The Role of Intelligent Transportation Systems in the Development of Transportation Safety

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Abstract. The article examines the reasons for the emergence of traffic jams, infrastructure overloading, and increased risks in transport safety, while modern transport systems significantly increase the intensity of people and goods transportation, stimulate economic activity, and contribute significantly to the strengthening of global relations. To solve these problems, the structure of the Intelligent Transport System (ITS) is presented using advanced technological approaches. ITS combines sensors, information technologies, communication networks, automated control, and data analysis to perform real-time monitoring and management of transport processes. The use of such applications results in accident detection, traffic flow optimization, driver assistance, and provision of technical maintenance during infrastructure forecasting. Studies show that the introduction of such systems in cities and regions has reduced accidents by 20–35% in the first three years, while significantly minimizing operational efficiency, efficiency, and operating costs. ITS technologies are applied in a number of transport modes, including rail, road, air, and sea transport. However, there are difficulties such as system compatibility problems, high financial costs, data confidentiality violations, and human adaptation. This article examines the role of ITS in organizing transport safety, solutions to existing technological issues, application problems, and future prospects, as well as an analytical analysis of artificial intelligence and big data.

Keywords: Intelligent Transportation Systems, Transportation Safety, Traffic Monitoring, Traffic Management, Automated Management, Big Data Analytics.

1 Introduction

In modern times, transport systems are considered one of the main elements of economic development and social relations. The acceleration of the global urbanization process, the increase in population and the increase in the number of vehicles in cities have significantly increased the demand for transport infrastructure. As a result of this process, the management of transport systems has become more complex and road

safety issues have gained particular relevance. Traditional transport management methods are not considered effective enough in managing the increasing traffic flow and ensuring road safety. Especially in large cities, the increase in traffic jams, the increase in road accidents and the increase in the load on the transport infrastructure have necessitated the application of new technological solutions. In this regard, Intelligent Transport Systems (ITS) act as one of the main elements of the modern transport management concept. ITS is based on the integration of information and communication technologies, sensor systems, big data analytics and automated control mechanisms. These systems make it possible to monitor traffic flow in real time, analyze traffic density and make optimal management decisions.

The application of intelligent transport systems not only improves transport safety, but also optimizes transport flows, uses energy resources more efficiently and reduces environmental impact [1]. Studies conducted in various countries show that the application of ITS technologies has reduced the number of road accidents, minimized transport delays and managed transport infrastructure more effectively [2]. At the same time, the role of artificial intelligence, machine learning and big data technologies in the development of modern transport systems is increasingly increasing. These technologies make it possible to predict traffic flows, identify accident risks in advance and automate the management of transport systems. The main purpose of this article is to examine the role of intelligent transport systems in ensuring transport safety, to analyze the technologies applied in this field and to assess their application possibilities in various types of transport. In addition, the article also discusses the problems arising during the application of ITS systems and their future development prospects.

Other studies show that the application of ITS:

- Real-time traffic monitoring and management
- Accident prevention with driver assistance systems
- Optimal use of infrastructure through predictive maintenance
- Automated signaling and adaptive traffic management
- Increased safety in various modes of transport (road, rail, air, sea).

Subsequent paragraphs, however, are indented.

2 Intelligent Transportation Systems Research Methodology

The rapid increase in the number of vehicles in modern cities has made the management of transport systems a more complex and difficult process. As a result of the increase in the level of urbanization, population density and expansion of economic activity, the load on the transport infrastructure has increased significantly. This leads to the formation of traffic jams, increased transport delays and reduced road safety. Statistica data show that a significant part of road accidents is associated with the human factor, improper management of traffic flow and lack of information. Traditional transport management systems do not have sufficient capabilities to manage the increasing traffic flow promptly and effectively. On the other hand, real-time monitoring of the technical condition of transport infrastructure and early detection of malfunctions are also important problems. In existing approaches, technical maintenance is mainly carried out

in a planned manner, which sometimes does not allow for the timely detection of unexpected malfunctions. To solve these problems, the application of modern information and communication technologies in the management of transport systems is considered necessary. Intelligent transportation systems enable more efficient and safe management of transportation systems through sensor technologies, data processing, and automated control [3].

In this regard, the main research problem is to determine how transport safety can be increased through the application of intelligent transport systems and how to manage traffic flow more optimally. In this study, a complex methodological approach was used to study the impact of intelligent transport systems on traffic safety. Both theoretical and analytical methods were used in the research process. In the first stage, the existing scientific literature and international research results on the topic were analyzed. In this stage, studies conducted on the development of intelligent transport systems, their application areas and impact on traffic safety were systematically examined [4]. In the next stage, ANS technologies applied in various modes of transport were comparatively analyzed.

