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Implementing logistics technologies to optimize road transport flows: Urban planning, traffic capacity, and safety

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Abstract: The relevance of the research topic is driven by contemporary challenges of urbanization and the increasing number of vehicles, which necessitate effective management of transport flows and enhancement of road traffic safety. Implementing logistics technologies, such as Intelligent Transport Systems (ITS) and Geographic Information Systems (GIS), is becoming a priority for optimizing urban transport infrastructure. The research aims to analyze and assess the implementation of logistics technologies for optimizing transport flows in road transport, with the transport system of cities being the research object. The methodological basis of the research is a systems analysis, including theoretical substantiation and practical assessment of the efficiency of using ITS and GIS. The research showed that ITS reduces congestion and increases road capacity through adaptive traffic management and real-time monitoring. Implementing GIS allows for more precise planning and management of transport infrastructure, reducing traffic jams and improving road safety. The practical significance of the results lies in the possibility of their application for improving urban planning, saving time and resources, and enhancing road safety. The analysis showed that successful implementation of logistics technologies requires consideration of technical, organizational, and social aspects, as well as continuous data updating and staff training. Prospects for further research include integrating new technologies and methods to enhance the efficiency of transport systems management and improve the overall transport situation in cities.

Keywords: *Capacity, Organization and road traffic safety, Road transport, Transport flows, Urban planning.*

1. Introduction

Under the conditions of modern urbanization and the increase in the number of cars on the roads, ensuring effective transport flow management and improving road safety have become priority tasks for urban agglomerations. Intelligent Transport Systems (ITS) and Geographic Information Systems (GIS) are vital technologies capable of significantly improving the road situation. These technologies provide new opportunities for monitoring, analyzing, and optimizing transport flows, which helps reduce congestion and increase road capacity. Research shows that the implementation of ITS and GIS not only improves transport infrastructure but also enhances road safety. Additionally, these technologies

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can bring significant economic benefits by reducing fuel costs and travel time. However, successful implementation and use of these systems require considering various technical, organizational, and social aspects. This article examines different approaches and methods for optimizing transport flows using ITS and GIS and analyses the results of their application in various cities. The main goal of the research is to identify the most effective solutions for managing the transport system and ensuring road safety.

Modern cities face numerous challenges in transport logistics, with critical issues including the increasing number of cars, road congestion, and declining road safety. With the constant growth of urbanization, traditional methods of managing traffic flows are becoming ineffective. According to research by Alkhatib and Sawalha [1] implementing Intelligent Transport Systems (ITS) can significantly improve traffic management and enhance road safety. However, Gurjanov, et al. [2] point out that the application of Internet of Things (IoT) technologies in the organization of road traffic requires substantial financial and technical resources, which may hinder their widespread implementation. Additionally, Zhu, et al. [3] emphasize that using ITS in urban settings reduces congestion and optimizes traffic flows, positively affecting road capacity. Nevertheless, Park, et al. [4] highlight the need to consider the human factor and possible technical failures when integrating automated vehicles into existing infrastructure.

Another significant issue is the underutilization of Geographic Information Systems (GIS) for planning and managing urban transport infrastructure. Budzyński, et al. [5] demonstrated that GIS allows for more accurate analysis and visualization of spatial data, contributing to improved transport route planning. However, Vasile, et al. [6] note that maintaining the relevance and accuracy of GIS data requires constant updates, which also demands substantial resources. Thus, despite the proven effectiveness of ITS and GIS, their implementation and use are associated with several problems, including technical, financial, and organizational aspects. This study aims to identify the most effective solutions for optimizing traffic flows and improving road safety, considering the existing challenges and limitations.

This article aims to study and analyses the implementation of logistics technologies for optimizing traffic flows in road transport, focusing on urban planning, increasing capacity and ensuring road safety.

