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USING ARTIFICIAL INTELLIGENCE FOR ROUTE OPTIMIZATION AND PLANNING

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Purpose: The objective of this article is to examine the impact of artificial intelligence applications on solutions employed in logistics, with a particular focus on the transportation sector. The analysis investigates how AI-based technologies contribute to the optimization of transport processes, the improvement of fleet management, route planning, and the enhancement of operational efficiency. The article also aims to identify the potential benefits of implementing intelligent systems, as well as the challenges and limitations associated with their deployment in the logistics industry.
Design/methodology/approach: This study's methodology is grounded in analysis, synthesis, abstraction, and generalization. The use of these scientific methods facilitates a detailed examination of the study's subject and object, along with gathering and analyzing data to assess how information systems optimize transport routes (TMS). In addition, the study employs the case study method.
Findings: Data analysis shows that artificial intelligence is currently most effective in road transport. This is primarily due to the current level of technological development, industry experience, and the practical outcomes achieved.
Practical implications: The research findings give practical guidance for evaluating whether AI-based systems are sufficiently effective, economically justified, and applicable across all modes of transport. Moreover, the research helps to partially systematize current literature on AI in logistics and transport, serving as a valuable reference for further studies.
Originality/value: This is an original study that could be applied to address specific problems either independently or in combination with other research methods. The comparison of results for a given research problem obtained through the application of different methods may prove highly insightful.
Keywords: artificial intelligence, optimization, planning, transport.
Category of the paper: Case study.

1. Introduction

Artificial intelligence (AI), defined as a data processing system that emulates the functions of the human brain, continues to expand into new areas of life rapidly. It is increasingly being applied across diverse sectors, supporting decision-making processes or streamlining day-to-day operations. Today, this phenomenon can be seen in fields like robotics, education, and e-commerce. AI significantly transforms the way individuals perform professional tasks and acquire information in everyday life. The development of intelligent systems, a key driver of economic growth, results in major shifts in production structures and methods, while also affecting the range and quality of consumer goods and services. Fields such as management, and logistics in particular, will not remain unaffected by this revolutionary technology – on the contrary, they are poised to undergo a profound transformation in the near future.

One of the areas where artificial intelligence finds particularly extensive application is transportation and logistics. AI enables the effective optimization of processes such as route planning, fleet management, delivery monitoring, and demand forecasting. Machine learning algorithms enable dynamic real-time route adjustments by considering current road, weather conditions, and changing logistical priorities.

Artificial intelligence plays a main role in modernizing traditional transport systems and improving methods for route planning and optimization. Using AI algorithms and machine learning (ML) methods allows for analyzing extensive datasets, processing data instantly, and continuously improving decision-making in logistics systems. Assisted, augmented, and autonomous AI-based solutions are designed to take over key tasks and improve their execution. These include handling large volumes of online orders with immediate route generation and delivery time estimation, considering variable factors such as weather conditions, traffic congestion, and other relevant parameters. In addition, these systems facilitate the creation of optimized routing algorithms and the evaluation of the effectiveness of implemented logistics strategies (Krishna Vaddy, 2023).

Advanced AI-driven systems analyze large volumes of data, including historical and real-time information, which enables higher operational efficiency, lower transportation costs, and quicker delivery times. AI also supports the development of sustainable transport by enabling optimal fuel management, minimizing CO_2 emissions, and improving route planning from an environmental perspective.

The implementation of intelligent solutions in logistics not only enhances the competitiveness of enterprises but also improves customer service quality by enabling more accurate delivery time predictions and quicker responses to potential delays. Altogether, artificial intelligence is becoming an indispensable component of modern transportation systems, redefining the way the entire industry operates.

2. Literature Review

The optimization of transport processes constitutes a fundamental component of operational efficiency in the management of contemporary enterprises. Advanced Transportation Management Systems (TMS) are a key element in the optimization of corporate logistics. They enable effective planning, execution, and monitoring of transport operations, which translates into cost reduction and improved efficiency. By applying optimization algorithms, it becomes possible to determine the most efficient routes with precision, taking into account economic, temporal, and operational factors (Coyle, Langley, Novack, Gibson, 2016).

According to Simchi-Levi (Simchi-Levi, Simchi-Levi, Kaminsky, 2017), modern Transportation Management Systems (TMS) play a crucial role in the effective optimization of logistics processes. They allow for the automatic planning, monitoring, and analysis of routes, thereby contributing to increased efficiency and cost reduction. TMS also supports the decision-making process by enabling dynamic route optimization in real time and efficient utilization of resources, which directly translates into improved profitability of transport operations.

