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Managing Operational Risks in High-Frequency Route Planning

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Abstract

This article presents a systematic analysis of operational risks emerging during the implementation and operation of high-frequency route planning systems in logistics, driven by the need for rapid response to changes in traffic conditions, new orders, and service quality requirements. The relevance of the study is determined by the growth of e-commerce volumes and heightened customer expectations regarding delivery speed. The objective of the research is to classify and assess operational risks in the context of high-frequency route planning, as well as to develop recommendations for their mitigation through the integration of modern technologies and organizational practices. The methodology includes the collection of incident data, analysis of IT project budget overruns and human errors statistics, and evaluation of the consequences of failures through examples of downtime costs. The novelty of the work stems from the holistic integration of process-oriented and strategic approaches to risk management: using ISO 31000:2018 standards and the COSO ERM model, a set of KPIs is suggested for dynamic route planning along with recommendations on how to configure SLAs regarding infrastructure resilience. The main findings show that switching to high-frequency planning can trim down total travel time by at least 23% in comparison to the static approach however, it would entail huge investments in reliable IT infrastructure, high-quality data, and personnel training. Key areas of risk management include ensuring the throughput capacity and fault tolerance of computing resources, regulating data input and processing procedures, automating notifications for immediate response, regular stress-testing of systems under realistic scenarios, and setting KPIs and SLAs with resource redundancy in mind. Integration of predictive analytics, digital twins, and AI-driven alerts increases transparency and reduces failure likelihood, while a "safe-to-fail" culture lessens the impact of the human factor. The article will benefit the managers of logistics operations, risk managers, and IT infrastructure specialists in transport companies. It will also benefit researchers interested in dynamic route planning optimization.

Keywords: *Operational Risks, High-Frequency Route Planning, Dynamic Planning, Predictive Analytics, Digital Twins, ISO 31000, COSO ERM, KPI, SLA, IT Infrastructure, Human Factor, Automated Notifications.*

INTRODUCTION

In recent years, increasing volumes of e-commerce and tightening customer requirements for delivery speed have impelled a shift from one-time route planning to a high-frequency system that can respond quickly to changes in traffic conditions and new orders. Such dynamism is required to be maintained to keep the competitive edge and lowering costs. At the same time, high-frequency planning creates new operational risks in algorithmic reliability, timeliness of data arrival, and infrastructure capacity to withstand load.

High-frequency route planning constitutes a continuous process in which decisions on successive route adjustments are made at intervals ranging from several minutes to tens of seconds. The fundamental principle is adaptability: the model regularly receives input data (current locations and statuses of vehicles, information on congestion and traffic incidents, changes in orders and delivery windows) and computes new optimal routes based on these inputs. Multi-criteria algorithms are employed, combining objectives of minimizing travel time, fuel costs, and adherence to service levels. Thanks to the cyclical nature and short planning horizon, a balance is achieved between reaction speed and decision quality.

In contrast to static planning, where a route is determined once before the shift begins based on averaged or predicted data, the high-frequency approach operates on real-time changes "here and now." Static solutions do not account for sudden delays, accidents, or urgent new orders, often leading to resource overuse and missed deadlines. Dynamic planning, however, can reduce total travel time by at least 23% compared to the static approach; for instance, in the Copenhagen public transport system, this is equivalent to savings of approximately €809,000 per year [1]. However, the high update frequency demands reliable communication channels in the IT infrastructure, fault-tolerant computing

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capabilities, and strict regulations on the quality of data entering the system.

MATERIALS AND METHODOLOGY

For the analysis of operational risks in high-frequency route planning, various sources were used, including studies on the quality of predictions for dynamic transport planning [1], data on the risks of IT project budget overruns [2], as well as statistics on human errors and their impact on operational incidents [3, 4]. As illustrations of technological risks, it utilized reports on IT infrastructure failures and their logistical consequences [5], and information on system downtime costs [7]. For more profound risk analysis and planning optimization, it applied data on the use of predictive analytics in supply chains [8], digital twins for process modeling [9], and notification systems to improve response timeliness [10].