1.1. Objectives

1. To analyze the existing logistics technologies and methods optimizing traffic flows.
2. To assess modern approaches to urban planning and their impact on traffic flows.
3. To identify the main factors affecting road capacity and propose ways to increase it with the help of logistics technologies.
4. To study how introducing logistics technologies can improve road safety.
5. To offer practical recommendations for city authorities and transport companies on optimizing traffic flows using logistics technologies.
6. To assess the economic efficiency of implementing logistics technologies: To analyses the economic benefits and costs associated with introducing logistics technologies in the urban transport system.

2. Literature Review

Intelligent transport systems (ITS) and traffic management. Intelligent Transport Systems (ITS) are crucial in optimizing traffic flows and enhancing road safety. This section covers research conducted for the implementation and evaluation of ITS effectiveness. Alkhatib and Sawalha [1] explored various traffic optimization methods, emphasizing the importance of ITS for improving traffic flows. Gurjanov, et al. [2] investigated using Internet of Things technologies in traffic management. Zhu, et al. [3] analyzed intelligent planning and urban traffic congestion studies, demonstrating ITS effectiveness. Park, et al. [4] assessed the impact of automated vehicles on traffic flow and road capacity in urban networks. Kutsyna and Slyvka [7] and Nagrebelna and Korchevskaya [8] analyzed domestic and

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international experiences in road safety management using ITS. Smirnovs and Lāma [9] examined road safety in Latvia, highlighting the role of ITS. Evtiukov, et al. [10] and Kurakina and Sklyarova [11] researched the application of intelligent transport systems in road transport infrastructure. Saraswati and Iskandar [12] analyzed road capacity in the Sei Liat city area, stressing the need for ITS implementation. Hanifah, et al. [13] considered the impact of vehicle volume on road damage and safety. The analysis shows intelligent transport systems significantly improve traffic management and enhance road safety. These systems optimize traffic flows and reduce congestion.

Geographic information systems (GIS) and urban planning. Geographic Information Systems (GIS) are used to analyses and visualize spatial data, which aids in more effective urban transport infrastructure planning. This section reviews studies dedicated to the application of GIS in transport logistics. Using GIS, Budzyński, et al. [5] investigated transport node issues in port cities. Barabash, et al. [14] studied the formation of traffic safety profiles in city centers using GIS. Calvo-Poyo, et al. [15] conducted an international study on road investments and traffic safety employing GIS. Using GIS, Vasile, et al. [6] researched road safety in Romanian cities. Polishchuk and Nahrebelna [16] utilized GIS to examine traffic management principles in the "PEREHIN" system. Osetrin and Shilova [17] discussed street organization as a key to improving road safety using GIS. Kepa [18] explored visibility issues on roads and traffic safety using GIS. Normatov, et al. [19] studied the impact of road width on traffic safety using GIS. Mospan [20] considered the planning of automobile freight transport in sustainable urban development conditions using GIS. Geographical information systems allow for more precise planning and optimization of transport routes, improving urban infrastructure and road safety. GIS technologies are a crucial tool for modern urban planning.

Traffic flows and road capacity. Optimizing traffic flows and increasing road capacity are critical tasks in transport logistics. This section reviews studies aimed at improving these aspects. Zhezherun [21] investigated traffic flow forecasting in urban networks, considering road capacity. Anokhin [22] examined international experience in ensuring road safety and preventing accidents. Gössling [23] explored the perspectives of road safety police and transport policy in Germany. Abdullaev, et al. [24] improved methods for assessing road safety at single-lane road intersections. Lanovoy, et al. [25] conducted a recent evaluation of road traffic conditions, emphasizing the importance of traffic flow management. Alkhatib and Sawalha [1] studied traffic optimization methods, focusing on road capacity. Park, et al. [4] assessed the impact of automated vehicles on traffic flow and road capacity. Zhu, et al. [3] examined intelligent planning and urban traffic congestion studies. The analysis shows that optimizing traffic flows and increasing road capacity are crucial for improving transport infrastructure and road safety. Modern technologies and methods significantly enhance the efficiency of the transport system.