Hines (2016) emphasizes the importance of Transportation Management Systems (TMS) as an integral element of an integrated logistics strategy. According to him, TMS makes decision-making easier by handling essential tasks automatically, including route planning, choosing carriers, and auditing freight costs. By providing access to real-time data, these systems facilitate transport performance monitoring, operational cost reduction, and the improvement of service quality.

To achieve efficiency in route planning and optimization, a TMS must account for numerous factors. This includes traffic patterns, road conditions, weather, vehicle capacity, fuel usage, delivery timing, distances, and other pertinent data to identify the best route. In other words, simply planning delivery routes using only an order list, destinations, and expected delivery dates is not enough. (Roundy, 2024).

Vehicle route optimization involves determining an optimal plan (lowest cost, highest service level, or lowest risk) for a fleet of vehicles. Such planning includes identifying the set of nodes (or customers) to be visited by each vehicle in the fleet, as well as the sequence in which they should be visited. Depending on the problem's characteristics, it is also necessary to determine the route start and end times, driver rest periods, and the paths between each pair of customers. In general, optimization aims to manage resource constraints in the most efficient way possible (Tyszkiewicz, Pawlak-Wolanin, Ulewicz, 2017). Transportation refers to the movement of individuals or goods. This definition underscores the primary benefit of transport services – the delivery of passengers and cargo. However, at the international level, transport is also perceived as a system that creates utility in time and space. Utility refers to the capacity of a good to satisfy needs. The main objective of a product purchased by a consumer is to fulfil a specific need, associated with a particular activity or the provision of a sense of satisfaction (Manzini, Gamberini, 2008).

Transport logistics is crucial for optimizing how resources are distributed spatially and for managing transportation demand. In practice, this involves the comprehensive management and supervision of shipments – from the moment they are collected from the sender to their delivery to the final recipient. Key challenges in distribution involve the traveling salesman problem and the time window problem, both of which are addressed through optimization methods. In the case of the cyclic transport problem, a critical assumption is that all planned points are visited by vehicles along the shortest possible route. The time window problem is even more challenging, as it requires servicing customers within strictly defined time intervals, individually established by each of them (Pečený et al., 2020). To meet all customer expectations, including a larger number of vehicles in the route planning process, is mandatory. Enterprises need to tackle both simple and complex routing challenges to improve operational efficiency, cut costs, and maintain high service standards.

The development of the economy and social progress are closely linked to the functioning of transportation. An efficiently functioning transportation system promotes trade growth by providing access to areas that were previously difficult to reach, both within the country and abroad. This expansion not only increases market size but also enhances its complexity and quality through the freer flow of innovations and products. The influence of transport, however, is not limited to the economic sphere – it also has significant social and cultural implications. Efficient transport systems integrate communities, facilitating the exchange of ideas, experiences, and values (Toth, Vigo, 2014). Moreover, the development of transport infrastructure affects ways of thinking and perceiving the world – both at the national and global levels. For example, it would be difficult to imagine the smooth functioning of nationwide press distribution or postal systems without fast and efficient transport means. Transport not only reduces the costs of distributing goods and services but also contributes to shaping a sense of belonging to a broader culture that extends beyond an individual's immediate surroundings.

Planning involves organizing activities by developing a plan that outlines sequential implementation stages and assigns time to various activity areas. In simplified terms, two basic types of schedules can be distinguished: the first is a template designed for individuals attending numerous business meetings in various locations with different partners; the second is intended for planning time-limited activities (Pasierbski, 2020). Based on these two models, a new type of schedule has been developed, one that is based on planning according to time intervals and also takes into account the location of specific tasks. Additionally, each element of such a plan can be described and labeled, which facilitates more integrated and transparent time management.

Routes, typically composed of geometric elements such as straight lines, circular arcs, or transition curves, may be global or local in nature (Ezell, 2010). A global route is usually generated offline, on a map of the entire operational environment, while a local route is generated online – considering dynamic obstacle avoidance based on data from external sensors installed on an autonomous vehicle. A route is characterized by a series of points that the autonomous vehicle must reach or come within a certain distance of, beginning from the starting point and ending at the destination (Figure 1). For a route to be effectively implemented in a given environment, it must meet certain requirements – primarily matching the vehicle’s kinematic and dynamic constraints, which greatly support trajectory planning. Furthermore, routes should pass exclusively through permitted areas, in compliance with current traffic regulations, while avoiding nature protection zones such as green areas or vegetation-covered regions (e.g., lawns or flower beds). Additionally, the system responsible for route generation should allow for offline calculations while maintaining low memory and computational requirements (Badzińska, Cichorek, 2015).