The research methodology comprises several key stages. Initially, a qualitative analysis of operational risks was conducted, focusing on technological, systemic, informational, and human-factor–related risks. For this purpose, data on the influence of human errors on operational incidents [3], as well as statistics on data breaches [5], were used. The implementation of risk mitigation measures, including the creation of resilient architectures and integration of modern solutions such as predictive analytics and digital twins, was examined through practices of stress-testing and monitoring [6, 9]. The final stage involves the establishment of regulated procedures for risk management and monitoring via dashboards, as well as the evaluation of the effectiveness of implemented solutions [12].

RESULTS AND DISCUSSION

In the context of high-frequency route planning, operational risks can be divided into four interrelated categories, each of which requires particular attention when constructing a reliable and adaptive delivery system. According to [13], global parcel shipping volumes demonstrate how rapidly the load on logistics is growing and why systems with “updates every minute” are needed, as shown in Figure 1.

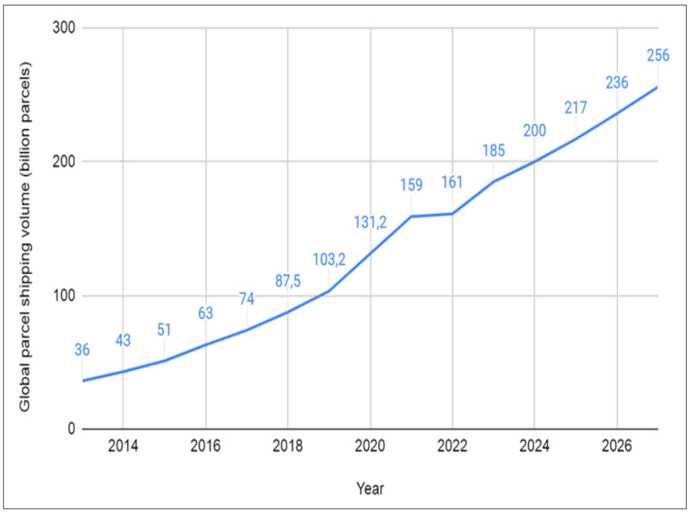

Fig. 1. Global parcel shipping volume [13]

Technological risks include failures of software components and infrastructure, without which rapid route reconfiguration is impossible. An analysis of 1,471 IT projects showed an average budget overrun of 27%, with one in six cases exceeding 200% and leading to serious service disruptions [2]. Moreover, high update frequency exacerbates requirements for communication channel throughput and fault tolerance of compute clusters, since even the slightest failure can trigger a chain reaction of disruptions across the entire fleet of vehicles.

Human-factor risks permeate all stages of route planning, from data input by the dispatcher to the driver’s reaction to changes. Studies show that human errors underlie 80–90% of all operational incidents [3], and in dynamic logistics planning, even a minor mistake during manual intervention can disrupt load balance and lead to delays across an entire delivery chain. The need for rapid response often pushes personnel toward hasty decisions, increasing the likelihood of errors and complicating subsequent restoration of normal operation.

External, or systemic, risks are associated with factors beyond the company’s direct control. These include regulatory changes, such as the enactment of new rules for access to toll roads or restrictions on cross-border transportation, as well as force majeure events: natural disasters, strikes, and epidemics. Such external shocks require the presence of hedging strategies, resource reservation, and flexible contractual conditions.

Information and cyber risks encompass threats related to the quality and security of data necessary for system operation. Poor data quality reduces employee productivity. At the same time, 74% of all data breaches are associated with human errors, from incorrect system configuration to phishing attacks [4]. The annual Verizon Data Breach Investigations Report for 2024 indicates that in 68% of confirmed incidents, an inadvertent human factor was involved [5]. Combating information and cyber risks requires integration of modern protection mechanisms, anomaly detection systems, and regular personnel training in cybersecurity practices.