3. Materials and Methods

This article used various research methods to comprehensively analyze and evaluate the effectiveness of implementing intelligent transport systems (ITS) and geographic information systems (GIS) to manage traffic flows and ensure road safety.

1. Literature review. A thorough analysis of scientific articles, reports, and other sources related to ITS and GIS was conducted to determine the current state and identify critical issues related to transport logistics. The review included works such as the studies by Alkhatib and Sawalha [1]; Gurjanov, et al. [2] and Zhu, et al. [3] which provided a theoretical foundation and insights into current trends and best practices.

2. Comparative analysis. Data on the implementation of ITS and GIS in different cities and countries were compared. Studies by Budzyński, et al. [5]; Vasile, et al. [6] and Polishchuk and Nahrebelna [16] provided examples of successful use of these technologies and helped identify factors influencing their effectiveness. The comparative analysis included an assessment of economic efficiency, impact on safety, and road capacity.

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3. Systems analysis. A systems approach was applied to analyze the interaction of various transport system elements, including technical means and organizational and social aspects. Works by Park, et al. [4] and Kutsyna and Slyvka [7] were used to understand the comprehensive impact of ITS and GIS on traffic flows and road safety.

4. Economic analysis. An economic analysis of the costs and benefits of implementing ITS and GIS was conducted. Studies by Calvo-Poyo, et al. [15] and Anokhin [22] provided data to assess the economic efficiency and payback of investments in these technologies. The analysis assessed initial costs, operational costs, and economic benefits of reducing congestion and improving safety.

These research methods gave a comprehensive understanding of the current state and promising directions for developing transport logistics using modern technologies.

4. Results

Logistic technologies are crucial in optimising transport flows, especially in increasing urbanisation and the rising number of vehicles. These technologies enhance road capacity, improve city planning, and ensure road traffic safety. This work will analyse existing logistic technologies and methods for optimising road transport flows. Existing logistic technologies and methods for optimising transport flows in road transport are presented in Table 1.

Table 1.
Existing logistics technologies and methods used to optimise traffic flows in road transport.

Technology/Method	Description	Methods	Advantages
Intelligent transport systems (ITS)	Use of information and communication technologies to manage traffic flows in real time	Traffic monitoring and control systems, adaptive traffic lights, navigation systems, fare collection systems	Improved traffic capacity, reduced congestion, increased road safety
Traffic management systems	A set of measures and solutions for coordinating and regulating traffic	Management of traffic lights, creation of dedicated lanes for public transport, route optimisation	Reduced travel time, increased efficiency of road infrastructure use
Geographic information systems (GIS)	Technologies for analysing and visualising spatial data for transport infrastructure planning	Cartographic analysis, traffic modelling, road conditions forecasting	Precise planning of road networks, improved urban planning, and more efficient transport logistics
Vehicle monitoring systems	Technologies for tracking and managing the movement of vehicles in real-time	GPS trackers, motion sensors, video surveillance systems	Ensuring safety, preventing violations, and improving the efficiency of incident response
Methods of mathematical modelling and simulation	Application of mathematical models for analysing and optimising traffic flows	Transport network models, simulation programmes, linear programming methods	Predicting the behaviour of transport systems, evaluating the effectiveness of measures to improve traffic flows, supporting decision-making

Source: Developed by the author based on [1-3].

An analysis of existing logistic technologies and methods shows that their application significantly improves transport flows in road transport. Implementing intelligent transport systems, traffic flow

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management systems, geographic information systems, vehicle monitoring systems, and mathematical modelling methods increases road capacity and enhances city planning and road safety. These technologies play a crucial role in modern transport logistics and continue to evolve, adapting to new challenges and demands.

Transport infrastructure is the foundation of a modern city's functioning, significantly impacting economic development, quality of life, and environmental conditions. Analysing the current state of transport infrastructure and contemporary approaches to city planning allows for assessing their impact on transport flows and identifying areas for improvement. Table 2 presents the leading aspects and descriptions of transport infrastructure.

