this reason, it is necessary to use this system in smart buildings to prevent or reduce human losses [4].

- Active fire safety measures are measures activated by a fire, while passive measures conducted before the fire, use for early detection of fire, reducing the possible effects of fire and extinguishing the fire. Active fire safety measures consist of 5 main groups dependency on according to the work done:

- Measures to ensure fire detection (fire detection and warning system, explosive rain system)

- Measures to ensure the announcement of the fire (emergency lighting system, emergency sound system, call the fire brigade, etc.)

- Evacuation measures (control of elevators and security systems)

- Smoke control measures (Pressure equipment, control of HVAC - heating, ventilation and air condition systems)

- Fire control and extinguishing measures (use of fire extinguishers, fire extinguishing systems).

- Passive fire safety measures are measures taken before the fire to ensure the safety of evacuation routes in buildings, to control the spread of smoke, to prevent the collapse of the building, the spread of fire and to prevent the spread of fire. Unlike active security measures, these measures do not include automatic control systems. In addition, measures taken to ensure the safety of the occupants of a building during the design and planning phase of a building, to reduce the likelihood of fire occurrence and spread, and to reduce the amount of any material losses and damages are included in this group [4, 5, 6].

III. PROBLEM SOLUTION

Home automation is the application of evolving technologies to suit the needs and special desires of users. For fire module used in project demand software to work with the central control device Arduino Mega 2560.

A flame detector designed to detect and respond to the presence of a flame or fire shown in Figure 2. The response to any detected flame depends on the developed system, it is possible to use given sensor to close a fuel line and sound an alarm, to activate of the fire extinguishing system [1, 2]. A flame detector is faster and more accurate than a smoke or heat detector due to operation principal of it. The visual flame detectors also known, those analyze IR radiation by (CCD) device and use flame recognition technology to confirm fire. Infrared (IR) flame detectors track a special infrared spectral group emitted by burning gases. The typical response time of an IR detector is 3-5 seconds. Dual IR (IR/IR) flame detectors compare signals in the infrared range of the two media, and send an alarm when this difference exceeds a certain value.

These sensors can detect fire up to 3 meters. Flame sensors are one of the most widely used devices due to their reliability. There are two types of flame sensors. Both types of sensors (with three and four pin) can easily communicate with any microcontroller [1].

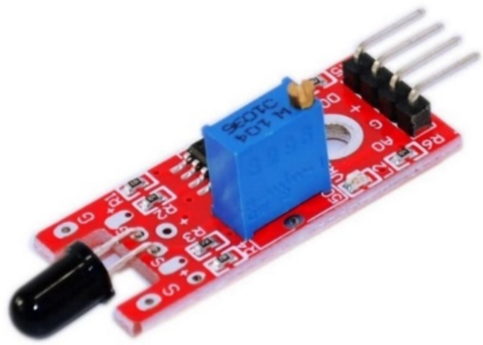

Figure 2. Fire sensor KY-026

KY-026 sensor used as a fire alarm. Connecting of fire sensor to the Arduino Mega2560 + Wool Shield module (Figure 3).

First of all, it is necessary to input of the libraries of the modules to the Arduino IDE program. To do this, the command "#include" is used. After this command, the name of the library must be entered inside the uppercase and lowercase (<>) characters.

In the next step, we enter the Auth Token given to us in the Blynk program. To do this, we will use the command "char auth [] =". If the fire value is > = 500, the Active beep module is activated, the red light on the Rgb LED on the front is lit, and the information about the fire is also sent to the Blynk program on the phone. If the fire value is less than 500, is selected "No Fire!" which displayed in "Serial Monitor" section (Figure 4).

The following figure shows the software block of the MG-2 smoke sensor. If the smoke value is > = 240, the Active beep module is activated, the red light on the Rgb LED on the front is lit, and the smoke information is also sent to the Blynk program on the phone. If the smoke value is below 240, "No smoke!" will be displayed in the "Serial Monitor" section (Figure 5).