As noted earlier, high-frequency route planning implies decision-making in a shortened cycle, which significantly reduces the time margin for verifying the correctness and adequacy of the algorithms applied. Instead of waiting for sufficient data accumulation over hours or even days, the system is forced to respond to new events within tens of seconds or minutes. Such speed creates a situation in which the slightest inaccuracy in calculation or delay in telemetry transmission immediately becomes a serious problem for the entire logistics operation chain.

At the same time, the “chain reaction” effect becomes a key source of vulnerability: an error in the route of a single vehicle (for example, due to an unanticipated traffic volume or incorrect arrival-time forecast) almost instantly affects resource availability for other tasks. If the system fails to immediately reallocate an available vehicle or reorder the delivery point sequence, delays will grow exponentially, violating predefined SLAs and incurring additional overtime and compensation costs.

Such systems under real conditions are often limited: To reproduce all possible combinations of traffic events, changes in demand, and driver behaviors requires enormous computational resources and very detailed historical data. Laboratory tests are typically conducted on simplified models, which leads to the emergence of "blind spots" not detected until production deployment. As a result, many issues manifest only in live operation, when there is no opportunity to adjust code promptly without risk of further failures.

For the systematic management of emerging risks, it is most appropriate to refer to established international frameworks. The ISO 31000:2018 standard proposes a sequential risk management lifecycle—from identification and analysis to evaluation, treatment, and continuous monitoring—with particular emphasis on integrating risk management processes at all organizational levels. Meanwhile, the COSO ERM framework focuses on tying risk management to the company's objectives and strategy, underscoring the importance of corporate governance, risk culture, and interdepartmental communication. Such a combination of "process-oriented" and "strategic" approaches enables building a comprehensive system capable not only of timely threat detection but also of adapting to them without loss of efficiency.

The operational risk management process in high-frequency route planning begins with the systematic identification of potential threats. At this stage, past-period incident data are collected and analyzed, key processes are mapped, and experts from IT, logistics, and operational units are surveyed to identify vulnerabilities in route-building algorithms and telemetry transmission systems.

The next stage involves risk assessment and prioritization using both qualitative and quantitative methods. For 99% of organizations, probability × impact matrices suffice for preliminary risk evaluation; however, for the most critical scenarios, quantitative models are applied, including stress tests on historical and synthetic data [6]. This hybrid approach allows ranking threats by their financial and operational consequences and directing resources to the most significant ones.

Development and implementation of risk mitigation measures are based on data indicating that a simple IT system costs on average USD 5,600 per minute of downtime [7]. Technical solutions include resilient architecture, redundant communication channels, and automatic failover to "hot" standby copies, while organizational measures cover formalized escalation protocols, personnel training, and version control of software.

Monitoring and review of the effectiveness of implemented measures are ensured through dashboards and visualizations, as well as periodic audits. Such tools allow real-time tracking of route computation time, number of failures, and SLA compliance, and provide the capability to respond quickly to deviations.

Continuous improvement is achieved through analysis of incidents, feedback from dispatchers and drivers, and regular review of regulations. In this context, it is important to note the widespread adoption of the ISO 31000:2018 standard. Integration of its principles into corporate culture and processes ensures adaptation of risk management to a changing environment and enhances system resilience to new challenges.

In today's high-frequency systems for route planning, the use of predictive and prescriptive analytics methodologies allows for detecting possible troubles in the supply chain in advance and adjusting route parameters from historical and real-time data. As stated by [8], 31% of supply chain managers adopt predictive and prescriptive analytics to make their processes more efficient. Specifically, machine learning algorithms enable forecasting variations in traffic conditions, vehicle load status, and potential technical issues, thereby minimizing operational risks as well as system downtime.