Intelligent Transportation Systems (ITS) are a complex technological platform that plays a crucial role in the safe and efficient management of modern urban transportation. The conceptual diagram of the intelligent transportation system, presented visually, is given as follows (see **Error! Reference source not found.**1):

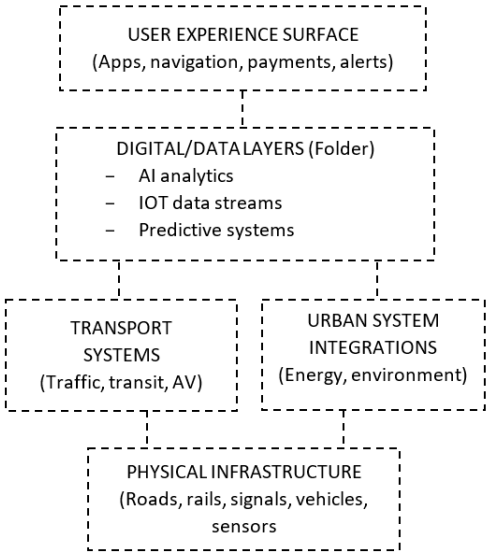

Fig. 1. Conceptual diagram of the smart city and transportation ecosystem

The visual composition presented below clearly reflects the integrated and multi-level structure of modern intelligent transportation systems (ITS). The parallel depiction of various means of transport - cars, public buses and high-speed trains - against the backdrop of an urban environment emphasizes the multimodal nature of the transport system. This shows that different modes of transport operate in a interconnected and coordinated manner in modern urban mobility **(see** Error! Reference source not found.2**)**.

Fig. 2. Visual representation of an intelligent transportation system.

During this analysis, technological solutions used in the fields of road, rail, air and sea transport and their effectiveness were evaluated. In the next stage of the study, statistical data analysis was conducted and the impact of the application of intelligent transport systems on the reduction of road accidents and the optimization of traffic flow was investigated. For this purpose, the experience of various countries and statistical data provided by international organizations were used. In addition, the application possibilities of modern technologies used in the management of transport systems - sensor systems, big data analytics, and artificial intelligence algorithms - were also evaluated.

The global network symbol placed in the center of the visual indicates that intelligent transport systems are based on the exchange of information not only locally, but also globally. This element demonstrates that communication technologies operating in real time, in particular satellite systems, wireless communications and internet-based platforms, play a key role in transport management. Signals, sensor icons and surveillance cameras placed around symbolize data collection and monitoring mechanisms. The wireless communication signs on the car depicted in the foreground of the image indicate the connection of vehicles with each other and with the road infrastructure (V2X – Vehicle-to-Everything). Through this technology, drivers are warned in advance about potential dangers, as a result, the risk of accidents is minimized. At the same time, intelligent control devices and traffic lights located on the side of the road reflect the

application of adaptive control principles; that is, automatic adjustment is carried out in accordance with the intensity of road traffic.

Elements pointing to the "smart city" concept on the bus, which is presented as a public transport vehicle in the image, indicate that passenger transportation is also digitalized. This involves the implementation of functions such as real-time schedules, electronic payment systems and passenger flow analysis. On the other hand, the image of a high-speed train emphasizes the development of intra-city and inter-city transport with high speed and safety standards. Another important element that stands out in the visual is the transport management interface presented via a tablet. This component shows that intelligent transport systems have centralized management and decision-making mechanisms. Such systems work on the basis of big data analysis, optimizing transport flows and responding promptly to emergencies.

Overall, this image comprehensively reflects the main features of intelligent transport systems - digitalization, automation, real-time information exchange, adaptive management and increased safety. The visual approach shows that the transport systems of the future do not consist only of physical infrastructure, but are also based on highly integrated information and communication technologies, which also serve the sustainable and safe development of urban life. ITS combines four main components: sensors, communication networks, automation and data analytics. Together, these elements optimize transport operations and safety (Table 1).

Table 1. ITS Components and Functions.

Component	Function
Sensors	Detects vehicle position, speed and environment
Communication networks	Transmits data between vehicles, infrastructure and control centers
Automation	Prevents collisions, provides adaptive signals and autonomous guidance
Data analytics	Real-time traffic analysis, predictive maintenance, decision-making

These systems combine various information and communication technologies to optimize traffic flow and prevent traffic accidents. In particular, applications conducted in recent years have shown that the integration of ITS directly affects the reduction of accidents and the increase in operational efficiency [6]. One of the main advantages of ITS is real-time traffic monitoring capabilities. Changes in the road network are recorded promptly through sensors, surveillance cameras, and satellite-based tracking systems. This data is processed in central control systems, allowing for early identification

of the possibility of traffic jams and immediate intervention. As a result, both traffic flow is optimized and the risk of accidents is reduced.

