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Research Article

AI-Based Freight Delay Prediction and Dynamic Re-Routing System

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Abstract:

The utilization of the latest technologies in the logistics of freight is increasingly based on the necessity to manage the ever-growing complexity of the transportation network and the variability of delays. AI is also a major enabler of freight delay prediction and real-time dynamic re-routing of freight. The paper provides a well-grounded review of the current trend in the research area of AI-assisted freight delay prediction and dynamic re-routing schemes. Using citations from ten recent studies, the review was written about the application of AI to decision support systems, enterprise resource planning, car networks, intelligent transportation, and the logistics of electric vehicles. The paper also describes the implications of 6G communication technologies, sustainability-focused automation, and cold chain logistics on the optimization of freight operations by AI. The findings prove that AI can make all logistics networks more resilient, flexible, and efficient, enabling them to react to disruptions in real time and ensure sustainability and low costs. It is now possible to rely on AI as one of the pillars of the technological revolution in intelligent, autonomous freight due to such advances.

1. Introduction

The logistics and freight transport industry is embracing artificial intelligence (AI), and this is transforming the way freight delay is predicted and dynamic routing is conducted through supply chains within the global market. Due to the high pace of urbanization, globalization, and increased complexity of multimodal logistics networks, freight transportation systems are likely to face numerous disruptions such as congestion, accidents, natural disasters, and fluctuating demand [1]. These dilemmas are calling for new technological solutions that are capable of conducting real-time analysis, adaptive learning, and autonomous decision-making. These needs can now be satisfied using AI-powered systems because they have the capability to streamline freight flow, develop routes, and perform predictive analytics.

The review of the state-of-the-art application of AI to freight delay prediction and dynamic re-routing will be provided in the paper. The review is founded on ten properly identified sources of recent research and publications, according to which AI-driven models, methods, and frameworks are proposed to address the underlying problems in the sphere of freight logistics [17]. Decision support systems, dynamic routing schemes, vehicular ad hoc networks (VANETs), intelligent transport systems (ITS), 6G-enabled connectivity, cold chain logistics, and electric vehicle (EV) routing are the most significant ones.

2. AI Decision Support Systems for Freight Delay Management

This contemporary freight management has its foundation in AI-based decision support systems (DSS) that can be applied to provide an analytic foundation for identifying potential delays and taking timely re-direction plans. These systems are used to predict interferences in rail and road networks through a combination of past information, live traffic data, and forecast models [2]. Particularly in relation to rail freight, DSS with AI support can be considered, since cascading delays may be prevented by ensuring that traffic is synchronized. Incorporating advanced neural networks and machine learning algorithms into these systems is effective in understanding the state of the infrastructure, the direction of the train, and the weather to predict the likelihood of delays and

propose alternative paths [12].Figure 1 illustrates the conceptual architecture of an AI-based freight delay prediction system. The model shows how real-time data, when fed into learning algorithms, enables dynamic decision-making that minimizes transportation bottlenecks.

These systems can potentially support alternative transport modes and alternative infrastructures in alternative regions through the use of deep reinforcement learning (DRL) along with data fusion. The DRL agents are continuously trained to locate the best available routing policy using a simulation environment based on real-life scenarios, which provides freight carriers with the capacity to predict and reassign resources to unexplored routes that are less frequently used. The minimization of dwell time, the enhancement of fuel efficiency, and the amplification of service reliability can be achieved later with the help of AI-based DSS [1] [20] .

3. Dynamic Routing with AI in ERP and Logistics

Such an opportunity to dynamically adjust freight routes in real time, based on varying traffic and environmental parameters, is key to avoiding costly delays. The integration of AI-based dynamic rerouting into Enterprise Resource Planning (ERP) systems significantly enhances logistics coordination processes [14]. ERP systems can also include machine learning modules that calculate telematics, truck schedules, warehouse capacity, and client delivery times to recommend the most efficient route at any given time. This allows freight carriers to self-adapt their routes in the event of disruptions, such as traffic jams or even infrastructure closures .

Dynamic routing that uses artificial intelligence can also allow logistics managers to simulate multiple delivery constraints simultaneously, such as vehicle capacity, priority orders, driving hours, and local laws. These systems are likely to exploit heuristics and metaheuristics, such as genetic algorithms and ant colony optimization, for multi-constraint pathfinding in complex logistics networks [2] [19]. Along with cloud computing and big data analytics, AI-enhanced ERP systems can serve as hubs of real-time logistics coordination.

