TRANSPORT
Systems and Technologies
https://tstjournal.org.ua/en

VOL. 29
№1
2026
ISSN 2617-9040 e-ISSN 2617-9059

UDC 656.073:004.9:331.45

DOI: 10.32703/2617-9040-2026-47-4

Integration of automated multimodal transportation management methods and occupational safety systems in transport and logistics processes

Olena Sorochynska*
Associate Professor
National Transport University
01010, 1 Omelianovych-Pavlenko Str., Kyiv, Ukraine
https://orcid.org/0000-0003-2477-1275

Oleksandr Bovkun
Postgraduate Student
National Transport University
01010, 1 Omelianovych-Pavlenko Str., Kyiv, Ukraine
https://orcid.org/0009-0000-9760-6153

Abstract. The increasing complexity of multimodal transport chains under digital transformation creates the need for integrated management approaches that simultaneously ensure transportation efficiency and occupational safety. Across numerous transport and logistics enterprises, transportation management systems and occupational safety systems continue to operate separately, which reduces coordination efficiency, creates information gaps, and increases operational risks during transportation processes. This research aimed to design and validate integrated approaches for combining automated multimodal transport management with occupational safety systems, enhancing operational efficiency, reliability, and risk mitigation in transport and logistics processes. The study applied a conceptual modelling approach based on system analysis, multi-criteria evaluation, probabilistic risk assessment, scenario simulation, and sensitivity analysis. A simulation model was developed in AnyLogic to analyse three management scenarios with different levels of automation and system integration. The model evaluates transportation time, operating costs, downtime duration, number of incidents, and the integral occupational risk indicator under predefined operational conditions. Input parameters reflected typical operational conditions of transport enterprises and were varied to test model sensitivity. The results showed that the integrated model demonstrated the best overall performance among all analysed scenarios. The integral risk indicator decreased from 0.42 in the traditional system to 0.17 in the integrated model. Transportation time was reduced from 18.5 to 13.1 hours, downtime decreased from 120 to 58 hours per month, and the number of incidents declined from 12 to 4 cases per operational cycle. Operating costs decreased by approximately 22%. Sensitivity analysis confirmed the stability and internal consistency of simulation results. The practical value of the study lies in the potential application of the proposed model for developing digital decision-support systems for multimodal transport enterprises

Keywords: monitoring systems; risks; human factor; digital technologies; reliability

Introduction

Multimodal transportation plays an increasingly important role in modern logistics systems due to the growth of international trade, expansion of supply chains, and rising requirements for delivery speed and service quality. The combination of road, rail, maritime, and air transport within a single logistics chain creates additional opportunities for improving transportation efficiency, but at the same time significantly complicates operational management processes. The functioning of multimodal transport systems requires coordination between multiple participants, continuous information exchange, and rapid response to changes in transportation conditions. In recent years, transport companies have increasingly implemented automated management systems, digital platforms, real-time monitoring technologies, and decision-support tools to improve route planning, reduce delays, and optimise resource utilisation. At the same time, transport and logistics operations remain associated with significant occupational safety risks. Loading operations, maintenance of transport equipment, warehouse activities, and dispatch management may expose employees to hazardous working conditions. Technical failures, human

Received: 03.02.2026. Revised: 22.05.2026. Accepted: 25.06.2026. Published: 04.07.2026.

Suggested Citation: Sorochynska, O., & Bovkun, O. (2026). Integration of automated multimodal transportation management methods and occupational safety systems in transport and logistics processes. *Transport Systems and Technologies*, 29(1), 50-58. doi: 10.32703/2617-9040-2026-47-4.

*Corresponding author (*ellena06.84@ukr.net*)

errors, and poor coordination between participants in the logistics chain may lead not only to economic losses but also to workplace injuries and operational disruptions. The growing use of automation technologies has created new opportunities to reduce such risks. Digital monitoring systems and intelligent controls allow transport operators to detect operational deviations faster, improve process transparency and strengthen security controls. Nevertheless, in many practical applications, the haulage management and occupational health systems continue to function separately. Most existing approaches focus on either optimising transport or reducing occupational risk. The issue of integrating these components into a single management system remains poorly understood, in particular in the context of multimodal transport.