Another important component is driver assistance systems. These technologies warn drivers in real time about speed limits, lane departures, dangerous distances, and other critical situations. Such systems significantly increase traffic safety by partially preventing errors caused by the human factor. The role of these systems is especially felt on long-distance and intensively trafficked highways. Another important aspect of ITS is predictive infrastructure maintenance. Road surfaces, bridges, and other transport infrastructure elements are continuously monitored using various sensors. Based on the analysis of the collected data, potential failures are identified in advance and preventive measures are taken. This approach prevents sudden technical problems, increases safety, and optimizes maintenance costs.

In addition, adaptive traffic management is one of the most effective mechanisms of ITS. These systems automatically change the operating mode of traffic lights and traffic rules in accordance with real-time traffic density. Thus, the traffic flow is distributed more balancedly, congestion is reduced, and speed stability is ensured. Maintaining speed stability is one of the main factors that reduce the likelihood of accidents [7].

Finally, collision warning systems occupy a special place in transport safety. These systems, by exchanging information between cars and infrastructure, identify potential collision situations in advance and send warning signals to drivers. Such technologies serve to minimize the risk of accidents, especially in dense urban environments and complex road junctions.

The results of the conducted studies show that the implementation of ITS has a significant positive effect from the first years. According to statistical observations, the number of traffic accidents in cities that implement these systems decreases by an average of 20–35% during the first three years. This is assessed as a direct result not only of technological development, but also of the optimization of management. Thus, ITS makes it possible not only to manage traffic flows, but also to systematically ensure safety in the urban environment. The widespread implementation of these systems creates the basis for the formation of a more sustainable, safe and effective transport infrastructure in the future (Table 2).

Table 2. ITS Applications and Key Benefits.

Transport Type	ITS Applications	Key Benefits
Road	Adaptive signaling, vehicle routing, collision warnings	Reduce accident risk, optimize traffic
Rail	Automated signaling, predictive maintenance	Prevent collisions, safe schedules
Air	Flight monitoring, navigation, weather alerts	Increase safety, reduce delays
Sea	Ship tracking, port logistics	Prevent accidents, optimize operations

Challenges and Future Prospects
Despite the advantages of ANS, there are a number of challenges:
- System compatibility (interoperability)
- High investment costs
- Data confidentiality
- Human adaptation
Future trends: artificial intelligence, big data analytics, autonomous systems, adaptive traffic management and environmentally sustainable transport.

3 Intelligent transportation systems in Baku

In recent years, the application of smart transport technologies has expanded in Baku. Adaptive traffic light systems, video surveillance cameras and real-time traffic monitoring are used to manage traffic more efficiently. These systems reduce traffic jams, increase road safety and optimize traffic flow (Table 3).

Table 3**.** ITS Applications and Key Benefits.

№	Year	Traffic density index
1	2020	78
2	2021	74
3	2022	69
4	2023	63
5	2024	58

According to statistics, after the introduction of adaptive signal systems, traffic delays at some major intersections have decreased by approximately 15–20% **(see** Error! Reference source not found.3**)**

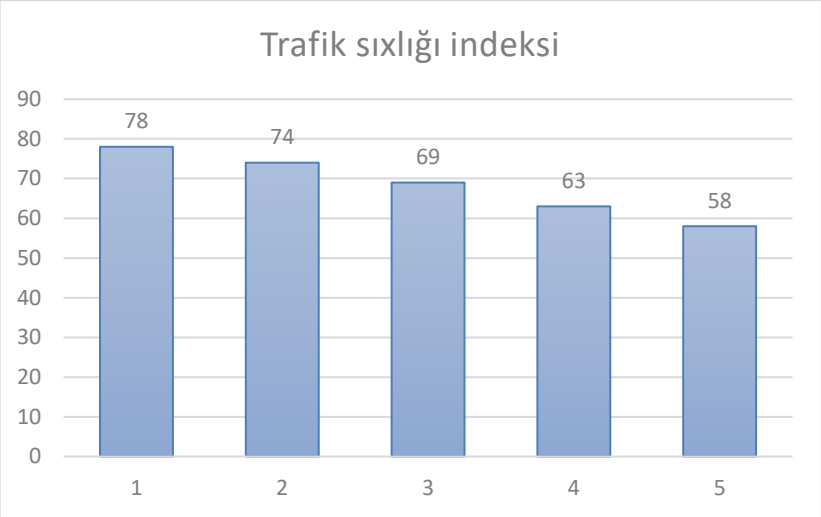

Fig. 3. Graphical representation of traffic density index system.