In addition, AI implementation in ERP is necessary, as it supports cross-docking, route optimization, and last-mile delivery. This is particularly true for just-in-time (JIT) supply chain models, where a single step of the production line or distribution chain has the potential to cause ripple effects if not properly followed. As the supply chain becomes digital and connected, AI-advanced ERP systems also offer a scalable solution for the real-time reconfiguration of logistics [11].

4. Context-Aware Intelligent Transportation Systems

Generative AI algorithms have become highly active in context-specific applications in the creation of intelligent transportation systems (ITS). These systems exploit Belief-Desire-Intention (BDI) agent architectures, enhanced by generative models, to allow them to react to changes in the real-time environment and user objectives [3]. This is particularly relevant in urban freight systems, where frequent interference from traffic conditions, pedestrians, and road blockages disrupts regular operations.

Smart routing protocols based on BI are an AI-based system of sensor data interpretation, inference of possible outcomes, and the suggestion of policies that may be used to re-route traffic in a way that aligns with the logistical goals of the system. They are built on vehicle-to-everything (V2X) communication systems, which enable the real-time coordination of vehicles. This infrastructure allows AI agents to model not only physical paths but also network behavior, including expected traffic density and the likelihood of an accident [16].

Generative AI can also be used in routing in predictable ways. It helps in the proactive creation of paths, and scenarios are simulated ahead of time so that long-range measures can be taken before interruptions occur. The model-based solution contributes to enhancing the transportation system and ensuring the flow of freight even during peak demand or emergency situations [18].

5. 6G Connectivity and Real-Time Supply Chain Adaptation

High-speed communication networks will gain more relevance in the future of real-time freight delay prediction and dynamic routing. The 6G innovation in logistics has provided new possibilities for data-driven transport management. These are high-speed networks that guarantee smooth connectivity among vehicles, sensors, drones, and central processing units, and routing decisions can be updated within milliseconds. Real-time digital twins of the supply chain can be created with the introduction of AI into 6G, which simulates the logistics situation in real time and reconfigures routing plans [4].Table 1 presents key comparisons between 5G and 6G technologies in logistics. With a 6G connection, logistics networks will be capable of applying AI-based decentralized

decision-making, whereby edge devices (vehicle processors and roadside units) collaborate to monitor local conditions. These devices are capable of self-directing freight vehicles without being centrally controlled. Thus, they render systems resistant to regional disruptions and capable of operating under uncertain conditions [13].

In addition, 6G technology offers the scaling of the Internet of Things (IoT), which allows for monitoring temperature, humidity, and managing the conditions of shipments in real time. The sensor data can later be analyzed or processed using AI algorithms to reroute sensitive commodities, such as pharmaceuticals or perishables, in case there is a violation of environmental limits [15].

6. Automation and Sustainability in Urban Freight Routing

Special challenges—such as short delivery times, congestion in urban areas, and environmental regulations—characterize urban freight logistics. The latter is being addressed to make urban freight delivery more effective with the help of smart automation and AI-driven sustainability systems, which also help align operations with environmental policies. AI devices play a role in centralizing deliveries, reducing the number of empty miles, and calculating the most energy-efficient paths based on vehicle type and landscape [5].

Some of the most outstanding applications in this category include the use of AI to control a fleet of vehicles, including electric delivery vehicles (EVs). The routes are designed with the assistance of AI-based algorithms, which optimize battery use, avoid busy routes, and plan charge stops based on existing electricity prices and station availability. These models consider dynamic energy needs, traffic patterns, and elevation along routes to reduce the overall carbon footprint [5].

One additional use of AI is the optimization of multimodal transport, whereby the flow of urban freight by trucks can be diverted to bikes or drones to reach the final destination. This ensures that both emissions and delivery time are reduced simultaneously. As the idea of sustainability is incorporated into AI routing logic, logistics businesses will be able to comply with green logistics regulations set by the city without compromising operational performance [5].

7. Congestion-Aware Routing and Traffic Management in VANETs

AI-driven freight routing is an inseparable component of the infrastructure, which includes Vehicular Ad Hoc Networks (VANETs). Inter-vehicle and vehicle-to-infrastructure communication become possible through these networks, which are essential for congestion-aware dynamic routing. The logistics ecosystems of VANETs apply AI algorithms to the obtained telemetry and traffic congestion data of vehicles to determine the likelihood of delays and recommend possible detours to reduce delivery time and fuel usage [6].