Table 2.
State of transport infrastructure.

Aspect	Description
Road network	In most cities, the road network faces congestion and wear and tear problems.
Public transport	In some cities, the rolling stock is ageing, there are no routes, and traffic is low-frequency.
Pedestrian and cycling infrastructure	Insufficient development and safety of pedestrian areas and bicycle lanes.
Parking spaces	Lack of parking spaces in the city's central areas and their non-compliance with modern standards.

Source: developed by the author based on [5, 14, 15].

Modern approaches to city planning aim to create sustainable, functional, and liveable urban spaces. The main focus is on integrating different modes of transport, optimising land use, and developing intelligent transport systems. These approaches improve the quality of life, reduce the burden on road infrastructure, and enhance the overall efficiency of urban transport systems (Table 3).

Table 3.
Modern approaches to urban planning.

Approach	Description	Impact on traffic flows
Compact planning	Striving to create compact cities with high density and mixed land use	Reducing the need for long journeys, increasing the use of public transport and non-motorised modes of transport
Transit-oriented development (TOD)	Planning developments around public transport stations	Increasing the share of public transport, reducing the load on the road network
Development of intelligent transport systems (ITS)	Implementation of modern technologies for traffic management and monitoring	Optimisation of traffic, reduction of congestion, increased safety
Integration of different modes of transport	Creating convenient interchange points and ensuring connectivity between different modes of transport	Improved overall transport accessibility, reduced travel time
Green and sustainable cities	Introduction of environmentally friendly modes of transport and development of green areas	Reduced air pollution, improved quality of life, reduced car traffic

Source: Developed by the author based on [6, 16, 17].

The impact of modern approaches on transport flows can be illustrated in Figure 1.

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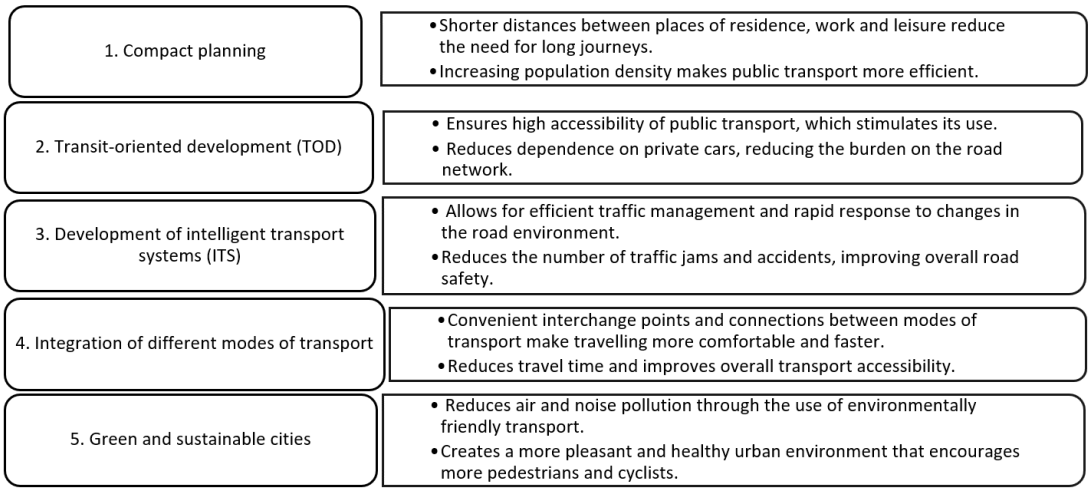

Figure 1.
Impact of modern approaches on traffic flows.
Source: Developed by the author based on [6, 14, 15].