A microcontroller is a microcircuit that is used to control electronic devices. A typical microcontroller contains the functions of both the processor and peripheral devices, and also contains random access memory and read only memory. In short, a microcontroller is a computer operating on a single chip that is capable of performing relatively simple operations. Microcontrollers are widely used in computing, consumer electronics, industry, etc.

A microcontroller is essentially a microcircuit, which consists of:

– Central processing unit. It includes a control unit, registers, ROM.

– Peripheral, which includes I/O ports, interrupt controllers, timers, various pulse generators, analog converters, and the like.

A microcontroller is often referred to as a microprocessor. But it is not so. The latter carries out only certain mathematical and logical operations. And the microcontroller also includes a microprocessor with other elements, being only part of the MC.

During operation, the microcontroller reads commands from memory or input port and executes them (7). What each command means is determined by the microcontroller's command set. The system of instructions is embedded in the architecture of the microcontroller and the execution of the command code is expressed in the implementation of certain micro-operations by the internal elements of the microcircuit. Microcontrollers, as a rule, do not work alone, but are soldered into a circuit, where, in addition to it, screens, keyboard inputs, various sensors are connected. There are several architectures on the basis of which microcontrollers are built. These are CISC (Complex Instruction Set Computers), RISC (Reduced Instruct Set Computers), Harvard, Princeton.

The difference between RISC and CISC is that CISC processors execute a large set of instructions with advanced addressing capabilities (direct, index, etc.), giving the developer the opportunity to choose the most appropriate instruction to perform the required operation, and in RISC processors, a set of executable instructions are reduced to a minimum (8, 11). In this case, the developer must combine commands to implement more complex operations.

Princeton architecture was developed by John von Neumann and independently by Academician S.A. Lebedev. It uses shared memory to store programs and data (fig. 1). The main advantage lies in the simplification of the CPU circuitry and in the flexibility in allocating resources between memory areas.

A feature of the Harvard architecture is the presence of separate address spaces for storing commands and data (fig. 2). This architecture was almost never used until the late 1970s, when MC developers finally realized that it was precisely this architecture that gave them certain advantages. In particular, the analysis of real programs shows that the amount of MC data used to store intermediate results is about an order of magnitude less than the required amount of program memory. This means that you can reduce the bit width of the data bus, reduce the number of transistors in a microcircuit, and at the same time speed up access to information in both "hemispheres" of memory. As a result, most modern MCs now use the Harvard-style RISC architecture.