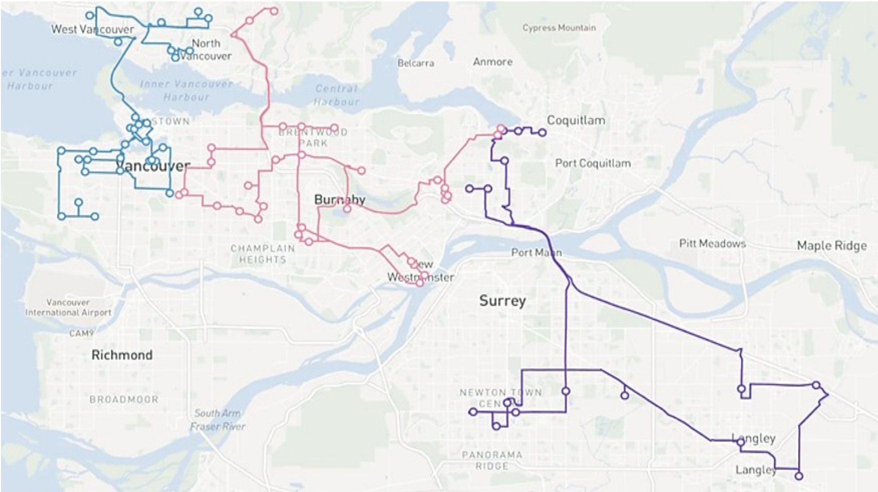

Figure 1. Example of routes as sets of points.

Source: (Kuo, 2023).

In the context of route planning, it can be observed that over the last decade, the topic has received considerable attention from software developers, resulting in the emergence of many efficient approaches based on fundamental concepts of graph algorithms (Badzińska, Cichorek, 2015). From a scientific perspective, the route planning problem can be formulated as a variant of an optimization problem involving the identification of the shortest path between two points. Translated into graph theory, the objective function becomes the selection of edges with the lowest cost – most often interpreted as travel time – connecting the starting node to the destination node. In the current project, additional optimization criteria are also considered, such as distance, fuel costs, and energy consumption. Although travel time remains the main priority, in some cases financial savings or emission minimization are of particular importance (Ozbaygin, Karasan, Yaman, 2018).

With the arrival of the Fourth Industrial Revolution, the freight transportation industry must tackle the challenge of enhancing sustainability and boosting delivery efficiency by adopting innovative technologies. Modern logistics solutions offer businesses and management teams more opportunities than threats, enabling them to refine and modernize existing business models without the need for substantial investments in entirely new systems. Most innovative technologies focus on automation and process streamlining. Tasks like inventory control and route planning will likely need much less human input soon. Presently, The progression of freight transportation is strongly influenced by emerging technologies such as AI, big data analytics, IoT, and blockchain. (Dong, Akram, Andersson, Arnäs, Stefansson, 2021).

Although implementing these modern solutions in information systems involves costs, logistics companies are expected to benefit from lower operating and fixed expenses, more efficient delivery execution, and higher customer satisfaction levels. The extensive use of expensive RFID tags in IoT has prevented the technology from fully realizing its benefits although transport operates on tight margins, it is expected that continued IoT hardware development will lower implementation costs, making this technology more cost-effective and applicable even to low-value freight transport.

Digitalization is gaining increasing importance as part of the extended transportation process optimization. This involves implementing integrated data exchange platforms using blockchain technology and advanced data analytics tools. Digital transformation enhances operational efficiency and considerably minimizes errors caused by manual processes. Automation spans a wide range of activities – from warehouse process robotization to the deployment of intelligent loading and unloading systems – resulting in a noticeable productivity increase throughout the supply chain (Ramasamy, Natarajan, Sathyamoorthy, 2024).

