

Application of FMEA for Risk Management in Urban Freight Transport Systems

Małgorzata Dendera-Gruszka^a, Dariusz Masłowski^a, Julia Giera^a, Jakub Baszak^a ¹

^a*Opole University of Technology, 45-758 Opole, Poland*

Abstract

This article presents an analysis of risk factors affecting the operation of urban freight transport using the FMEA (Failure Mode and Effects Analysis) method. The study was conducted for a selected urban area, which made it possible to account for local infrastructural, legal, and social conditions. Risk factors were identified and assessed across eight key areas: technological, temporal, locational, economic, political-legal, economic-developmental, social, and environmental. The results indicate that the most significant risks are related to technological issues, particularly failures of information systems and the lack of integration of logistics tools, as well as locational constraints resulting from urban infrastructure. Economic factors, such as rising fuel and labor costs, and political-legal conditions—especially those associated with the implementation of low-emission zones—also have a considerable impact on the efficiency of urban freight transport. Based on the analysis, practical recommendations were formulated, including fleet modernization, the implementation of advanced transport management systems, and the adaptation of operational strategies to dynamically changing market and regulatory conditions. The findings may support logistics operators and decision-makers in minimizing risks and improving the efficiency of urban freight transport.

Keywords: urban freight transport; risk analysis; FMEA method; logistics management; low emission zones; transport efficiency; urban logistics

1. Introduction

Urban freight transport (UFT) plays a critical role in ensuring the efficient functioning of contemporary cities (Ridaoui, Moufad & et.al. 2024; Bjørgen & Ryghaug 2022; Rześny-Cieplińska, Tomaszewski & et.al. 2023; Williamsson & Moen 2022). The continuous growth of urban populations, progressive urbanization, and the rapid expansion of e-commerce have substantially increased the demand for logistics services, intensifying operational complexity and exposing transport operators to new categories of risk (Campisi, Russo & et.al. 2023; Orłowska 2024; Ramírez-Villamil, Montoya-Torres & Jaegler 2025).

Unlike long-haul freight transport, UFT operates within densely built-up areas characterized by high traffic volumes, infrastructural constraints, and regulatory restrictions. Congestion, limited loading and unloading zones, and the implementation of low-emission zones (LEZs) significantly affect delivery performance and operational reliability (Maxner, Rula & et.al. 2025; Ma, Ampong & Mészáros 2025; Bukhari, Somanagoudar & et.al. 2023; Manglano-Redondo, Paricio-Garcia & Lopez-Carmona 2025). At the same time, growing environmental expectations and increasingly stringent legal frameworks compel logistics operators to modernize fleets and adapt operational strategies. Consequently, effective risk management has become a prerequisite for maintaining transport efficiency and service quality in urban environments.

Risk management in urban freight systems contributes directly to process optimization, cost control, and operational resilience (Tabatabaei 2024; Morgado, Pereira, et.al. 2026; Kütahya & Kanmaz 2025; Patnala, Regehr & et.al. 2024). Structured analytical methods such as Failure Mode and Effects Analysis (FMEA) enable the systematic identification of potential failure modes, assessment of their impact, and prioritization of corrective or preventive actions. The application of FMEA supports decision-making by reducing uncertainty and enhancing the robustness of logistics systems under dynamic market and regulatory conditions (Peng, Wang & et.al. 2023; Hu & Salim 2023; Liou, Liu & et.al. 2022; Barhoumi, Frikha & Boujelbène 2026).

¹ Corresponding author. Małgorzata Dendera-Gruszka; Tel.: +48 785 092 756;
E-mail address: m.dendera-gruszka@po.edu.pl

The objective of this study is to conduct a comprehensive risk assessment of urban freight transport using the FMEA method. The analysis was performed for a selected urban area, allowing the inclusion of local infrastructural, legal, and socio-economic determinants. Based on the findings, practical recommendations were formulated to mitigate identified risks and improve operational efficiency.

In addition, the study includes a concise review of the literature on risk management frameworks, relevant standards, and analytical methods applied in logistics practice. Particular attention is given to environmental impacts, technological integration, and infrastructure-related constraints in urban freight systems. The results provide both a methodological contribution and practical guidance for logistics operators and policymakers seeking to enhance the sustainability and resilience of urban freight transport.

2. Research methodology

The methodological framework was designed to address the study's objective of identifying and assessing key risk factors affecting the performance of urban freight transport (UFT) systems. The research focuses on (i) the identification of critical failure modes in urban freight operations, (ii) the evaluation of their impact on efficiency, safety, and reliability, and (iii) the development of risk mitigation strategies. As the study is oriented toward structured risk assessment and managerial recommendations rather than hypothesis testing, no causal hypotheses are formulated.