ITS play an important role in the development of modern transport infrastructure and are widely used in various transport sectors. These technologies not only increase transport safety, but also ensure efficient management of traffic flow. ITS technologies are most widely used in the field of road transport. Adaptive traffic light systems, monitoring of traffic flow and providing real-time information to drivers allow for safer and more efficient organization of road traffic.
Data collected through sensors and video surveillance cameras is analyzed to determine the causes of traffic jams and optimize traffic flow through traffic management systems. In addition, route recommendations are provided to drivers through mobile applications, which helps to reduce traffic congestion.

In railway transport, ANS technologies are mainly used to ensure safety and coordinate the movement of trains. Automated signaling systems allow for real-time monitoring of train movements and the prevention of possible collisions. In addition, predictive maintenance technologies assess the condition of rails and other infrastructure elements in advance. This approach allows for timely detection of technical malfunctions and reduces the risk of accidents. In the field of air transport, intelligent transport systems play an important role in increasing flight safety. Air transport movements are accurately monitored using modern radar systems, satellite navigation and flight monitoring technologies. These systems analyze data on weather conditions, flight routes and airport infrastructure, ensuring safer and more efficient flights.

In maritime transport, ITS technologies are mainly applied in the field of ship tracking and port logistics. The position and direction of movement of ships are monitored in real time through automatic identification systems (AIS). These technologies

contribute to more efficient management of cargo transportation in ports and prevention of maritime accidents. The application of intelligent transport systems makes a significant contribution to increasing transport safety and efficiency. Studies conducted in various countries show that the number of road accidents is significantly reduced as a result of the application of ITS technologies and traffic flow management is carried out more effectively [10].

However, the application of ITS technologies is also accompanied by certain problems. These problems include high financial costs, the need to modernize existing infrastructure, and information security issues. On the other hand, interoperability of various systems is also an important issue. Integration of various technologies on a single platform is important for increasing the efficiency of transport systems (Table 4).

Table 4**.** Directions of application of smart transport technologies in Azerbaijan.

Technology	Application Area	Main goal
CCTV cameras	Urban Roads and Intersections	Controlling traffic and increasing safety
Adaptive traffic light systems	Major Intersections	Optimising traffic flow
Electronic fine system	Traffic Violations	Monitoring the implementation of rules
Public transport monitoring	Bus Routes	Improving the quality of transport services
Digital information panels	Highways	Providing real-time information to drivers

Below are 5 practical examples of real-world implementation in Azerbaijan[11}:

1. “Green Wave” traffic light system in Baku

The “green wave” system implemented in Baku ensures the synchronous operation of traffic lights and optimizes the uninterrupted movement of traffic flow. As a result, traffic jams are reduced, traffic flow is accelerated, and pedestrian safety is increased. This system has already been implemented on the main streets of the city and coordination between intersections has been established.

2. Baku Intelligent Transport Management System (ITS)

The Intelligent Transport System established in Azerbaijan collects data in real time through sensors, cameras, and radars and processes it on central servers.

Technological components:

- Video detectors and CCTV cameras
- Automatic incident detection
- Traffic management

Practical result:

- Operational detection of accidents
- Traffic jam management
- Increased traffic safety

3. BakuKART electronic payment system

A unified electronic card system applied in public transport ensures passenger flow management and digitalization of transport.
Practical result:
- Cashless payment → fast boarding/disembarking
- Collection of statistical data on passenger flow
- Optimization of transport planning
This system has been applied in the metro and buses since 2015.
4. Baku "Digital Twin" project
A digital model of the city of Baku is created and transport flows are simulated in advance.
Practical application:
- Early identification of bottlenecks
- Testing of new road and infrastructure projects
- Optimization of urban planning
Result:
- Less risky and scientifically based decision-making
- Proactive improvement of transport safety
5. Absheron Circular Railway (Baku Suburban Railway)
Operating since 2019, this system creates a fast and safe transport connection between the inner city and the surrounding areas.
Practical result:
- Reduction of vehicle load
- Reduction of environmental impact
- Indirect impact on reducing accidents
The system already serves millions of passengers and makes urban transport alternative.
The Azerbaijani example shows that intelligent transport systems:
- Digital management (ITS, Digital Twin)
- Automated signaling (Green Wave)
- Electronic payment and data analytics (BakiKART)
Through these, it has a significant impact on increasing transport safety, reducing accident risks, and optimizing urban mobility (Table 5).