The scientific community is showing a growing interest in two interrelated areas of research: improving the efficiency of multimodal transport systems through digitalisation and optimisation, and ensuring occupational safety in automated logistics settings. With the obvious interdependence of these problems, they were mainly studied separately, which formed a significant gap in scientific knowledge. The issue of sustainability of multimodal systems under dynamic environments is explored in the work by N. Wang *et al.* (2023), where a comprehensive framework was proposed that take into account both passenger demand and infrastructure constraints. The authors emphasised the need for adaptive management models that are favourable to respond effectively to transport failures. At the same time, aspects of occupational health and safety remained outside the proposed evaluation structure, which limited the practical applicability of the obtained results. A systematic review of optimisation approaches in multimodal freight transport was presented in the work by C. Archetti *et al.* (2022). The authors summarised multi-criteria models that integrate indicators of cost, time and reliability, and outline the problem of harmonising these criteria in a single analytical framework. At the same time, security parameters related to personnel risks were overlooked in the context of optimisation goals. An algorithmic approach to route planning for regular multimodal transport was developed in a study by N. Dini *et al.* (2024). The proposed methodology provides an increase in operational performance under various constraints through formal optimisation. However, the model was focused exclusively on transport efficiency and does not involve the integration of occupational risk indicators.

Optimisation of cargo flows in broken multimodal networks were considered in the work by M. Ahmady & Y. Eftekhari Yeghaneh (2022). The authors justified the importance of mathematical modelling for processing uncertainty in freight transportation systems. Despite addressing issues of operational instability, the study does not establish a link between failure management and workplace safety monitoring. Probabilistic modelling of intermodal processes using stochastic Petri nets is presented in the paper by Y. Lei *et al.* (2024). The proposed approach allowed to reproduce the complexity and variability of multimodal coordination however, the study focused mainly on the synchronisation of transport operations, leaving the issue of labour safety integration outside the scope of the analysis. The issue of labour protection in the conditions of digitalisation was highlighted in the work by N. Karanikas *et al.* (2022), which examined the principles of system thinking laid down in the ISO 45001 standard. The authors identified structural gaps in the compliance of current safety standards with the requirements of highly automated production environments, which indicated the need to develop integrated management solutions. The empirical basis for the impact of Industry 4.0 technologies on labour safety indicators was formed in the study of G. Aran-Landin *et al.* (2023). The obtained results proved that automation, reducing the impact of traditional physical hazards, simultaneously creates new risks associated with the reliability of digital systems and the nature of human-machine interaction. Organisational aspects of implementing digital monitoring in the interests of security were considered in the work of I.C. Obasi & C. Benson (2025). The authors emphasised that real-time monitoring systems increase the effectiveness of detecting dangerous situations, but their practical effectiveness depends on the degree of integration into operational decision-making processes. An overview of modern technologies of sensors and analytics in the context of occupational safety management was presented in the work of O. Flor-Unda *et al.* (2023). The authors argued that technological data acquires practical value only if it was embedded in existing management systems, and not functions as a separate tool. The transformation of the human operator role in automated production environments was addressed in a study by L. Cunha *et al.* (2022) and J.E. Naranjo *et al.* (2025). The authors analysed the risks caused by a gradual decrease in the level of direct human control and justified the need for integrated systems of monitoring and decision support. The application of digital twins for predictive maintenance and risk detection in transport systems was investigated in the publication of S. Werbinska-Wojciechowska *et al.* (2024). Despite the demonstrated advantages in terms of improving the reliability of technical systems, the proposed methodology does not extend to the task of monitoring occupational safety.