The paper adopts a problem-oriented and application-based research approach, integrating elements of risk management theory with empirical analysis conducted in a real urban context. The study combines a review of theoretical frameworks with field data collected from logistics operators to ensure both methodological rigor and practical relevance.

First, a targeted review of the literature was conducted, covering scientific publications on urban logistics, risk management standards, and analytical tools applied in transport systems. Particular attention was given to prior applications of Failure Mode and Effects Analysis (FMEA) in logistics and infrastructure systems, as well as to regulatory frameworks shaping urban freight operations, including environmental and low-emission policies.

The empirical study was conducted in the urban area of Świdnica, characterized by diversified transport infrastructure and typical challenges associated with medium-sized cities. The analysis focused on key components of the urban freight system, including main transport corridors, loading and unloading zones, and interactions between freight and passenger traffic. Data were obtained from local sources and publicly available transport statistics. Additionally, a structured survey was conducted among 78 enterprises representing different sectors and company sizes. The research was carried out at the turn of 2024 and 2025.

The core methodological component of the study is the application of the FMEA method to urban freight transport processes. This approach enabled the systematic identification of potential failure modes across technological, temporal, locational, economic, political-legal, social, and environmental dimensions. For each identified risk factor, three parameters were assessed: the probability of occurrence, the severity of impact, and the detectability of the failure. Based on these criteria, the Risk Priority Number (RPN) was calculated, allowing the prioritization of critical risks requiring corrective or preventive measures.

The FMEA framework facilitated the identification of high-priority risks related primarily to technological system failures, infrastructural constraints, rising operational costs, and regulatory changes associated with low-emission policies. The structured assessment enabled the formulation of targeted mitigation strategies, including fleet modernization, digital integration of logistics tools, operational reconfiguration, and adaptive compliance strategies.

The methodology developed in this study provides a replicable analytical framework for assessing risk in urban freight systems. It supports evidence-based decision-making and may be applied in other cities with comparable infrastructural and regulatory characteristics, contributing to improved efficiency, resilience, and sustainability of urban logistics.

3. Risk factors in urban freight transport

Urban freight transport (UFT) constitutes a core subsystem of urban economies. Its operational efficiency and reliability directly shape retail and service continuity, residents' quality of life, and the environmental performance of cities. At the same time, UFT is exposed to a wide spectrum of risks arising from the complexity of urban space, the multiplicity of stakeholders, and the strong dependence of freight operations on infrastructure and regulatory conditions.

This section identifies and classifies risk factors affecting UFT across eight analytical domains: technological, temporal, locational, economic, political-legal, macroeconomic/developmental, social, and environmental. The purpose of this classification is twofold: (i) to systematize the most frequently reported risks in the urban logistics literature and (ii) to highlight less obvious, yet potentially high-impact factors that may remain under-recognized in operational practice.

Based on a structured literature review, a set of representative risk factors was selected as the analytical basis for the subsequent FMEA assessment. These factors—reflecting both operational and systemic dimensions of UFT—are presented in Table 1. The selection was guided by the recurrence of specific risk themes in the literature, their relevance to urban freight performance (cost, time, service level, and safety), and their plausibility under contemporary trends such as digitalization, e-commerce growth, and the implementation of low-emission policies. The following subsections provide a concise rationale for each domain and explain why the selected risks are particularly salient for UFT systems. The following section presents selected examples of risk factors identified within each analyzed domain.