The Internet of Things broadens the scope for real-time monitoring of vehicles by data collection pertaining to engine status, fuel consumption, and driver behavior. Implementation of predictive maintenance based on IoT sensors reduces equipment downtime and significantly lowers unplanned repair costs.

Digital twins of the logistics process make up both physical infrastructure and operations in the virtual world so that event scenarios can be simulated and the impact of changes can be assessed before their deployment in the production environment. As per the prediction [9], present-day market volume for digital twin technologies is going to increase at an average annual rate of 60% to USD 73.5 billion by 2027.

The shift to application containerization and cloud architectures ensures very reliable, scalable, and easy delivery of new versions of services. This allows firms to quickly adjust computing resources in times of peak loads and keep the dynamic route planning services highly available.

When configuring SLAs for high-frequency route planning systems, it is necessary first to select indicators reflecting critical service quality characteristics, such as route computation service response time, percentage of successful route calculations, and delivery timeliness. SLAs typically include metrics for on-time delivery, system availability, and data integration accuracy. It is important to consider that overly stringent target values without corresponding resource redundancy may lead to infrastructure overload and an increase in incident frequency.

According to [14], customer complaints regarding the "last mile" have shown the following trends: since 2022, the number of complaints about delays has decreased by 8%, and compared to 2023 remains 1% lower; the distribution of causes for all complaints is as follows: "delivered but missing" – 28%, "delayed" – 28%, "carrier-related complaints" – 17%, "damage" – 14%, "returned to sender" – 4%, "incorrect item" – 4%, as shown in Figure 2.

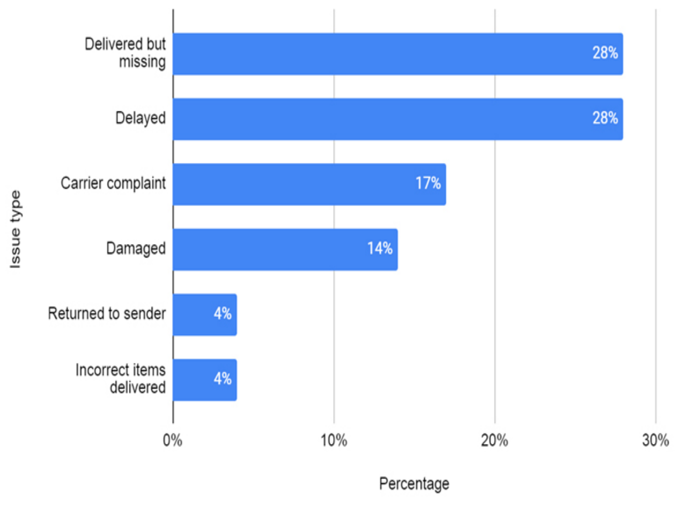

Fig. 2. Distribution of Delivery Issues Reported by Customers [14]

The creation of an automated alert system plays a crucial role in a prompt response to anomalies in the routing process. According to [10], the implementation of AI-driven notification systems increases the on-time delivery rate by 40% through instantaneous informing of dispatchers about critical events. McKinsey emphasizes that telemetry and real-time visibility tools have already been widely adopted by 93% of logistics providers, indicating the high effectiveness of such systems in supporting dynamic planning [11], as shown in Figure 3.

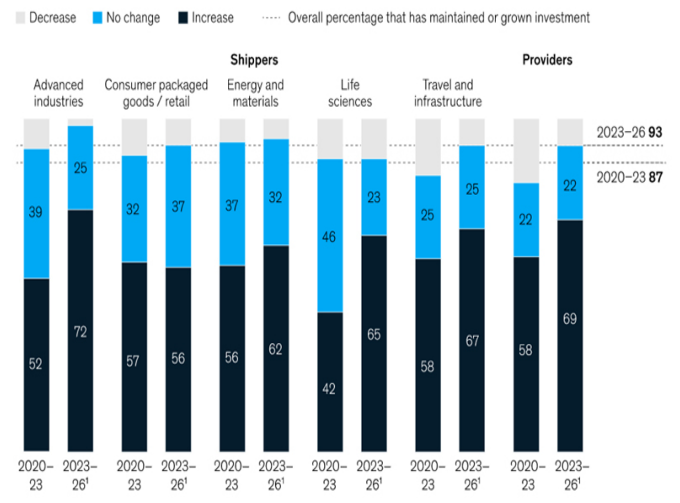

Fig. 3. Actual vs. Expected Investment in Logistics Technology by Sector and Respondent Type [11]