Thus, the current state of scientific research shows significant progress in two mostly separate directions: optimisation of multimodal transport systems and digitalisation of labour safety management. Available studies only occasionally combine these components in a single functional and model structure. The mentioned fragmentation is especially noticeable in multimodal logistics, where the complexity of interdepartmental coordination increases risks both at the operational level and in the plane of labour safety. The lack of integrated models that would simultaneously formalise transport optimisation and occupational risk management constitutes a scientific and practical gap that this study aims to address. The purpose of the research was to develop and scientifically substantiate approaches to integrating methods of automated management of multimodal transportation with systems for ensuring occupational safety in transport and logistics processes in order to increase their efficiency, reliability, and safety. To achieve the research goal, three main tasks were defined:

1) to analyse modern approaches to automated multimodal transportation management and occupational safety systems in the context of digitalisation;

2) to develop a formalised multi-criteria model that integrates economic, time and safety parameters within a unified management framework;

3) to evaluate the effectiveness of the proposed model using scenario-based simulation and sensitivity analysis.

Materials and Methods

By its nature, this study was conceptual and built on the modelling of – without experiments and without enterprise-specific data. Generalised illustrative parameters were employed to evaluate how modifications in the management structure influence key operational indicators. Object and subject of research. The object of the study was the logistics process of a transport enterprise, which involves multimodal transportation. Research subject – integration of automated transportation management methods with occupational health and safety systems within a single management model. System analysis was used to determine the structure of the integrated management model and the connections between its elements. Simulation modelling was used to reproduce the logistics cycle and compare different management scenarios. The multi-criteria evaluation based on C. Archetti *et al.* (2022) allowed the analysis of performance simultaneously in terms of indicators, system cost and risk. A simple probable risk score was used to calculate the integral R score. The simulation was implemented in the AnyLogic environment. The model created a generalised logistics cycle of a transport enterprise: subsequent transport operations in which risk events and management decisions responsive to them are embedded. The parameters used in the simulation are presented in Table 1.

Table 1. Input parameters and ranges used for simulation modelling

Parameter	Value/range	Description
Number of operations per cycle	1,000	Simulation workload
Average transportation distance	250 km	Typical multimodal route length
Number of identified risks	10	Risk set used in model
Probability of risk occurrence (p_i)	0.01-0.15	Range for probabilistic assessment
Severity of consequences (s_i)	1-10	Expert scale
Automation level (A)	0.2-0.9	Scenario variation parameter

Source: developed by the authors

These values were selected as illustrative typical inputs to demonstrate model behaviour rather than to replicate a specific real enterprise. For each operation, the model calculates: transportation time (T); operating costs (C); occurrence of risk events; number of incidents; downtime duration. The integral risk indicator (R) was calculated using simple probabilistic assessment (Pajić & Andrejić, 2023):

$$R = \sum_{i=1}^{n} p_i \cdot s_i, \tag{1}$$

where p_i – probability of occurrence of the i-th dangerous event; s_i – the severity of its consequences (scale 1-10); n – total number of identified risks.

System performance was evaluated using a multi-criteria objective function with normalised indicators (Okyere *et al.*, 2022):

$$F = \alpha \cdot \frac{C}{C_{max}} + \beta \cdot \frac{T}{T_{max}} + \gamma \cdot \frac{R}{R_{max}} \to min, \tag{2}$$

where C – total transportation costs, USD; T – delivery time, hours; C_{max}, T_{max}, R_{max} – normalisation coefficients; α, β, γ – weighting factors. Weights ($\alpha = 0.4$, $\beta = 0.3$, $\gamma = 0.3$) were determined according to a reasoned assessment of the relative significance of the criteria.

Three scenarios were defined to represent different levels of automation and functional integration in the transport management system. Their characteristics are presented in Table 2. The scenarios differ in automation, route optimisation, safety monitoring, and system integration, illustrating a progressive enhancement from minimal to full operational capabilities. A sensitivity analysis was conducted by varying the automation level (0.2-0.9) while keeping all other parameters constant. The impact of these changes was observed on the integral risk indicator, transportation time, number of incidents, and downtime. To confirm the reliability of the model, three validation procedures were applied, focusing on internal consistency and practical plausibility of results. First, a logical consistency check confirmed that changes in input parameters lead to expected and coherent changes in output indicators, including risk level, number of incidents, downtime, and transportation time. Second, a sensitivity check demonstrated that gradual variation of the automation parameter produces smooth and monotonic changes in all output indicators, without abrupt fluctuations, confirming the stability of functional relationships in the model. Third, a plausibility check showed that simulated results correspond to reported ranges in transport logistics studies for medium-distance multimodal freight transport, confirming the realism of model outputs under the adopted assumptions.