Blockchain is another example of a promising digital technology, enabling secure, transparent, and immutable data recording in the supply chain. With its distributed architecture and the use of smart contracts, this technology supports process automation, enhances trust between trading partners, and reduces the risk of errors and fraud. Optimization, in its simplest form, means finding the best solution in a given situation or when using specific resources. The field of route planning is developing dynamically, supported by a diverse array of digital platforms customized to meet the unique needs of enterprises across different industries (Pasierbski, 2020). From delivery route planning systems to next-generation advanced logistics tools – the market offers solutions that meet diverse requirements.

Although businesses have historically used manual route planning, traditional approaches are struggling to keep up with the complexity and dynamic nature of modern transport networks. The Vehicle Routing Problem (VRP) involves determining the shortest possible routes while minimizing the use of available fleet resources. These routes typically start and end at a warehouse, with the goal of delivering goods to geographically dispersed customers. Planning must account for constraints such as maximum vehicle capacity and varying customer demand (Pawlikow, Petersen, Sørensen, 2023).

VRP-solving methods fall into two main categories: exact algorithms and approximate algorithms. Exact algorithms aim to find the optimal solution but are seldom used in practice because their computation time grows exponentially with the number of customers. Approximate algorithms, in contrast, deliver high-quality solutions more quickly, but they do not guarantee optimality (Battarra, Golden, Vigo, 2006). Among exact methods, branch-andbound algorithms are notable (Pereira, Tavares, 2009). Their initial step involves addressing the problem through a linear programming relaxation, allowing variables to take non-integer values. Approximate methods are an effective alternative to exact algorithms, enabling solutions to problems involving even thousands of points (Badzińska, Cichorek, 2015). This group includes classical heuristics and metaheuristics. In solving the VRP, metaheuristics like simulated annealing, genetic algorithms, and neural networks are commonly employed, tabu search, ant colony optimization, and GRASP (Ochelska-Mierzejewska, Sztajerowski, 2014).

To solve complex optimization problems effectively, logistics companies use dedicated software. Route planning and optimization require not only specialized software but also several preparatory and analytical stages. The process begins with systematic data collection, including information on demand, available vehicle fleet, operating costs, load capacity, warehouse locations, and customer addresses. Other key operational parameters influencing overall system efficiency are also taken into account. Modern logistics platforms also factor in past data, including traffic flows, delivery requirements, and driver schedules. Next, the company must determine the type of VRP it faces to align the appropriate strategy with its business objectives. The following step involves customizing and configuring either an off-the-shelf or dedicated software solution and applying suitable algorithms, enabling efficient calculations and the generation of optimized routes (Pečený, Meško, Kampf, Gašparík, 2020). The results of these calculations support planners and managers in making operational decisions. Once the planned routes are implemented, specialists monitor key performance indicators – such as delivery times, customer satisfaction levels, and cost savings. Data from completed routes are used to further improve processes, initiating another planning iteration.

It is notable that many optimization algorithms operate iteratively, building a solution step by step. In practice, the algorithm starts with an initial solution and iteratively adds the element judged best according to the chosen standard (Chao, Golden, Wasil, 1993). Improvement methods, in turn, focus on enhancing the quality of an already valid solution – for example, by swapping delivery points within a single route or between different routes. These are known as local search techniques, which operate within a subset of the solution space to find the best possible local solution (Wilck, Cavalier, 2012).

Despite their previous effectiveness, traditional methods of route planning and optimization increasingly face significant limitations that reduce their efficiency. They largely rely on the quality of available historical data, while failing to incorporate real-time information or integrate it into the current decision-making process. Meanwhile, modern logistics is becoming increasingly demanding – the number of delivery points is growing, market competition is intensifying, and customer expectations regarding punctuality and service quality are steadily rising. All of this makes the route optimization process increasingly computationally complex. Additionally, companies need to consider various dynamic factors, including weather conditions, traffic, and unexpected events along routes. External constraints are also becoming more frequent, including street congestion or environmental regulations, which require a flexible and intelligent approach to route planning. The table below presents the types of route planning platforms.