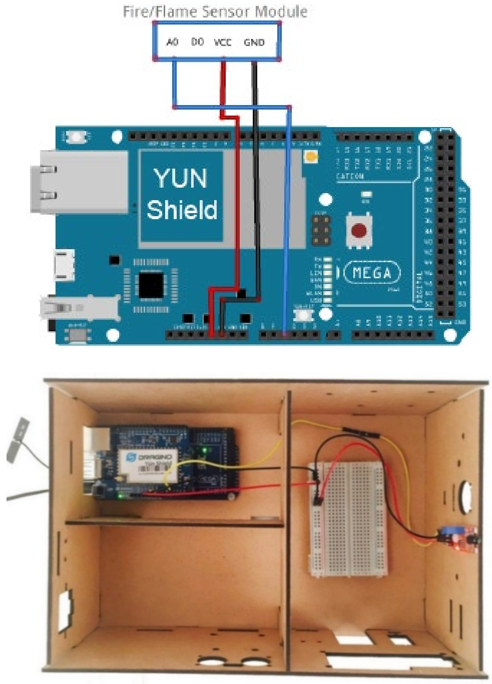

Figure 3. Connecting of fire sensor

Figure 4. "Serial Monitor" section

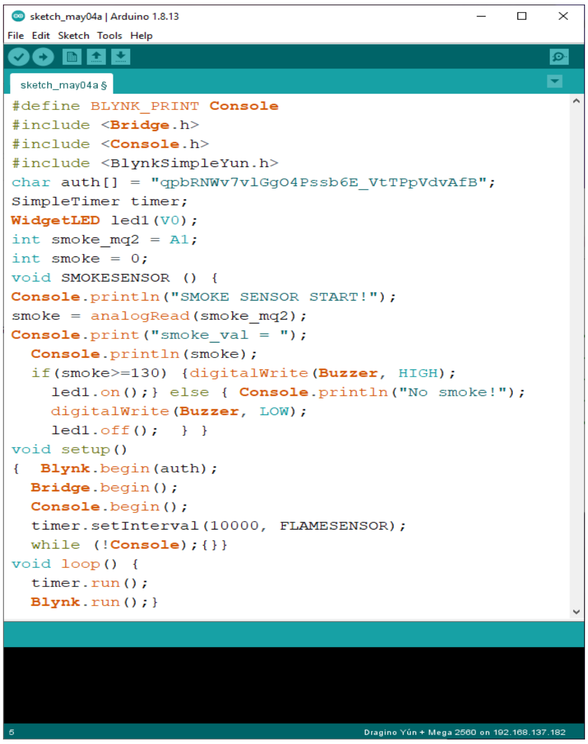

Figure 5. "Serial Monitor" section

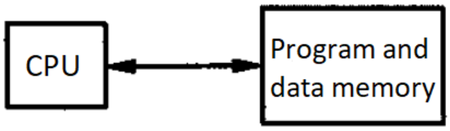

Figure 6. Princeton architecture

CONCLUSION

The following conclusions have been drawn from the research: The proposed system allows to easily manage of the process occurred in home via to remote control. If there is a gas leak or fire in the house, the alarm system is activated and a notification is sent to the phone. Changes in the apartment are under the controlled of the system can be seen in the "Serial Monitor" section.

REFERENCES

[1] Belov, A.V. Practical Encyclopedia of Arduino / A.V. Belov. M .: Science and technology. DMK Press, 2018. 272p.

[2] Bloom, D. Learning Arduino. Tools and methods of technical magic: a textbook / D. Bloom. - M: BHV-Petersburg, 2016 . 336 p.

[3] Ibrahimov B.G. Analysis performance multiservice telecommunication networks with using architectural concept future networks. / B.G. Ibrahimov, R.T. Humbatov, R.F. Ibrahimov // T-Comm, Moskow: 2018.vol.12, no.12, pp. 84-88.

[4] Michael P.F. Fundamentals of Communications Systems. Communications Engineering. / P.F. Michael. New-York: McGraw-Hill Companies, 2007. 436 p.

[5] Morozov E. Weak regeneration in modelling of queueing processes // Queueing Systems, 2004. № 46, pp. 295–315.

[6] Schlegel C.B. Trellis and turbo coding. / C.B. Schlegel, L.C. Perez, - Chichester: John Wiley & Sons, 2004. 393 p.

[7] Zadorozhniy V. N. Optimizing Uniform Non-Markov Queueing Networks/ V.N. Zadorozhniy // Automation and Remote Control, 2010, Vol. 71, No. 6, p. 1158–1169.

[8] Zhang-Shen R., McKeown N. Designing a fault-tolerant network using valiant load-balancing/ R.Zhang-Shen, N. McKeown // Conf. publ. the 27-th conf. on computer communications, IEEE INFOCOM, 2008, p. 2360-2368.

The Dynamic Model of GDP for Azerbaijan

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***Abstract*—One of the indicators of the country's economic growth is the gross domestic product (GDP), and one of the factors of economic growth is capital. The main criteria and source of economic development is economic growth. Economic growth is a sustainable increasing tendency of the main indicators of national theory production (GDP, GNI). Furthermore, absolute value and growth per capita are also considered. In economic and statistics, various indicators are used to measure the volume of national production. The most important of these is gross domestic product (GDP). GDP is expressed by monetary unit of the final products and services produced in the economy. Here should be taken into account the fact that GDP comprises final products and services produced within the particular country. In this work, was created the dynamic model that demonstrates the dependence of GDP on investments in case of Azerbaijan economy.**

Keywords—gross domestic product, macroeconomics, dynamic model, optimal trajectory, mathematical modeling of economic systems

I. Introduction

Consider the following task: how much investment should be allocated in a certain year to achieve the desired level of GDP after a certain period of time?