Table 2. Characteristics of management scenarios used in simulation

Scenario	Automation level	Route optimisation	Safety monitoring	System integration
Traditional system	0.2	No	No	Absent
Partial automation	0.5	Yes	Limited	Partial
Integrated model	0.85	Yes	Full	Full

Source: developed by the authors

On routes 200-300 km long, the delivery time is usually between 12 and 24 hours depending on how harmoniously the different modes of transport interact, how loading is organised and whether delays are created at transfer points. The model gives values between 13.1 and 18.5 hours for excellent scenarios and they all fit into this realistic section. A similar picture with downtime. For transport enterprises with an average load of the fleet, monthly downtime is necessarily fixed within 50-150 hours depending on the technical condition, frequency of incidents and service organisation. Simulated values of from 58 to 120 hours – are accurately passed into this part. The frequency of incidents in transport and warehouse operations for enterprises with a comparable load is usually described as 3-15 cases per operating cycle. The model results of from 4 to 12 incidents do not go beyond these limits and naturally change when the automation and integration parameters vary. Of course, the described procedures do not replace full empirical verification. But the fact that model values coincide with real working functions already says a lot: the model does not produce abstract numbers detached from practice. It works within the limits characteristic of real transport and logistics systems, which confirms its conceptual and practical validity for scenario analysis within the given assumptions. The results are indicative and reflect model behaviour under predefined assumptions. The model does not account for implementation costs, personnel training costs, cybersecurity risks, or infrastructure adaptation constraints. Figure 1 presented an integrated system for multimodal transport management and occupational safety, illustrating the interaction of data collection, analytics, transport and safety management, and decision support to enhance efficiency, risk mitigation, and adaptability.

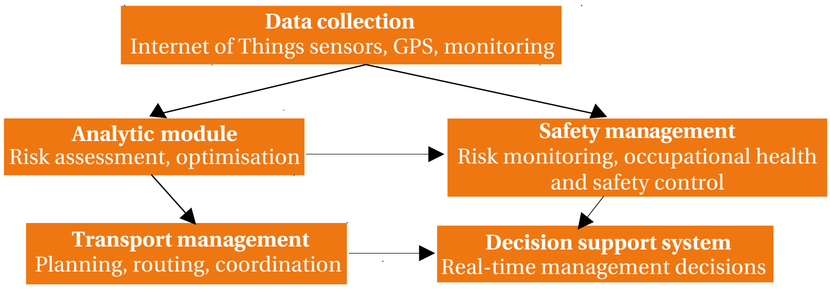

Figure 1. Conceptual scheme of the integration of automated multimodal transport management and occupational safety systems

Source: developed by the authors

Figure 1 showed the flow of information between system components, where IoT sensors and GPS data fed into the analytic and safety modules, which in turn coordinated transport operations and generated real-time management decisions. It highlighted the sequence of data-driven decision-making and risk control across the integrated transport and occupational safety system. A single information environment ensures seamless interaction between all participants in the process – from multimodal transport operators to occupational health and safety services and management. This allows not only to effectively coordinate transport operations, but also to constantly monitor key safety indicators, such as the probability of accidents, vehicle overloading and violations of occupational health and safety rules by personnel. In addition, the integration system includes adaptive management algorithms that take into account dynamic changes in transportation conditions and risks in real time. This ensures timely response to dangerous events, automatic route adjustment, optimal resource allocation and provision of recommendations on safe personnel behaviour.