An example of an AI model that may be applied in computing the best freight routing paths is TrafNet-DCMCRP (Traffic Network Data-Centric Multi-Constraint Route Planning), which utilizes current vehicle density, road capacity, average speed, and environmental factors to compute the optimal route. By implementing deep convolutional networks and clustering schemes, the ranking of traffic flow patterns within the network is dynamic, and it also enables real-time prediction of potential choke points before they occur [6].

These advanced AI software tools can also be used for predictive load balancing of city routes so that arterial roads are not overloaded. The modules attached to freight vehicles, which are equipped with AI, are updated periodically, recalculating the most optimal routes based on the changing situation. Unlike using these tools simply as a method for plotting a path with fixed routes, AI-enhanced VANETs are adaptively learned, meaning that previous traffic results are used to make future predictions more precise. Figure 2 displays a graph of predicted versus actual delays using AI-based VANET algorithms in freight logistics.

Such real-time and predictive services will be critical in minimizing last-minute delays in urban freight networks. In addition, these systems are integrated with cloud services and edge computing to enable scalable deployment across city and intercity routes [6].

8. AI Route Optimization in Emergency Logistics and Rescue Freight

The implementation of AI in optimizing routes can be applied not only to commercial freight logistics but also to rescue and emergency services, which are time-sensitive. The freight of emergency supplies, such as food, medicine, and shelter, often has to be dispatched under pressure during disasters. AI routing systems operating in such applications focus on the shortest paths, as well as road accessibility, weather conditions, and urgency [7].

The framework envisioned in recent studies is made up of optimization models that are capable of handling uncertainty through fuzzy logic, Bayesian

inference, and reinforcement learning. The systems are designed to work even in erratic settings in which traditional GPS and cellular networks may be disrupted. AI models are fed with geospatial satellite images, drone surveillance data, and emergency broadcast images to successfully reroute rescue freight [7].

These AI tools can be used to select the most suitable route during problematic situations by taking into consideration the feasibility of routes, their urgency, and the probability of successful delivery. This system will also be able to prioritize cargo based on its urgency, ensuring that life-saving goods reach their target destinations in a timely fashion. AI-based emergency freight logistics represents a paradigm shift, with an emphasis on resilience and intelligence as an improved method of planning, as opposed to reactive planning [7].

9. Electric Vehicle (EV) Routing and Infrastructure Integration

A significant feature of electric freight vehicles is that their range is moderate and depends on the number of charging stations and the rate of battery depreciation, which makes electric freight vehicles more difficult to navigate. The answer to such complexities lies in AI-based EV routing models, which use multi-constraint optimization to balance distance, load, charging frequency, and terrain. The analysis of trip history, battery conditions, temperature, and road elevation allows for forecasting energy consumption by EVs, which ensures they can reach their destinations [8].

Moreover, AI applications assist in the flexible selection of charging stations based on location factors, current electricity rates, and charger compatibility. Such features can be adopted alongside freight management systems to allow operators to minimize charging times and downtime. The optimization models also consider delivery windows based on the time of day, as well as the load on regional power grids, to prevent infrastructure overloading during peak times [8].

Federated learning to optimize the fleet on a general basis is the most recent development in AI-based EV logistics. All EVs in the fleet exchange data with a universal AI model that does not compromise vehicle privacy. The use of this learning model also leads to significant enhancements in routing decisions, battery management plans across the fleet, information security, and operational consistency [8].

Secondly, AI routing algorithms and vehicle-to-grid (V2G) technology are creating a closed loop of energy, with EVs acting as small batteries on wheels that feed energy back into the grid when idle. Not only does this increase energy savings, but it also aligns with global sustainability requirements for logistics systems [8].

10. Real-Time Decision Architectures in Autonomous Freight Vehicles

Self-driving trucking is founded on AI decision architectures that make decisions based on complex settings and dynamically reroute in response to delays or other disruptions. These architectures incorporate sensory data from LiDAR, radar, and visual cameras, which are dynamically processed using AI algorithms to localize, identify objects, and make route predictions. Artificial intelligence is projected to help ensure that autonomous systems can detect anomalies on the road, such as non-functional vehicles or construction zones, and divert accordingly [9].

Autonomous systems have decision-making architectures that use layered models, whereby perception, planning, and control are addressed independently but interactively. Simulation environments that replicate real-world logistics conditions are typically used to train reinforcement learning agents on these vehicles. These agents are taught to trade off between objectives such as safety, on-time delivery, and fuel economy, all within a set of constraints [9].