Table 1.
Types of route planning platforms

Types of Platforms	Description
Basic route planning program	a) basic route planning capabilities, such as creating point-to-point routes and performing basic travel plan optimization. b) ideal for small businesses or those beginning to automate their planning processes. c) Google Maps and Waze: point-to-point route searches, where there is no need for optimization or operational parameterization (Segerstedt, 2014).
Advanced route planning software	a) more advanced features, such as integration with real-time GPS systems, multi-variable optimization (weather, traffic), and predictive analytics (Ochelska-Mierzejewska, Sztajerowski, 2014). b) offer greater customization capabilities. c) can be integrated with other logistics systems.
Comprehensive logistics solutions	a) all-in-one solution (Archetti, Speranza, 2012). b) drivin: provides full control over logistics operations, standing out as a robust solution for efficient and effective shipment route management (Xia, Fu, 2018). c) offer a full range of route planning functionalities, from scheduling to delivery. d) can be integrated with real-time tracking and monitoring systems. e) combine route planning with other logistics management functions, such as inventory management, fleet management, and real-time tracking.

Source: own study based on (Segerstedt, 2014, p. 76; Xia, Fu, 2018, p. 13).

This study focuses on transportation route planning, especially systems that use artificial intelligence. The object of the research comprises AI algorithms and methods for planning and optimizing transport routes.

The aim of the study is to analyze existing solutions based on artificial intelligence techniques, identify the types of transport in which they are most effective, and formulate forecasts regarding the further development of AI in logistics.

To achieve this aim, it is necessary to:

a) analyze contemporary logistics approaches to transport organization,

b) examine AI algorithms used in solving the Vehicle Routing Problem (VRP), and

c) conduct case studies of real-world implementations of AI-based systems.

The practical significance of this study lies in the fact that the conclusions and recommendations obtained will allow assessment of whether AI-based systems are sufficiently efficient, economically justified, and applicable across different modes of transport. Furthermore, the study contributes to the partial systematization of existing scientific literature on the application of AI in transport logistics. It could serve as a valuable starting point for future research in this field.

The research methodology relies on analytical approaches, synthesis, abstraction, and generalization methods. These universal scientific techniques allow for a thorough examination of both the subject and the object of the study, as well as the collection and interpretation of data to assess how information systems are used for route optimization within Transportation Management Systems (TMS).

Additionally, the study employs the case study method, a universal methodology that allows in-depth analysis of a specific phenomenon, event, or entity to gain a precise understanding of the researched problem. This approach integrates various techniques, including document analysis, survey methods, and observation. While the case study is categorized as a qualitative approach, it is advisable to supplement it with quantitative methods to achieve a holistic understanding of the situation. The choice of this methodology is justified by the relatively new and dynamically evolving nature of the research topic, which makes conducting independent experiments or tests challenging. Consequently, using data from business practice and available secondary sources appears to be the most appropriate research approach.

Moreover, the literature used for both analyzing real-world AI applications and developing the theoretical part was selected using the Systematic Literature Review (SLR) method. A systematic literature review is an effective tool for organizing, comparing, and synthesizing existing knowledge sources and supports evidence-based decision-making.

The SLR approach differs from meta-analysis, which focuses on the quantitative assessment of results, and from citation network analysis, which examines relationships between references. The benefit of SLR is its capacity to perform a consistent, transparent, and thorough review of existing literature, it allows for better insights into the phenomenon being analyzed. In this study, the SLR method was applied to systematically synthesize the available knowledge regarding the use of AI in various branches of transport – road, air, maritime, and rail. Only publications from reliable scientific sources focusing on the implementation of artificial intelligence in transport logistics were considered. Works unrelated to this topic or failing to meet quality criteria were excluded.

In the next phase of the research, the case study method was used to deeply analyze specific examples of AI applications focused on enhancing logistics, especially in planning and optimizing delivery routes. This combined methodological approach allows for obtaining both a broad theoretical overview and practical insights into real-world technology applications in logistics enterprises.

Future research could focus on examining the attitudes of companies and drivers towards AI-based solutions and the factors influencing the pace of their implementation. A limitation of the study is the small sample size, meaning that the analysis included only selected transport companies described in the case study.

3. Casy study

Practical examples clearly demonstrate that the use of artificial intelligence can significantly enhance operational efficiency and contribute to cost reduction in route planning processes. The most representative examples is the SenseAware ID system, developed and implemented by FedEx. Built on machine learning, the platform integrates data streams from multiple inputs, including GPS technology, environmental sensors, and weather forecasts, enabling dynamic real-time optimization of delivery routes.

The system not only allows continuous shipment monitoring but also predicts potential disruptions in the supply chain, enabling FedEx managers to take proactive measures to mitigate risks at early stages of the logistics cycle (Veluru, 2023). By allowing immediate route adjustments, the platform substantially improves operational efficiency and enhances customer satisfaction. Data and observations collected clearly indicate that the use of the SenseAware system contributes to a reduction in operational costs.