Results and Discussion

The simulation modelling made it possible to assess how different levels of automation and system integration influence the key performance indicators of transport and logistics processes. Since the study is simulation-based, the results should be interpreted as indicative and demonstrating model behaviour under predefined assumptions. Table 3 presents the generalised results obtained for the three modelled scenarios. When moving from a traditional system to an integrated management model, all indicators improve – and this is not a coincidence, but a natural result of the internal logic of the model. The mechanism is simple: the higher the level of automation, the fewer operations require manual intervention. And less human factor – is a lower likely component in the risk calculation, and, accordingly, fewer incidents. Transport time is reduced by automated route optimisation and better coordination between stages of transportation – delays between processes simply disappear (Dini *et al.*, 2024). Operating costs are reduced not so much by direct savings from automation as by reducing downtime and reducing disruption caused by incidents. The downtime itself is shortened because the integrated system detects failures faster and reacts to them more coherently. At the same time, it is critical to acknowledge the limitations of the model: it may overestimate operational efficiency and does not incorporate the financial and logistical challenges associated with digital transformation, including implementation costs, personnel training, cybersecurity risks, and infrastructure adaptation requirements. Therefore, with the results of Table 3, these are model estimates within given assumptions, and not a guaranteed forecast for any transport enterprise. Comparative analysis of scenarios demonstrated on Figure 2.

Table 3. Results of simulation modelling for three management scenarios

Indicator	Traditional system	Partial automation	Proposed model
Risk level (R)	0.42	0.28	0.17
Transportation time (hours)	18.5	15.2	13.1
Operating costs (%)	100	87	78
Number of incidents	12	7	4
Downtime (hours/month)	120	82	58
Automation level	0.2	0.5	0.85

Source: developed by the authors

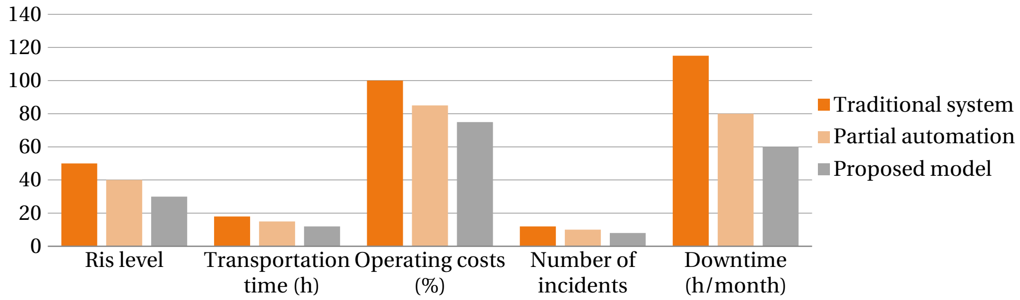

Figure 2. Comparative analysis of performance indicators for three management scenarios
Source: developed by the authors

The proposed model is assessed against four criteria: minimisation of incidents and downtime as indicators of technical reliability; reduction of operating costs as a measure of economic efficiency; reduction of transportation time as a performance benchmark; and decrease in the integral risk indicator as a safety outcome. Together, these criteria underpin the comparative analysis across management scenarios and serve as the interpretive framework for the simulation results. Figure 2 provides a visual comparison of key operational indicators across three scenarios: the traditional system, partial automation, and the proposed integrated model. The comparison highlights the magnitude of performance changes and identifies which indicators are most sensitive to improvements in management and system integration. The most pronounced changes are observed in indicators directly related to operational reliability. The number of incidents decreases from 12 cases in the traditional system to 4 cases in the proposed model, representing a 66.7% reduction. Monthly downtime is reduced from 120 to 58 hours, corresponding to a 51.7% decrease. These results indicate that systematic diagnostics and predictive analytics primarily enhance the stability of transport operations and deliver the most tangible improvements in reliability.