Incorporation of digital twins into such architectures also enhances the route planning process, as it provides real-time simulation of prevailing traffic, road structure, and weather conditions. Digital twins offer a dynamic testing environment in which routing decisions can be virtually modeled and later implemented in the physical environment. This goes a long way in reducing the possibility of failures in mission-critical freight deliveries [9].

In addition to this, autonomous freight systems with AI infrastructure allow fleet operators to perform proactive maintenance, predict accidents, and forecast vehicle availability. This operational intelligence not only ensures that autonomous freight vehicles reach their destinations efficiently, but also that they operate with minimal disruption [9].

11. Cold Chain and Reverse Logistics: AI for Specialized Freight Routing

The problems that can be solved with the assistance of AI implementation involve specific logistics processes such as cold chain logistics and reverse logistics. Cold chain logistics requires a high level of monitoring and rapid response in the event of

deviations, especially for temperature-sensitive items like food and pharmaceuticals. AI algorithms track data from IoT temperature sensors mounted in freight containers and trigger re-routing operations in case of a spoilage threat [10].

These intelligent systems utilize real-time analytics to determine whether a different path or delivery location would better preserve the integrity of the shipment. Furthermore, AI models can be used to optimize multi-drop route sequencing in such a way that the most sensitive cargo is carried at the final stage. Machine learning systems can forecast potential points of spoilage by assessing traffic conditions, predicted ambient temperature, and humidity [10].

In a reverse logistics environment, AI can be used to facilitate the planning of effective routes for transporting goods back, particularly in an e-commerce setting. The algorithms are used to compute the optimal pickup locations, consolidation facilities, and drop-off points based on customer location clusters, frequency of returns, and warehouse capacity. Reverse logistics routing must also be managed as regularly as outbound logistics, and AI has the potential to minimize total route redundancy and environmental impact [10].

AI also supports the lifecycle analysis of freight assets, helping logistics firms determine when to refurbish, recycle, or discard returned goods. The results of such decisions contribute to sustainable and cost-effective logistics management practices across the supply chain through the use of AI predictive models [10].

12. Benefits of AI-Driven Freight Delay Prediction and Dynamic Re-Routing Systems

AI-based freight delay prediction and dynamic re-routing systems provide numerous operational and strategic benefits across modern supply chains. These systems enhance efficiency, transparency, and customer satisfaction, contributing to competitive advantage in logistics. Key benefits include:

- End-to-end visibility that elevates customer satisfaction, enabling proactive communication and transparency across the entire shipment lifecycle.
- Accurate, real-time tracking updates for customers, vendors, and partners, reducing uncertainty and improving trust.
- Higher on-time, in-full (OTIF) delivery performance through predictive insights and intelligent re-routing.
- Shorter overall lead times from plant to customer by anticipating disruptions and optimizing routes dynamically.
- Data-driven analysis of delay root causes, allowing continuous improvement of transportation planning and execution.
- Early detection and communication of delays or exceptions to internal teams—such as warehouses and customer service—so they can take timely corrective actions.
- Transparent communication of additional freight costs resulting from re-routing, shared with carriers and customers in advance rather than after delivery.
- More accurate revenue recognition based on predictive delivery dates instead of static carrier transit times.
- Improved prediction of transfer-of-ownership timing for stock transport orders, supporting cleaner financial and operational processes.
- Enhanced material availability checks at the destination when predictive arrival dates are known.
- Reliable inbound delivery visibility for destination plants or warehouses, strengthening production planning and outbound order commitments—and enabling customers to be notified of potential delays well ahead of time.

These capabilities illustrate how AI technologies can dramatically enhance responsiveness, trust, and transparency in freight operations, helping businesses achieve superior customer service and operational efficiency.