The development of a "safe error" culture helps reduce the influence of the human factor on system reliability. Methods for fostering a positive safety culture, such as encouraging timely sharing of information about failures without fear of punishment, have already proven their effectiveness: in organizations with a high level of employee engagement, a 64% reduction in the number of incidents has been observed according to [12].

Regular stress testing of IT systems with high-frequency route updates is necessary for the timely identification of bottlenecks and validation of architectural resilience. In practice, it is recommended to conduct comprehensive load scenarios at least quarterly, including peak and extreme conditions. To assess the risk profile in logistics, one should select a set of KPIs reflecting reliability, speed, and accuracy of operations. The leading ones are on-time delivery and ETA accuracy, inventory-to-sales ratio, and perfect order delivery rate; besides, the number of route computations per second and the average route recalculation time directly affect SLA levels and resource requirements. These KPIs combined how we can balance risk mitigation measures with the efficiency of fleet and IT infrastructure use, making sure there is operational stability in various conditions.

Modern cloud architectures, containerization, clearly defined SLAs with realistic metrics, and a well-designed automatic alert system together make a reliable, high-frequency route-planning foundation. The "safe error" culture formation and regular system stress testing have a very important role because they allow for early identification of bottlenecks and limit the human factor influence. The integration of telemetry and AI-driven notifications increases process transparency and contributes to incident reduction, whereas a balanced set of KPIs—from ETA accuracy to the number of computations per second—ensures optimal resource allocation and SLA compliance. Only a comprehensive approach that unites technology, processes, and culture will allow organizations to confidently manage operational risks and achieve stable performance under conditions of dynamically increasing load.

CONCLUSION

In recent years, high-frequency route planning has become a key tool for ensuring responsiveness and accuracy in logistics, especially amid the rapid growth of e-commerce volumes. Despite its evident advantages, such as reduced transit times and resource savings, this approach entails new operational risks that must be considered during the design and operation of such systems.

The major risk is that of technology, specifically, the continuous functioning of all software and hardware components. Failure avoidance requires provision for a fault-tolerant infrastructure plus resilient communication channels—essentially, a great deal of investment in IT system maintenance and development. Just as importantly, the very high frequency with which data must be updated places extremely stringent requirements on the quality of information going into the system because, quite literally, small errors can cascade into major disruptions across the whole logistics network.

Another important aspect is the risks associated with the human factor. Carelessness of employees at any process stage—from data entry to decision-making by dispatchers or drivers—can lead to significant operational delays. This underscores the importance of staff training and the implementation of a "safe error" culture, which contributes to reducing the number of incidents.

Equally critical are systemic risks related to external factors, such as changes in legislation or force majeure circumstances. To reduce such risks, it is necessary to develop hedging strategies and flexible contractual terms to ensure system resilience in a sudden change in the external environment.

In conclusion, a comprehensive approach will make the successful management of operational risks possible. The development of advanced technologies, reliable organizational processes, and risk management culture is are component of such an approach. The implementation of technologies such as predictive analytics, digital twins, and AI-driven notification systems significantly contributes to reducing the likelihood of failures and enhancing overall system efficiency. Combining these methods with regular stress tests and thoughtfully selected KPIs enables a successful balance between risk minimization and maximization of operational efficiency, ensuring uninterrupted operation of logistics systems even under high-load conditions.

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