When evaluated across all defined criteria – incidents and downtime, operating costs, transportation time, and integral risk level the integrated model demonstrates the most balanced performance across all parameters. Two indicators show the highest sensitivity to management changes: the number of incidents (-66.7%) and downtime (-51.7%). This is expected, as these indicators most directly reflect system reliability, where integration effects are strongest. Transportation time and operating costs demonstrate moderate reductions (-27.8% and -22%, respectively). The integral risk indicator shows a substantial decrease due to the cumulative effect of multiple probabilistic components embedded in the model structure. Operating costs decrease by 21% in the proposed model compared to the traditional system. This reduction is primarily associated with fewer emergency repairs, improved maintenance planning, and more rational allocation of technical and human resources. Transportation time exhibits smaller relative changes than reliability indicators. The reduction from 18 to 13 hours (-27.8%) is constrained by the influence of external logistical conditions, which are only partially controlled by management decisions. The smallest absolute changes are observed in the integral risk level. Although it decreases consistently across scenarios, the reduction is gradual because risk is an aggregated indicator influenced by multiple external and internal factors. Improvements in internal processes alone cannot produce abrupt changes in this parameter. Figure 3 illustrates the dependence of the integral risk level on the degree of automation.

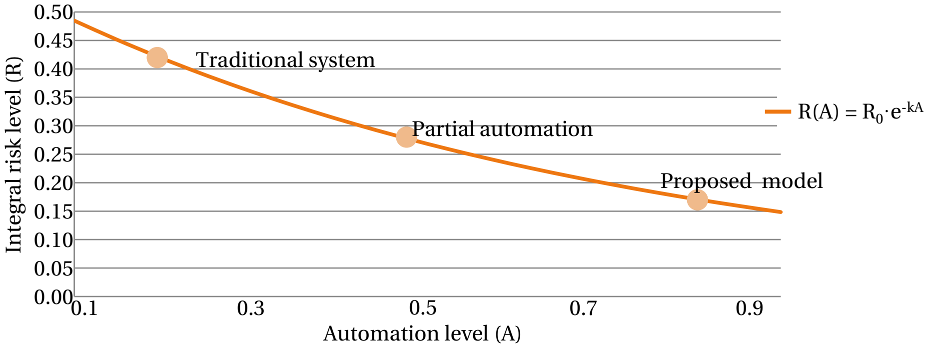

Figure 3. Dependence of risk level on the degree of automation in transport and logistics processes
Source: developed by the authors

To plot Figure 3, the level of automation in simulation models was raised step by step from 0.2 to 0.9, all other parameters being unchanged. For each intermediate value, the integral risk measure R was calculated anew. The resulting curve reflects the internal logic of the built-in probabilistic risk model: as automation increases, the risk decreases nonlinearly. It is important to understand that this is not a universal regularity, empirically confirmed – is the behaviour of a specific model under given conditions. A sensitivity analysis was performed to further verify the reliability of the results. He showed that the change in the level of automation each time gave predictable and logically explained changes in R, T, number of incidents and duration of downtime. This confirms that the model is internally consistent and behaves stably. The observed improvements are consistent with the internal structure of the simulation model, where increased automation reduces risk exposure and operational disruptions. In addition, the implementation of automated control algorithms allows for reduced transportation time by optimising routes and increasing coordination between different modes of transport. The reduction in operating costs is due to more efficient use of resources, reduced downtime, and minimised losses associated with emergency situations. For each scenario, the integral risk indicator was calculated using the normalised system of operational, technical, and safety indicators described in the methodology section (Fig. 3).