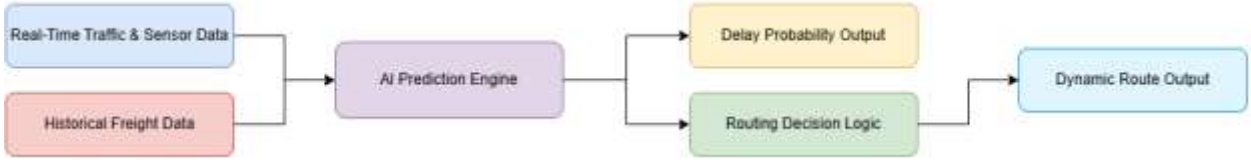

Figure 1: *Conceptual Diagram of AI-Based Delay Prediction and Dynamic Re-Routing System [1]*

Table 1: *Comparison of 5G vs 6G Capabilities for AI-Driven Freight Routing [4]*

Feature	5G	6G
Data Transfer Speed	Up to 10 Gbps	Up to 1000 Gbps
Latency	1–10 ms	Sub-millisecond (0.1 ms)
Device Density	1M/km²	10M/km²

Feature	5G	6G
AI Integration Level	Moderate	High (Embedded AI)
Predictive Routing	Partial	Full Real-Time Optimization
Network Architecture	Centralized Cloud	Distributed Edge + Cloud

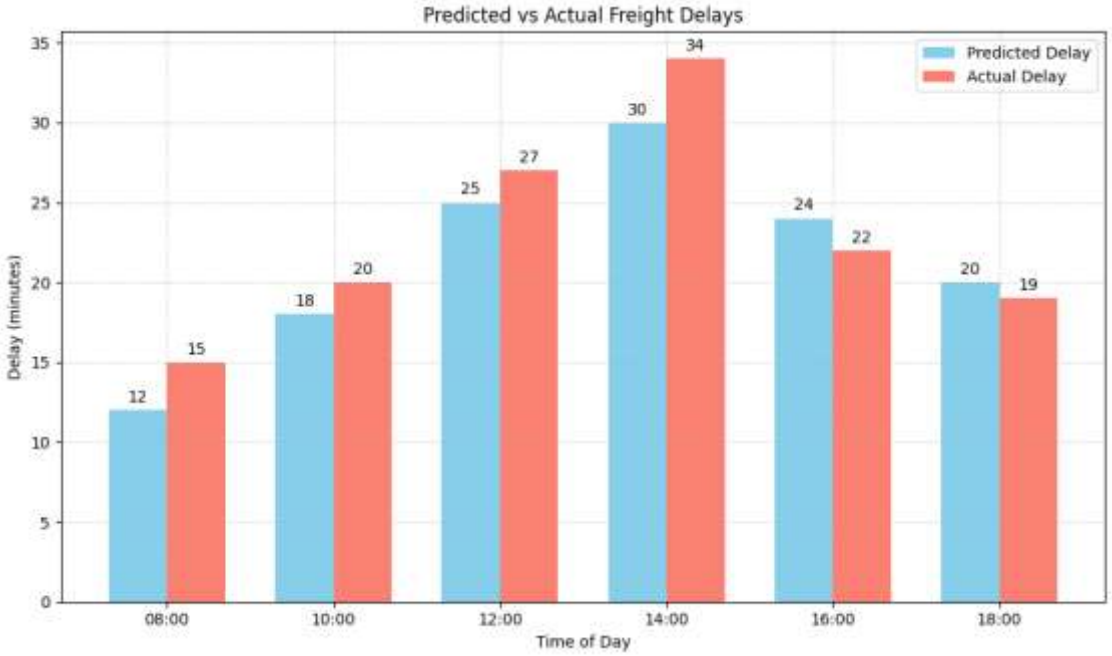

Figure 2: *Comparison of Predicted vs Actual Freight Delays Using AI-VANET Models [6]*

13. Conclusions

Comparing the studies conducted on AI-based freight delay prediction systems and dynamic re-routing systems, it is evident that this is a multidisciplinary field that is evolving rapidly. AI-based solutions are enabling greater flexibility, effectiveness, and intelligence in logistics networks than ever before. AI can support decision-making in the rail freight industry, real-time routing in autonomous vehicles, sustainable freight optimization in autonomous EVs, and cold chain management.

AI, in turn, supports real-time freight decision-making, reduces losses due to delays, lowers operational costs, and enhances the resilience of the supply chain through predictive analytics, context-driven architectures, and high-speed connectivity. A system of technologies such as 6G, IoT, VANETs, and federated learning will merge with AI, enabling logistics systems to optimise themselves and operate autonomously. As freight networks continue to expand and customer expectations evolve, the need to deliver goods in a timely, efficient, and sustainable manner will remain — AI will support, but not eliminate, this fundamental requirement.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
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- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.
- **Use of AI Tools:** The author(s) declare that no generative AI or AI-assisted technologies were used in the writing process of this manuscript.

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