FedEx also employs the ORION system, which is examined as a case study of a modern Transportation Management System (TMS). ORION enabled UPS to achieve annual savings of USD 300-400 million by reducing operational costs. The system helps UPS optimize the supply chain by offering route data that accounts for both energy efficiency and delivery time. ORION analyzes over 200,000 potential routes for each driver, based on a single day of operational data. Calculations consider factors like pickup times, past route efficiency, and the number of stops, which often reaches 100 (Holland, Levis, Nuggehalli, Santilli, Winters, 2017). Consequently, the average daily driving distance was reduced by 6-8 miles. Annually, ORION reduces total mileage by approximately 100 million miles. Importantly, the latest system is capable of adjusting routes dynamically in response to real-time traffic data (Weise, 2019).

Unlike traditional manual route planning and outdated systems, ORION does not require specialized staff for route determination. each driver inputs a destination address and gets the most efficient route, optimized for travel time, distance, and fuel use. The system evaluates traffic data using artificial intelligence and machine learning to deliver the best solution. This enables drivers to deliver shipments faster while avoiding congestion and other obstacles. Additionally, AI enables real-time route adjustments when facing sudden changes like new orders, bad weather, or traffic incidents, helping to save time and fuel and ensuring more punctual deliveries.

Similarly, DHL leverages machine learning models to reduce delays and avoid failed deliveries. The implemented system significantly enhances last-mile delivery efficiency by predicting potential logistical disruptions. AI algorithms analyze historical delivery performance, weather data, and real-time traffic conditions to dynamically adjust routes (Veluru, 2023). These technologies make the delivery process more predictable, accurate, and reliable, benefiting both logistics operators and end customers.

Moreover, DHL uses advanced technologies not only to optimize routes but also to enhance warehousing and international trade services. The company has partnered with Robust.AI to implement AI-assisted robots that support employees in tasks such as sorting, order picking, and loading shipments onto vehicles. These robots, named Carter, are capable of learning from the specific conditions of individual warehouses and are designed to collaborate effectively with humans. Their purpose is to assist employees, reducing cognitive workload and increasing overall operational efficiency in warehouses (AIX, 2024). Real-world implementations confirm that AI serves as a transformative factor in the transport and logistics sector, enhancing both efficiency and service quality.

Another successful AI-based implementation is the route management system employed by Walmart. The company uses AI in combination with big data analytics to optimize last-mile logistics, one of the most costly stages of delivery. The algorithms analyze real-time factors such as warehouse stock levels, customer preferences, traffic intensity, and weather forecasts (Ping, Zhu, Ling, Niu, 2024). Based on this analysis, the system dynamically adjusts routes and delivery schedules, considering both cost efficiency and environmental aspects of transport.

Walmart also uses AI for demand forecasting and automatic allocation of transport resources to locations where they are most needed. This approach reduces order fulfillment time, minimizes empty vehicle trips, and decreases fuel consumption. Consequently, the company achieves higher operational efficiency, lowers CO_2 emissions, and improves customer service. By implementing AI for route optimization, Walmart has eliminated 110,000 inefficient routes, reduced total mileage by 30 million miles, and avoided the emission of 94 million pounds of CO_2. The success of this software encouraged Walmart to diversify by offering the developed technology to other companies (Avila, 2024), allowing external firms to benefit from advanced route planning systems without investing in their own development.

The Chinese technology giant Alibaba uses its logistics network, Cainiao, which integrates reinforcement learning and deep learning technologies to improve distribution processes and intelligent scheduling (Stroh, 2023). Traffic management and monitoring systems provide full control over inventory, first-mile pickup, sorting, and last-mile logistics. AI analyzes historical data and current sales trends, enabling accurate demand forecasting for specific products. This allows strategic placement of goods closer to customers, reducing transport time, speeding up order fulfillment, and lowering logistics costs. Cainiao offers customers real-time package tracking, ensuring transparency at every delivery stage. By leveraging AI, the system analyzes multiple data sources, identifies potential delays or disruptions, and automatically takes corrective actions, increasing service reliability and customer satisfaction.

Other companies successfully implementing AI-based route optimization technologies include Amazon and Lyft.