The results of this study can be compared with low work, considering automation, risk assessment and decision support in logistics and occupational health and safety – each with adding to the topic in its own way. G. Fragapane *et al.* (2021) investigated autonomous mobile robots in internal logistics in detail. Their conclusion: when decisions are made at separate levels of agents, without centralised management, the warehouse reacts faster and loses less time to delay. The research proposal is supposed to be on the same logic, but go beyond warehouse logistics to multimodal transport chains. It appears that the principles of autonomy and coordination, which have well recommended themselves at the level of individual facilities, also effectively reduce the number of incidents and downtime in intermodal logistics. It is essential to recognise that improvements in the indicators do not occur autonomously. Achieving the reductions in downtime and incident rates predicted by the model requires systematic diagnostics, continuous data acquisition, and the implementation of predictive analytics. At the start, this means additional costs and time for team preparation. But the long-term prospect of such an investment justifies itself – operating costs are decreasing, reliability is increasing, and this is in good agreement with what other researchers in the field are recording. V. Pajić & M. Andrejić (2023) used the Fine-Kinney method to assess risks in internal transport processes. Their approach is static: risks start on a probability and severity scale at a specific moment. The same principle is used in this study, but with different mechanics: risk assessment is built into the simulation model and varies according to the level of automation. This allows the observation of risk dynamics as they evolve in response to organisational changes, rather than being assessed solely under static conditions.

The evolution of Industry 4.0 and its implications for logistics has been examined by E. Hofmann & M. Rüsch (2017), who discussed current status and future prospects in integrating digital technologies into transport and production systems. The issue of collaborative works in logistics and production is considered in the work of L. Pietrantoni *et al.* (2024), which collected expert opinions of industry specialists. The main conclusion of the authors: technology in itself does not make work safer, this happens only when it is built into the decision-making process and the organisational structure of the company. These findings corroborate the results of this study, indicating that the depth of system integration has a greater impact on operational efficiency than the level of automation alone. The role of new technologies in occupational health and safety was analysed in detail in an extensive review by L. Möckel *et al.* (2023). The authors highlight that digital monitoring, predictive analytics, and data-driven security management play an increasingly significant role. However, the question remains regarding how these tools can be effectively integrated into transport coordination. The present study addresses this gap by demonstrating how security analytics can be systematically incorporated into logistics management within a unified model. The state of occupational health and safety management in modern organisations is investigated in the work of D. Ramos *et al.* (2022). The authors emphasised that security is effective only when it is systematically integrated into operational processes, rather than functioning in parallel. This finding aligns with the simulation results, where increased reliability and reduced downtime are achieved by embedding security monitoring within transport management decisions rather than treating it as a separate function. The use of anthropocentric digital twins to ensure workplace safety was analysed by A. Kim *et al.* (2023). The study revealed the mechanisms for integrating safety data into the working environment, however, the proposed approach was not adapted to the specificity of multimodal transport chains. Multicriteria optimisation of multimodal cargo systems based on genetic algorithms was presented by S. Okyere *et al.* (2022). The proposed model provided a balance of sustainability, cost and time indicators however, occupational risk is not considered as an independent parameter in the decision-making process. The application of genetic algorithms for multimodal freight transport optimisation is addressed in the work of S. Okyere *et al.* (2022), where sustainability, time and cost are balanced within a multi-criteria model. A key distinction from the proposed approach is that professional risk is treated as a separate optimisation parameter rather than being derived from other indicators. In this way, occupational safety is considered alongside traditional logistics criteria, rather than being peripheral to the model. Overall, existing studies tend to focus either on logistics optimisation or on the digitalisation of occupational safety, but rarely address both simultaneously. The present study addresses this gap by integrating these domains within a single model. As a result, it demonstrates how automation and system integration jointly affect transportation time, operational costs, reliability, and risk, providing a comprehensive assessment that considers all aspects together rather than in isolation.

