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.

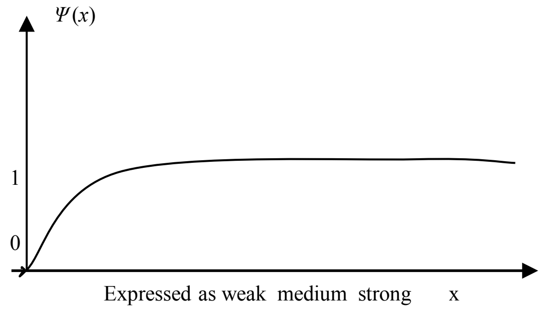

Fig.1. Graphical description of affiliation function

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 $\tilde{V}_g = \{\mu_{L_{gi}}(y)/y, i = \overline{1,16}\}$, and the real pattern of employee holding this position can be described as a fuzzy pattern $\tilde{S}_g = \{\mu_{L_{gi}}(y)/y, i = \overline{1,16}\}$.

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 $\theta(\tilde{S}_g, \tilde{V}_g)$ is calculated using the following formula [31]:

$$\theta(\tilde{S}_g,\tilde{V}_g) = \& \, \theta(\mu_{S_gL_i}(y), \mu_{VgL_i}(y)) = \underset{y\in Y}{\&} (\max(1-\mu_{S_gL_i}(y), \mu_{V_gL_i}(y))) =$$
$$= \min_{y\in Y}(\max(1-\mu_{S_gL_i}(y), \mu_{V_gL_i}(y)))$$

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 $\theta(\tilde{S}_g, \tilde{V}_g) \geq \psi[0,8;1]$, then the real fuzzy pattern $\tilde{S}_g$ is completely similar to the reference fuzzy pattern $\tilde{V}_i$ and the relevant specialist "corresponds to the position";
2. If $\theta(\tilde{S}_g, \tilde{V}_g) \geq \psi[0,5;0,79]$, then the real fuzzy pattern $\tilde{S}_g$ is moderately similar to the reference fuzzy pattern $\tilde{V}_i$ and the relevant specialist "moderately corresponds to the position";
3. If $\theta(\tilde{S}_g, \tilde{V}_g) \leq \psi[0,1;0,49]$, then the real fuzzy pattern $\tilde{S}_g$ is not similar to the reference fuzzy pattern $\tilde{V}_i$ 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.

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