Modern approaches to city planning and transport infrastructure development significantly impact transport flows. Compact planning, transit-oriented development, the implementation of intelligent transport systems, the integration of different types of transport, and the creation of green cities all contribute to improving road capacity, road safety, and quality of life in cities. These approaches require a comprehensive and strategic approach to their implementation, considering the needs of all road users. Road capacity is a critical indicator that affects the efficiency of the transport system and the quality of life in cities. Analysing the main factors influencing road capacity and proposing ways to improve it using logistics technologies will help improve transport flows and reduce congestion (Table 4).

Table 4.
Critical factors affecting road capacity.

Factor	Description
Traffic intensity	The number of vehicles passing? through a particular section per unit of time.
Width and number of lanes	The number of lanes and width directly affect the number of vehicles that can pass simultaneously.
Condition of the road surface	The quality of the road surface affects the speed and safety of traffic.
Traffic light control	Incorrectly set traffic lights can cause congestion and reduce throughput.
Incidents and accidents	Road accidents and other incidents significantly reduce throughput.
Pedestrian crossings and intersections	Intersections and pedestrian crossings slow down traffic and can create congestion points.
Parking zones	Parking along the road can narrow the carriageway and impede the free traffic flow.

Source: Developed by the author based on [11, 21-23].

Modern logistics technologies are crucial in increasing road capacity and improving transport flow management. They offer solutions that reduce congestion, speed traffic, and improve city transport. Employing intelligent transport systems, automated toll collection systems, and geoinformation technologies opens up new opportunities for optimising transport infrastructure.

Using Intelligent Transport Systems (ITS) for real-time management and coordination of traffic flows helps reduce wait times at traffic lights, decrease congestion, and increase traffic speed.

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Implementing electronic toll collection systems, such as automated toll collection systems, speeds up the payment process, reduces congestion at toll points, and increases road capacity. Geoinformation Systems (GIS) are used for planning and optimising traffic routes, analysing traffic flows, modelling road conditions, and predicting road congestion, which helps reduce road congestion and improve traffic flow management. Vehicle monitoring and management systems allow for real-time tracking and management of vehicles using GPS trackers, video surveillance systems, and motion sensors, which enhances traffic safety, rapid response to incidents, and improves traffic flow management. The creation and modernisation of public transport infrastructure, including dedicated lanes and improved service frequency and quality, help reduce the number of private cars on the roads, increase road capacity, and improve the environmental situation.

Road capacity depends on various factors, including traffic intensity, width and number of lanes, road surface conditions, and the effectiveness of traffic light regulation. Using logistics technologies such as Intelligent Transport Systems (ITS), automated toll collection systems, geoinformation systems (GIS), vehicle monitoring and management systems, and the development of infrastructure for public transport can significantly increase road capacity. These measures help reduce congestion, increase traffic speed, and improve the overall transport situation in cities.

Road traffic safety is one of the critical objectives of transport logistics. Modern logistics technologies can significantly improve road safety by managing traffic flows, monitoring road conditions, and quickly responding to incidents. This study will use statistical data and calculations to assess the impact of logistics technologies on road safety.

Table 5.
Key logistics technologies and their impact on security.

Technology	Description	Elements	Impact
Intelligent transport systems (ITS)	Systems that use information and communication technologies to improve traffic management.	Adaptive traffic light control, traffic monitoring systems, and driver alerts.	Reducing the number of accidents by optimising traffic and reducing the risk of accidents at intersections and traffic lights.
Vehicle monitoring systems	Technologies for tracking and controlling vehicles in real-time.	GPS trackers, video surveillance, and motion sensors.	Prompt response to incidents, prevention of traffic violations, and increased safety.
Automated fare collection systems	Systems that provide contactless fare collection.	Electronic toll collection systems, contactless cards, and number plate recognition systems.	Reduced congestion and accidents at toll plazas and improved traffic flow.
Geographic information systems (GIS)	Technologies for analysing and visualising spatial data for transport planning and management.	Map analysis, traffic modelling, and road conditions forecasting.	Optimising routes, reducing road congestion, and improving safety.
Speed control systems	Technologies for monitoring and controlling vehicle speed.	Radars, speed cameras, and speed warning systems.	Reducing the number of speeding violations, reducing accidents.