Lyft, a U.S.-based ride-sharing company, has implemented advanced AI algorithms that dynamically optimize rides. By using real-time data from drivers and passengers, the system continuously improves route efficiency and reduces waiting times. This approach boosts customer satisfaction and increases fleet utilization.

Amazon extensively employs AI in transportation and logistics to increase operational efficiency and shorten delivery times. AI supports planning of optimal routes for drivers (Amazon Delivery Service Partners) by considering real-time traffic data, weather forecasts, package and customer locations, and historical route performance. This results in shorter delivery times, reduced fuel consumption, and faster response to disruptions (Ulmer, Thomas, Lütke, Entrup, 2020). AI enables Amazon to fulfill commitments under Prime services, providing same-day or two-day deliveries. The system's flexibility allows real-time adaptation to changing conditions, forming a key competitive advantage in customer service.

Within Amazon Logistics (AMZL) and Last Mile AI, artificial intelligence manages the "last mile" – the final stage of delivery – by assigning packages to delivery personnel, determining the optimal delivery sequence, and predicting potential delays. Amazon is also developing autonomous transport technologies, such as the Scout delivery robot, which navigates sidewalks, and the Zoox autonomous electric vehicle for urban driverless transportation. Additionally, Prime Air uses AI-controlled drones to deliver packages in under 30 minutes, avoiding obstacles and selecting the shortest routes. In distribution centers, AI controls robot movement (e.g., Kiva robots), optimizes shelf placement, and predicts demand, moving products closer to customers to accelerate order fulfillment and reduce operational costs.

These case studies demonstrate that automating logistics and incorporating AI lead to increased operational efficiency, lower costs, and better service quality. The use of large language models, deep learning, and predictive techniques allows companies to respond flexibly to transportation and fleet management challenges while developing more adaptive and innovative logistics strategies.

4. Disscusion

Road transport is among the most widely used modes of transportation, particularly for cross-border deliveries and direct-to-customer shipments. Its primary advantage lies in its high level of flexibility – enabling "door-to-door" deliveries and dynamic adjustment of routes and schedules in real time, which differentiates it from other transport modes. It performs especially well over short and medium distances and is suitable for transporting diverse types of cargo, such as perishable goods, hazardous materials, or small parcels.

Despite increasing congestion of road infrastructure in highly developed countries, average delivery times and road transport costs remain acceptable for both customers and providers. Moreover, road transport plays a key role in integration with other transport modes, facilitating both first-mile and last-mile deliveries – capabilities that other transportation modes cannot provide to the same extent.

Conversely, road transport faces limitations as it is not ideal for moving oversized or bulk cargo, given vehicles' lower carrying capacity compared to maritime or rail options. Truck fleets incur high fuel consumption, require costly maintenance, and contribute significantly to emissions. Additionally, road transport is vulnerable to external factors for example as traffic congestion, accidents, and road closures, making delivery times difficult to predict accurately.

These weaknesses make the implementation of artificial intelligence solutions in road transport particularly promising. AI can greatly improve fleet management and route planning, leading to higher efficiency and lower costs. A crucial step is estimating potential gains from implementing planning and optimization systems for each transport mode. A key benefit of modern transportation management software is its capacity to significantly lower fuel expenses and reduce pollutants released into the environment.

Table 2 presents fuel consumption by U.S. carriers in 2016. Data published by the Bureau of Transportation Statistics (2016) were used to calculate annual total fuel costs by transport mode. The results confirm that road transport generates the highest fuel consumption during deliveries, which translates into the highest average operational costs. Air transport ranked second in fuel consumption, while maritime transport proved to be the least fuel-intensive sector in the United States during the analyzed period.

Table 2.
Fuel consumption by mode of transportation in the US

Type of transport	A million liters	Average price	Total fuel cost (mln USD)
Road transport (all vehicles except buses)	659417	0,65	428621,05
Air transport	42273	0,65	27477,45
Rail transport (class 1 freight)	12814	0,65	8329,1
Sea transport	28381	0,65	18447,65

Source: own study based on (Bureau of Transportation Statistics, 2016).

The application of artificial intelligence can lead to significant reductions in operational costs, although the effects might vary depending on the area of implementation. Table 3 presents estimated fuel cost savings resulting from the adoption of AI-based solutions. The smallest benefits are observed in the optimization of air transport routes, allowing for an average cost reduction of 7.5%. Preventive maintenance has the greatest positive impact, reaching up to 20%, while optimization of land transport routes provides approximately 5% less savings (Miller et al., 2024). Additionally, autonomous navigation systems, aside from enhancing safety, enable a 12.5% reduction in fuel consumption.