Table 5**.** Expected results of implementing ANS.

Indicator	ANS application	After ANS application (approximate)
Number of road accidents	high	20–30% reduction
Traffic density	high	moderate level
Traffic delay	15–20 minutes	5–10 minutes
Traffic control	limited	real-time monitoring
Traffic management	traditional	digital and automated

The unified electronic card system applied in public transport ensures passenger flow management and digitalization of transport.
Practical result:
- Cashless payment → fast boarding/disembarking
- Collection of statistical data on passenger flow
- Optimization of transport planning
This system has been applied in metro and buses since 2015.
4. Baku "Digital Twin" project
A digital model of the city of Baku is created and transport flows are simulated in advance.
Practical application:
- Pre-identification of traffic jam points
- Testing of new road and infrastructure projects
- Optimization of urban planning
Result:
- Less risky and scientifically based decision-making
- Proactive increase in transport safety
5. Absheron circular railway (Baku suburban railway)
This system, which has been operating since 2019, creates a fast and safe transport connection between the city and surrounding areas.

Practical result:

- Reduction of vehicle load
- Reduction of environmental impact
- Indirect impact on reducing accidents

The system already serves millions of passengers and makes urban transport alternative.

The Azerbaijani example shows that intelligent transport systems:

- digital control (ITS, Digital Twin)
- automated signaling (Green Wave)
- electronic payment and data analytics (BakiKART)

Through them, they have a significant impact on increasing transport safety, reducing accident risks and optimizing urban mobility.

The models presented below explain the mathematical foundations of intelligent transport systems (ITS) in a more in-depth and systematic way. Fundamental model of traffic flow: This model is the most basic relationship of transport theory and forms the beginning of the "fundamental diagram".

q — road capacity (number of vehicles passing per unit time)

k — road density (vehicles per unit length)

v — average speed

This relationship shows that the flow intensity is the product of two main factors. However, this linear model is valid only for ideal situations. In real systems:

- Speed decreases as density increases
- Therefore, q decreases after the maximum point

Intelligent systems:
- By regulating speed (e.g., variable speed limits)
- By distributing density (alternative routes)
ensure that q is kept close to the maximum point.

Future Research Perspectives. Future research is mainly focused on the integration of artificial intelligence and big data analytics technologies into transportation systems. Through artificial intelligence algorithms, it will be possible to predict traffic flow, identify accidents in advance, and automate the management of transportation systems. In addition, the development of autonomous vehicles requires further improvement of ANS systems. These technologies will not only increase the safety and efficiency of transportation systems, but also contribute to ensuring environmental sustainability in urban environments.

Scientific Innovation of the Research. The scientific innovation of this research is expressed in the comprehensive analysis of intelligent transport systems in terms of increasing transport safety and in the systematic study of the possibilities of applying these technologies in various types of transport.

The article analyzes the main technological components of intelligent transport systems - sensor systems, communication technologies, big data analytics and artificial intelligence-based management methods. This approach allows for a more comprehensive assessment of the role of modern technologies in the management of transport systems.

Another innovation of the research is the comparative analysis of various types of transport - road, rail, air and sea transport - in terms of ensuring transport safety. This approach allows for a clearer definition of the areas of application of intelligent transport systems and an assessment of their effectiveness.

In addition, the article also considers the prospects of intelligent transport systems in the context of the development of transport systems in the Republic of Azerbaijan and the application of digital technologies. This approach allows for the identification of possible development directions for the modernization of transport systems at the regional level. Thus, the research conducted has shown that the application of intelligent transportation systems is of great importance in terms of increasing transportation safety and optimizing traffic flow.

Conclusion. Intelligent transport systems play an important role in the development of modern transport infrastructure and provide effective technological solutions for increasing transport safety. The integration of sensor technologies, big data analytics and automated control systems allows for real-time management of transport flows and reduction of accident risks.

The application of ANS technologies in various countries shows that these systems provide significant results in terms of increasing transport safety, reducing traffic jams and improving the overall efficiency of transport systems. At the same time, issues such as high investment costs, technological compatibility and information security are among the main problems that should be considered when implementing ANS systems.

In the Republic of Azerbaijan, important steps have been taken in recent years to modernize transport infrastructure and apply digital technologies. In particular, the transport

management systems, video surveillance infrastructure and electronic transport services implemented in Baku form an important basis for the development of intelligent transport systems.

In the future, the application of artificial intelligence, big data analytics and automated transport technologies may allow for more efficient and safe management of the Azerbaijani transport system. Scientific research and the application of innovative technologies in this direction will make a significant contribution to the development of intelligent transportation systems in the country.

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