Source: Developed by the author based on [13, 18, 19].

The implementation of logistics technologies has a significant impact on road safety. Intelligent transport systems, vehicle monitoring systems, automated toll collection systems, geoinformation systems, and speed control systems can substantially reduce the number of traffic accidents, decrease violations and incidents, and improve overall road safety. Statistical data and calculations confirm the effectiveness of these technologies in real-world conditions.

It is crucial to consider the economic efficiency of implementing logistics technologies. Figure 2 presents the economic benefits of this implementation.

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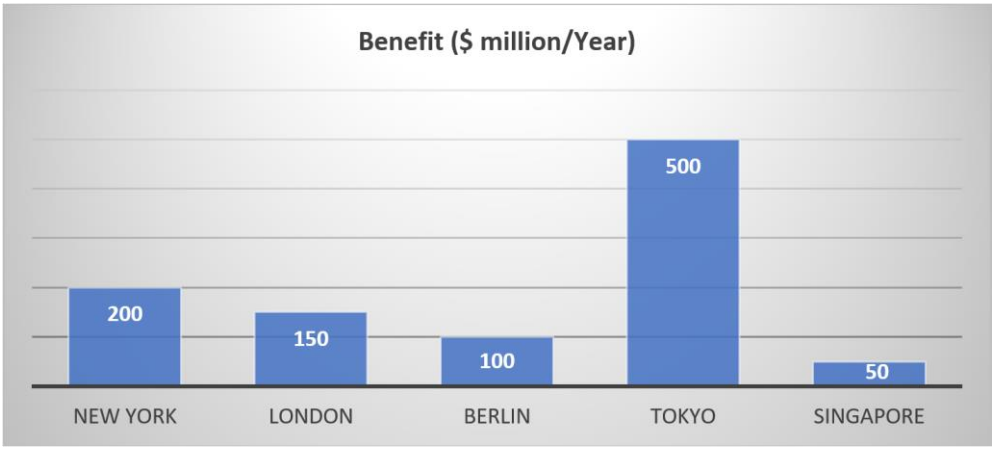

Figure 2.
Economic Benefits of implementing logistics technologies.
Source: Developed by the author based on [1, 3, 4].

Optimisation of traffic flows and routes reduces fuel consumption and vehicle wear and tear. Implementing ITS in New York led to a 10% reduction in fuel consumption, equivalent to $200 million annually. Improved road capacity and traffic management reduce travel time. In London, executing ITS reduced the average travel time by 15%, saving $150 million annually. Fewer accidents reduce costs for medical care, vehicle repairs, and administrative expenses. A 20% reduction in traffic accidents in Berlin resulted in $100 million in annual medical and repair cost savings. Improved traffic management increases road capacity, allowing the deferral or avoidance of costs for expanding the road network. In Tokyo, a 25% improvement in road capacity avoided $500 million in new road construction costs. Reduced congestion and optimised traffic flow lead to lower emissions of harmful substances, reducing environmental fines and health care costs. In Singapore, a 10% reduction in CO2 emissions resulted in $50 million in annual savings on environmental fines and health care costs.

Initial investments include purchasing and installing equipment, software, and infrastructure costs. Implementing ITS in New York costs $300 million. Operating costs include expenses for maintenance, software updates, and operator salaries. Annual operating costs for ITS in London amount to $20 million. Training and retraining personnel involve costs for training operators and technical staff in new technologies. Training personnel for ITS management in Tokyo costs $10 million.

The analysis of the economic efficiency of implementing logistics technologies in urban transport systems is presented in Table 6.

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Table 6.
Analysing the economic efficiency of implementing logistics technologies in the urban transport system.