Assuming these technologies had been implemented by all U.S. carriers in 2016, the largest financial savings would have been achieved in road transport, where route optimization could have generated as much as $642 million in savings. In air transport, costs would have decreased by approximately $20 million, and in maritime transport by $23 million. The lowest level of savings was observed in rail transport, despite the highest potential percentage reduction in energy consumption. This outcome is justified by the fact that the greater the total fuel consumption in a sector, the greater the potential for generating savings through the adoption of modern technologies.

Table 3.
AI Applications and Energy Efficiency

Type of transport	AI Applications	Medium energy efficiency impact	CO_2 reduction	Cost reduction (mln $)
Road transport	Route optimization	15%	11%	642,932
Air transport	Flight path optimization	7,5%	6%	20,608
Rail transport	Predictive maintenance	20%	16,5%	16,658
Sea transport	Autonomous navigation systems	12,5%	9%	23,060

Source: own study based on (Kaushik, 2024; Miller et al., p. 14).

It's important to note that the proportion of different transport modes in total fuel use can differ by region. However, a similar situation occurred in the European Union in 2022. According to statistical data, road transport consumed more energy than any other sector (73.6%), far ahead of maritime transport (13.0%), air transport (11.4%), and rail transport (1.4%) (Eurostat, 2025). This indicates that European carriers could also achieve significant fuel savings, depending on the type of transport mode used.

CO_2 emissions reduction is directly linked to energy consumption levels. The lowest potential for emissions reduction concerns air transport, while the highest applies to rail transport (see Table 3). Nevertheless, it should be emphasized that cutting road transport emissions by 11% would generate the greatest environmental advantages because of its leading role in fuel consumption (TechHive NextGen, 2025). As a result, companies that perform road deliveries can save a substantial amount of money by adopting modern technologies and also play a direct role in developing a sustainable, eco-friendly business model.

5. Conclusions

Transport is a process that encompasses cyclical activities aimed at moving people, goods, or space in a way that increases their utility in a new location. Undoubtedly, transportation is a vital component of economic and social progress, as it links producers to consumers via the movement of goods and services. Transport routes, which are a series of points scheduled to be visited within a certain timeframe, are essential for logistics and supply chain operations. Well-organized routes enable companies to substantially lower operational expenses, such as fuel use and the number of drivers needed.

Route planning focuses on finding the most efficient travel path, whereas optimization aims to attain the best possible result with the resources at hand. In practice, managers start with the planning stage and subsequently optimize the planned routes based on delivery performance, considering both time and cost.

Therefore, organizations are motivated to increasingly moving away from traditional, manual planning in favor of Transport Management Systems (TMS). These solutions may be basic, advanced, or comprehensive, depending on the operational needs of the enterprise.

TMS can be developed in-house (by an IT department), purchased as an on-premises solution, or used as a cloud-based service.

Currently, artificial intelligence techniques find the most favorable conditions for implementation in road transport, primarily due to fewer implementation barriers and the highest potential for reducing operational costs. In rail transport, AI technologies are most often applied in predictive maintenance, generating substantial savings and positively impacting the cost efficiency of the entire system. In maritime transport, autonomous navigation systems reduce fuel consumption by 12.5%, although these digital solutions are not yet fully mature. Calculations have shown that aviation also benefits financially and environmentally from route optimization, albeit to a lesser extent compared to other transport modes. Based on quantitative results, land transport should be prioritized for implementing such systems to significantly lower costs and increase profits.

The application of artificial intelligence algorithms allows for more precise route planning and demand forecasting for transport services. Advanced data analysis methods enable rapid adjustment of transport resources to changing conditions, enhancing flexibility and efficiency in logistics processes. Route optimization and improved fleet management can reduce costs and improve service quality.

In summary, each transport mode possesses unique advantages and limitations that determine its suitability under specific operational conditions. The costs of building and maintaining infrastructure vary depending on the mode of transport, which also affects the complexity of logistics-supporting software. Road transport generates the highest annual fuel consumption due to the need to execute numerous last-mile deliveries. Rail transport is a more cost-effective alternative for long-distance shipments, though its flexibility is limited by rigid infrastructure. Maritime and air transport, despite limited route variability, can also benefit from route optimization techniques, although to a slightly lesser extent than road transport.

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