To do this, consider the following task:

$$J = \sum_{i=0}^{N} \left(x_{jel,i} - x_i\right)^2 + \sum_{i=0}^{N-1} u_{i+1}^2 \to \min \quad (1)$$

$$x_{i+1} = Fx_i + Gu_{i+1} + v, i = \overline{0, n-1} \quad (2)$$

$$x(0) = x_0 \quad (3)$$

Here, u_i is the volume of investment and x_i is the volume of GDP in the i-th year.

II. The Model of the Desired Level of GDP

Since we want to achieve the desired level at the end of the trajectory ($x_{jel,i} = 0, i = \overline{1, N-1}, x_{jel,N} = x_{jel}$), we can write (22) as follows:

$$J = \left(x_{jel} - x_N\right)^2 + \sum_{i=0}^{N-1} (x_i^2 + u_{i+1}^2) \to \min \quad (4)$$

We can rewrite this problem in the following form:

$$J = \frac{1}{2} q\left(x_{jel} - x_N\right)^2 + \sum_{i=0}^{N-1} (k_1 x_i^2 + k_2 u_{i+1}^2) \to \min \quad (5)$$

$$x_{i+1} = Fx_i + Gu_{i+1} + v, i = \overline{0, n-1} \quad (6)$$

$$x(0) = x_0 \quad (7)$$

Here, q, k_1, k_2 are coefficients, F, G, v was defined in [10], x_{jel} is the desired level of GDP and N is the number of years. For this, we construct an extended criterion of quality $\bar{J}$ [8]. To do this, we add systems of equations with coefficients $\lambda(i)$[1, 7] to function J:

$$\bar{J} = \frac{1}{2} q\left(x_{jel} - x_N\right)^2 + \sum_{i=0}^{N-1} \left[\frac{1}{2}(k_1 x_i^2 + k_2 u_{i+1}^2) + \lambda_{i+1}(Fx_i + Gu_{i+1} + v - x_{i+1})\right] \quad (8)$$

We use the following notation:

$$\Phi\left(x(N)\right) = \frac{1}{2} q\left(x_{jel} - x_N\right)^2$$

$$H^i = \frac{1}{2} k_1 x_i^2 + \frac{1}{2} k_2 u_{i+1}^2 + \lambda_{i+1}(Fx_i + Gu_{i+1} + v)$$

We can rewrite (8) as such:

$$\bar{J} = \frac{1}{2} q\left(x_{jel} - x_N\right)^2 - \lambda_N x_N + \sum_{i=1}^{N-1} \left[\frac{1}{2}(k_1 x_i^2 + k_2 u_{i+1}^2) + \lambda_{i+1}(Fx_i + Gu_{i+1} + v) - \lambda_i x_i\right] + H^0 \to \min \quad (9)$$

We get the following problem:

$$\bar{J} = \frac{1}{2} q\left(x_{jel} - x_N\right)^2 - \lambda_N x_N + \sum_{i=1}^{N-1} \left[\frac{1}{2}(k_1 x_i^2 + k_2 u_{i+1}^2) + \lambda_{i+1}(Fx_i + Gu_{i+1} + v) - \lambda_i x_i\right] + H^0 \to \min \quad (10)$$

$$x_{i+1} = Fx_i + Gu_{i+1} + v, i = \overline{0, n-1} \quad (11)$$

$$x(0) = x_0 \quad (12)$$

To solve the problems (10)-(12), i.e. to find the values $\lambda_i, (i = \overline{0, n+1})$, $u_i, (i = \overline{0, n-1})$ and $x_i, (i = \overline{0, n})$, we need to solve the following system of equations [3]:

$$\frac{\partial H^i}{\partial x_i} = \lambda_i \quad (13)$$
$$\frac{\partial H^i}{\partial u_i} = 0 \quad (14)$$
$$\frac{\partial \Phi}{\partial x_N} = \lambda_N \quad (15)$$
From this we get:
$$\lambda_i = k_1 x_i + \lambda_{i+1} F \quad (16)$$
$$0 = k_2 u_{i+1} + \lambda_{i+1} G \quad (17)$$
$$\lambda_N = q(x_N - x_{jel}) \quad (18)$$
And from (17) we find:
$$u_{i+1} = -\lambda_{i+1} G k_2^{-1} \quad (19)$$
Using (19) in (11) we find,
$$x_{i+1} = F x_i - G^2 k_2^{-1} \lambda_{i+1} + v, i = \overline{0, n-1}$$
In (16) we do the following conversion:
$$F\lambda_{i+1} = -k_1 x_i + \lambda_i$$
Based on these transformations, we obtain the following system of equations:
$$\begin{cases} x_{i+1} = F x_i - G^2 k_2^{-1} \lambda_{i+1} + v, i = \overline{0, n-1} & (20) \\ F\lambda_{i+1} = -k_1 x_i + \lambda_i & (21) \end{cases}$$
Here we find:
$$\begin{cases} x_{i+1} + G^2 k_2^{-1} \lambda_{i+1} = F x_i + v, i = \overline{0, n-1} \\ F\lambda_{i+1} = -k_1 x_i + \lambda_i \end{cases}$$
We write the final system in form of matrices:
$$\begin{bmatrix} E & G^2 k_2^{-1} \\ 0 & F \end{bmatrix} \begin{bmatrix} x_{i+1} \\ \lambda_{i+1} \end{bmatrix} = \begin{bmatrix} F & 0 \\ -k_1 & E \end{bmatrix} \begin{bmatrix} x_i \\ \lambda_i \end{bmatrix} + \begin{bmatrix} v \\ 0 \end{bmatrix}.$$
From this we get x_{i+1} and λ_{i+1}:
$$\begin{bmatrix} x_{i+1} \\ \lambda_{i+1} \end{bmatrix} = \begin{bmatrix} E & G^2 k_2^{-1} \\ 0 & F \end{bmatrix}^{-1} \begin{bmatrix} F & 0 \\ -k_1 & E \end{bmatrix} \begin{bmatrix} x_i \\ \lambda_i \end{bmatrix} + \begin{bmatrix} E & G^2 k_2^{-1} \\ 0 & F \end{bmatrix}^{-1} \begin{bmatrix} v \\ 0 \end{bmatrix} \quad (22)$$
From (22) we get:
$$\begin{bmatrix} x_{i+1} \\ \lambda_{i+1} \end{bmatrix} = \begin{bmatrix} F + G^2 k_1 k_2^{-1} F^{-1} & -G^2 k_2^{-1} F^{-1} \\ -k_1 F^{-1} & F^{-1} \end{bmatrix} \begin{bmatrix} x_i \\ \lambda_i \end{bmatrix} + \begin{bmatrix} v \\ 0 \end{bmatrix} \quad (23)$$
We introduce the following notation:
$$A = \begin{bmatrix} F + G^2 k_1 k_2^{-1} F^{-1} & -G^2 k_2^{-1} F^{-1} \\ -k_1 F^{-1} & F^{-1} \end{bmatrix}$$
Then, (23) can be written as such:
$$\begin{bmatrix} x_{i+1} \\ \lambda_{i+1} \end{bmatrix} = A \begin{bmatrix} x_i \\ \lambda_i \end{bmatrix} + \begin{bmatrix} v \\ 0 \end{bmatrix} \quad (24)$$
We find:
$$\begin{bmatrix} x_{i+2} \\ \lambda_{i+2} \end{bmatrix} = A \begin{bmatrix} x_{i+1} \\ \lambda_{i+1} \end{bmatrix} + \begin{bmatrix} v \\ 0 \end{bmatrix} = A^2 \begin{bmatrix} x_i \\ \lambda_i \end{bmatrix} + A \begin{bmatrix} v \\ 0 \end{bmatrix} + \begin{bmatrix} v \\ 0 \end{bmatrix}$$
$$\begin{bmatrix} x_{i+3} \\ \lambda_{i+3} \end{bmatrix} = A \begin{bmatrix} x_{i+2} \\ \lambda_{i+2} \end{bmatrix} + \begin{bmatrix} v \\ 0 \end{bmatrix} = A^3 \begin{bmatrix} x_i \\ \lambda_i \end{bmatrix} + (A^2 + A + A^0) \begin{bmatrix} v \\ 0 \end{bmatrix}$$
From here we can simply write:
$$\begin{bmatrix} x_{i+k} \\ \lambda_{i+k} \end{bmatrix} = A^k \begin{bmatrix} x_i \\ \lambda_i \end{bmatrix} + (A^{k-1} + A^{k-2} + \cdots + A + A^0) \begin{bmatrix} v \\ 0 \end{bmatrix} \quad (25)$$
And so, (25) can be written in the following form:
$$\begin{bmatrix} x_N \\ \lambda_N \end{bmatrix} = A^N \begin{bmatrix} x_0 \\ \lambda_0 \end{bmatrix} + (A^{N-1} + A^{N-2} + \cdots + A + A^0) \begin{bmatrix} v \\ 0 \end{bmatrix} \quad (26)$$
We introduce the next notation:
$$A^N = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix},$$
$$\begin{bmatrix} f_1 \\ f_2 \end{bmatrix} = (A^{N-1} + A^{N-2} + \cdots + A + A^0) \begin{bmatrix} v \\ 0 \end{bmatrix} \quad (27)$$
So, (26) can be written as:
$$\begin{bmatrix} x_N \\ \lambda_N \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} x_0 \\ \lambda_0 \end{bmatrix} + \begin{bmatrix} f_1 \\ f_2 \end{bmatrix} \quad (28)$$
From this we get:
$$\begin{cases} x_N = a_{11} x_0 + a_{12} \lambda_0 + f_1 \\ \lambda_N = a_{21} x_0 + a_{22} \lambda_0 + f_2 \end{cases}$$
If we add condition (18) here, we obtain the following system of equations:
$$\begin{cases} x_N = a_{11} x_0 + a_{12} \lambda_0 + f_1 & (29) \\ \lambda_N = a_{21} x_0 + a_{22} \lambda_0 + f_2 & (30) \\ \lambda_N = q(x_N - x_{jel}) & (31) \end{cases}$$
The values of f_1 and f_2 are obtained from (27). Considering (29) and (30) in (31) we get:
$$\lambda_0 = (q a_{12} - a_{22})^{-1} \Big(x_{jel} q - (q a_{11} - a_{21}) - (q f_1 - f_2) \Big) \quad (32)$$
x_0 is given to us as an initial condition, and λ_0 can be calculated from (32). Using this, we can calculate $\lambda_i, (i = \overline{0, n+1})$, $u_i, (i = \overline{0, n-1})$ and $x_i, (i = \overline{0, n})$. Values of $\lambda_i, (i = \overline{0, n+1})$ and $x_i, (i = \overline{0, n})$ can be calculated from expression (23), and $u_i, (i = \overline{0, n-1})$ from expression (19).