Technology	City	Initial investments ($ million)	Annual operating costs ($ million)	Economic benefits ($ million/year)	Payback period (Years)
Intelligent transport systems (ITS)	New York	300	20	200	1.5
Vehicle monitoring systems	Berlin	100	10	100	1
Automated toll collection systems	London	200	15	150	1.33
Geographic information systems (GIS)	Tokyo	150	12	120	1.25
Speed control systems	Singapore	50	5	50	1

Source: Developed by the author based on [15, 16, 20].

As technology develops and equipment costs decrease, initial investments will decrease, increasing the economic efficiency of implementing logistics technologies. A 20% reduction in initial investments is forecast by 2030. Technological improvements and their integration with other systems will increase economic benefits, with a projected 30% increase by 2030 due to optimisation and system integration. New developments and improved technologies will extend equipment lifespans and reduce operating costs, with an expected 10% reduction by 2030.

Implementing logistics technologies in urban transport systems brings significant economic benefits, such as reduced fuel and maintenance costs, reduced travel time, fewer traffic accidents, and increased environmental sustainability. Despite significant initial investments, the payback period for such projects is typically 1-2 years, making them economically efficient. The future also looks promising, with expected cost reductions and increased benefits.

5. Discussion

Research by Alkhatib and Sawalha [1] emphasizes that intelligent transportation systems (ITS) significantly improve traffic management, as evidenced by numerous successful ITS implementations worldwide. Their work shows that ITS reduces congestion and enhances safety, aligning with the findings of Gurjanov, et al. [2] who examined Internet of Things (IoT) technologies for organizing vehicular traffic. Zhu, et al. [3] add that ITS can substantially reduce urban traffic congestion through intelligent planning and management of traffic flows. However, there are challenges. Park note that automated vehicles, as part of ITS, can improve and complicate traffic management depending on their integration level within the existing infrastructure. It is crucial to consider the impact of human factors and potential technology failures.

Budzyński, et al. [5] demonstrated that geographic information systems (GIS) effectively address transport hub issues, especially in port cities. Barabash, et al. [14] support this view, noting that GIS helps create traffic safety profiles in city centers, enhancing urban infrastructure planning. Calvo-Poyo, et al. [15] also proved that road investments and GIS applications can improve road safety internationally. However, there are drawbacks. Vasile, et al. [6] highlighted the need for constant data updates in GIS to ensure their relevance and accuracy. Moreover, Polishchuk and Nahrebelna [16] pointed out that implementing GIS requires substantial financial and time resources, which can be challenging for some municipalities.

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Zhezherun [21] emphasized the importance of forecasting traffic flows to improve road capacity. His research indicates that modern modelling methods can significantly enhance traffic flow management efficiency. It is supported by Anokhin [22] who reviewed international experiences in ensuring road safety and preventing accidents, showing that proper planning and traffic flow forecasting are crucial. However, Gössling [23] stressed that road safety also depends on socio-political factors, such as support and control by law enforcement agencies. Abdullaev, et al. [24] added that ensuring road safety requires considering technical and organizational measures, such as improving road safety assessment methods at single-lane road intersections.

The discussion shows that modern technologies like ITS and GIS are crucial in optimizing traffic flows and enhancing road safety. However, their successful implementation requires a comprehensive approach that considers technical and organizational aspects. It is essential to continue researching this field to find new solutions and improve traffic management methods.

6. Conclusion

The implementation of logistics technologies for optimizing traffic flows in road transport has shown significant improvements in road capacity and safety. Intelligent Transportation Systems (ITS) and Geographic Information Systems (GIS) are vital tools that significantly improve traffic flow management. Using ITS reduces congestion and increases travel speed, saving time and resources. GIS aids in more accurate planning and management of transport infrastructure, enhancing urban planning. However, successful implementation of these technologies requires consideration of technical, organizational, and social aspects. An important factor is the need for continuous data updates and personnel training for effective system use.

Future research prospects include the development and integration of new technologies to improve the efficiency of transport system management and enhance road safety.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

Authors' Contributions:

All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

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