Conclusions

In this study, a multi-criteria model was developed integrating economic, temporal, and safety parameters into a single objective function. Probabilistic risk assessment, indicator normalisation, and scenario-based simulation were conducted in the AnyLogic environment. Three management scenarios were simulated, differing in automation level and system integration: a traditional system (automation 0.2), partial automation (0.5), and the integrated model (0.85). Simulation results indicate that higher automation levels combined with integration of occupational safety within transport management potentially reduce the integral risk level, downtime, transportation time, and operational costs. Specifically, the integral risk decreased to 0.17 in the integrated model compared with 0.42 in the traditional system. Transportation time was reduced from 18.5 to 13.1 hours, incidents declined from 12 to 4 per operational cycle, and monthly downtime decreased from 120 to 58 hours. Operational costs were reduced by approximately 22%. Sensitivity analysis demonstrated that the model responded predictably to changes in automation: as the automation parameter A increased from 0.2 to 0.9, integral risk, transportation time, incidents, and downtime changed smoothly, without abrupt fluctuations. This indicates internal consistency and suggests that the model plausibly reflects the dynamics of an integrated management system under the defined assumptions. Notably, the depth of integration between subsystems had a greater influence on performance than automation alone. Integration facilitates coordinated operations, route optimisation, and timely risk assessment, thereby reducing human-factor impacts and improving the reliability of transport and logistics processes. From a practical perspective, the proposed model can assist managers of transport and logistics enterprises, particularly in multimodal systems with elevated operational risk, by providing a framework to evaluate management decisions. It may also serve as a conceptual basis for digital decision-support tools that combine logistical optimisation with occupational safety management. It should be noted that the findings are indicative, based on generalised modelling parameters rather than empirical data from a specific enterprise. Therefore, they should be interpreted as guidance rather than precise forecasts. Future work should focus on validating the model using real operational data and extending its capabilities through more detailed risk assessment and advanced optimisation methods.

Acknowledgements

None.

Funding

None.

Conflict of Interest

None.

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Інтеграція методів автоматизованого управління мультимодальними перевезеннями та систем забезпечення безпеки праці у транспортно-логістичних процесах

Олена Сорочинська
Доцент
Національний транспортний університет
01010, вул. М. Омеляновича-Павленка, 1, м. Київ, Україна
https://orcid.org/0000-0003-2477-1275
Олександр Бовкун
Аспірант
Національний транспортний університет
01010, вул. М. Омеляновича-Павленка, 1, м. Київ, Україна
https://orcid.org/0009-0000-9760-6153

Анотація. Зростаюча складність мультимодальних транспортних ланцюгів в умовах цифрової трансформації зумовлює потребу в інтегрованих підходах до управління, які одночасно забезпечують ефективність перевезень та безпеку праці. На багатьох транспортно-логістичних підприємствах системи управління перевезеннями та системи охорони праці й надалі функціонують відокремлено, що знижує ефективність координації, створює інформаційні прогалини та підвищує операційні ризики під час транспортних процесів. Метою цього дослідження було розроблення та валідація інтегрованих підходів до поєднання автоматизованого управління мультимодальними перевезеннями із системами охорони праці для підвищення операційної ефективності, надійності та мінімізації ризиків у транспортно-логістичних процесах. У дослідженні застосовано підхід концептуального моделювання, що ґрунтувався на системному аналізі, багатокритеріальному оцінюванні, ймовірнісній оцінці ризиків, сценарному моделюванні та аналізі чутливості. В середовищі AnyLogic було розроблено імітаційну модель для аналізу трьох сценаріїв управління з різними рівнями автоматизації та системної інтеграції. Модель оцінює тривалість перевезень, операційні витрати, тривалість простоїв, кількість інцидентів та інтегральний показник професійного ризику за визначених експлуатаційних умов. Вхідні параметри відображали типові умови функціонування транспортних підприємств і варіювалися для перевірки чутливості моделі. Результати показали, що інтегрована модель продемонструвала найкращі загальні показники серед усіх проаналізованих сценаріїв. Інтегральний показник ризику знизився з 0,42 у традиційній системі до 0,17 в інтегрованій моделі. Тривалість перевезень скоротилася з 18,5 до 13,1 години, простої зменшилися зі 120 до 58 годин на місяць, а кількість інцидентів скоротилася з 12 до 4 випадків за операційний цикл. Операційні витрати знизилися приблизно на 22 %. Аналіз чутливості підтвердив стабільність та внутрішню узгодженість результатів моделювання. Практична цінність дослідження полягає в потенційному застосуванні запропонованої моделі для розроблення цифрових систем підтримки прийняття рішень для підприємств мультимодальних перевезень

Ключові слова: системи моніторингу; ризики; людський фактор; цифрові технології; надійність