III. CONCLUSION

This approach provides an opportunity for strategic planning of GDP for the country. In this work, to achieve the desired level of GDP, the volume of investment is used as the independent variable in the dynamic model. But as indicated above, many other factors affect GDP. We chose one of them: the amount of investment. But even so, the dynamic model of the optimal GDP trajectory yielded good results (see Table 2 and Figure 1).

Further research will take into account the other\ most influential factors on GDP. In this case, a dynamic model of the optimal trajectory of GDP will give even more adequate results. Many parameters of the incoming model are approximate. Therefore, in the future, work can be developed with fluctuations in parameters - in other words, the study of stability with respect to the change in error (see [10]). Another direction for research is the application of pattern recognition methods with predetermined threshold numbers. In this case, the classification problem is obtained (see [11]).

REFERENCES

[1] Aliev F.A., Larin V.B.,Optimization of Linear Control Systems: Analytical Methods and Computational Algorithms, Amsterdam: Gordon and Breach Sci, 1998.

[2] Aliyev F.A., Metody resheniya prikladnykh zadach optimizachii dinamicheskikh sistem, Baku, 1989 (Aliev F.A., Solution methods of optimization dynamic systems applied problems, Baku, 1989) (in Russian)

[3] Aliyev F.A., Shafizade E.R. Shikhlinskaya R.Y., Murtuzaliyev T.F., Ekonomiko-matematicheskaya model maksimizachii pribyli Internet magazina, Aktualnye problemy ekonomiki, ISSN 1993 – 6788, 3(141), 2013, str.210-219 (Aliev F.A., Shafizade E.R. Shikhlinskaya R.Y., Murtuzaliev T.F.,Economic-Mathematical model of maximization revenue of e-store, Actual problems of Economics, ISSN 1993 – 6788, 3(141), 2013, pp.210-219)(in Russian)

[4] Aliyev F.A., Niftiyev A.A., Shafizade E.R. Shikhlinskaya R.Y., Murtuzaliyev T.F., Ekonomiko-matematicheskaya model v virtualnom biznese s primeneniyem nechetkogo apparata, Desyataya Mejdunarodnaya Aziatskaya Shkola-Seminar “Problemy optimizachii slojnykh sistem”, Kyrgyziskaya Respublika, 2014, str. 33-39 (Aliev F.A., Niftiev A.A., Shafizade E.R. Shikhlinskaya R.Y., Murtuzaliev T.F., Economic-Mathematical model in virtual business with fuzzy apparatus, 10-th International Asian School-Seminar “Optimization

problems of difficult sistems", Kyrgyz Republic, 2014, pp. 33-39) (in Russian)

[5] Aliyev F.A., Niftiyev A.A., Shikhlinskaya R.Y., Shafizade E.R., Murtuzaliyev T.F., Nechetkaya model elektronnoy torqovli, Proceedings of Inatitute of Applied Mathematics, V3, N1, 2014, pp.23-31 (Aliev F.A., Niftiev A.A., Shafizade E.R. Shikhlinskaya R.Y., Murtuzaliev T.F., Fuzzy model of e-trade, Proceedings of Inatitute of Applied Mathematics, V3, N1, 2014, pp.23-31) (in Russian)

[6] Aliev F.A., Shafizadeh E.R., Hasanova G.R., Zeynalov J., Fuzzy model and algorithm for solving of e-shop income maximization, The 5-th International Conference on Control and Optimization with Industrial Applications, 27-29 August, 2015, Baku, Azerbaijan, pp.179-185.

[7] Brayson A., Kho Yu-Shi, Prikladnaya teoriya optimalnogo upravleniya, Moskva, 1972 (Bryson A., Ho Yu-Chi, Applied Optimal Control, Moscow, 1972) (in Russian)

[8] Golichenko O.G., Ekonomicheskoye razvitiye v usloviyakh nesovershennoy konkurenchii: Podkhody k mnogourovnevomu modelirovaniyu, M:Nauka, 1999 (Golichenko O.G., Economic development under imperfect competition. Approximitation to multilevel modeling, M:Nauka, 1999) (in Russian)

[9] Gurman V.I., Osnovy makroekonomicheskogo analiza, Tver, 1995 (Gurman V.I., Basics of macroeconomic analyze, Tver, 1995)

[10] Shafizade E.R., Hasanova G., Dynamic model for Gross Domestic Product in Azerbaijan, 6th International Conference on Control and Optimization with Industrial Applications, COIA- 2018, 11-13 July, Baku, Azerbaijan (Web of Science)

[11] Zang V.B., Sinergeticheskaya ekonomika. Vremya i peremeny v nelineynoy ekonomicheskoy teorii, M: Mir, 1999 (Zang V.B., Synergetic economics. Time and changes in nonlinear economical theory, M: Mir, 1999) (in Russian)