Table 1. Risk factors in urban freight transport

Domain	Risk factor	
Technological	Outdated infrastructure	Aging roads, bridges, and other infrastructure elements may lead to failures and delivery delays.
	Lack of system integration	insufficient adaptation to modern traffic management technologies limits route optimization and operational efficiency.
	Technology failures	dependence on advanced logistics systems (e.g., GPS, automation) means that their malfunction may significantly disrupt transport operations.
	Challenges in implementing new technologies	The introduction of modern solutions often encounters financial and legal barriers, which may hinder sectoral development.
Temporal	Road congestion	Increased traffic during peak hours may lead to significant delivery delays. Many cities struggle with road congestion, which directly affects travel time.
	Traffic restrictions	In some cities, restrictions on heavy vehicle access to city centers may cause additional delays. Temporary road closures due to construction works or accidents may also require detours.
	Weather conditions	Unpredictable weather conditions, such as rain, snow, or strong winds, may affect both transport safety and speed. Weather changes may result in delays and a higher risk of accidents.
Locational	Interactions with other road users	Coexistence with pedestrians, cyclists, and public transport may lead to conflicts and delivery delays.
	Changes in land use	The development of new residential areas or industrial zones may alter traffic volumes and route accessibility.
	Meteorological conditions	Extreme weather conditions affecting transport infrastructure, such as flooding, may cause delivery delays.
Economic	Inflationary pressure	Rising costs of consumables, spare parts, and maintenance services may reduce profitability. Inflation also affects customers, thereby limiting demand for transport services.
	Unfair competition and price dumping	Grey-market operators offering cheaper but illegal transport services may undermine the competitiveness of legitimate operators.
	High insurance costs and financial liability risk	Carriers incur high insurance costs, particularly for high-value or hazardous goods. Additional risks arise from customer claims in the event of delays or cargo damage.
	Liquidity-related financial risk	Long payment terms and delays in receivables collection may lead to liquidity loss. Enterprises are often forced to rely on working capital loans, which generate additional costs.
Political–legal	Restrictions related to the EU Mobility Package	Requirements concerning drivers' working time, regular return of vehicles to the country of registration, and remuneration of drivers employed in different Member States increase organizational and financial burdens.
	Problems with enforcement of transport law	Insufficient control over compliance with legal regulations may contribute to the growth of the grey market and unfair competition.
	Changes in tax policy	Increases in VAT rates for transport services or new environmental taxes, such as CO ₂ taxes, directly raise enterprise costs.
Macroeconomic	Exchange rate fluctuations	This is particularly important for operators active in international transport markets.
	Changes in tax policy	The introduction of new taxes or increases in existing ones, such as fuel excise duties, may affect business performance.
	Economic recession	A decline in economic activity leads to reduced demand for freight transport.
	Limited access to credit	Difficulties in obtaining financing may limit the investment capacity of transport enterprises.
Social	Rising residents' expectations regarding quality of life	Increasing pressure to reduce noise, exhaust emissions, and heavy vehicle traffic in residential areas affects freight operations.
	Public protests against logistics infrastructure	Opposition to the construction of warehouses, terminals, or transport routes near residential areas may hinder infrastructure development.
	Demographic changes	Population ageing may change the structure of demand for goods and the requirements concerning their delivery.
Environmental	Air pollution	Emissions from heavy vehicles may lead to stricter environmental regulations, such as the introduction of low-emission zones.
	Climate change	Extreme weather events, such as heavy rainfall, heat waves, or strong winds, may disrupt transport operations.
	Increasing CO ₂ emission requirements	Restrictions introduced at international and local levels force fleet modernization and investment in electric or hybrid vehicles.

Source: Own elaboration based on (Nilssen, M., Hanssen, G., S., 2022. Patterson, J., J., Huitema, D., 2019., Kaimuri, B., Kosimbei G., 2017., Phimphanthavong H., 2014., Chen, G., Han, J., Yuan, H., 2022., Li, Z., Chen, H., Mo, B., 2023., Yigitcanlar, T., Corchado, J., M., Mehmood, R., Li, R., Y., M., Mossberger, M., Desouza K., 2021., Bondyra, K., Zagierski, B., 2019., Masłowski, D., Dendera-Gruszka, M., Kulińska, E., Rut, J., 2020., Kulińska, E., Masłowski, D., 2020)

Table 1 consolidates the risk landscape of urban freight transport (UFT) identified through the literature review and structures it into eight domains—technological, temporal, locational, economic, political–legal,

macroeconomic/developmental, social, and environmental—to support subsequent FMEA prioritization. The listed factors show that the highest disruption potential typically arises from the interaction of (i) technology-related vulnerabilities (aging infrastructure, limited system interoperability, ICT failures and cybersecurity, and constraints linked to electrification such as charging and grid reliability), (ii) time and space constraints inherent to cities (congestion, access/time-window restrictions, insufficient loading/unloading capacity, complex street layouts), and (iii) cost and regulatory pressures (fuel/energy volatility, labor shortages, compliance and investment needs driven by LEZs and broader decarbonization policies). In addition, macroeconomic shocks (inflation, credit constraints, supply-chain disruptions), social expectations (noise/emission tolerance, acceptance of new technologies, e-commerce-driven service demands), and environmental stressors (air quality impacts, extreme weather, and climate-related infrastructure degradation) jointly shape UFT performance, indicating a strongly interconnected, multi-dimensional risk profile requiring integrated mitigation measures rather than isolated interventions.

Table 2 presents the weight assessments assigned by the surveyed enterprises to each identified risk factor. The rows correspond to the defined risk categories, while the columns represent the evaluations provided by individual companies participating in the study. For each factor, an average weight was calculated, enabling comparative analysis and subsequent integration into the FMEA framework. These aggregated values constituted the basis for determining the relative significance of risk factors and for calculating the Risk Priority Number (RPN) in the next stage of the analysis. Below, the study results are presented for five surveyed entities, together with a selected set of identified risk factors. Based on the conducted survey research, risk factors occurring in urban freight transport were identified. These factors were evaluated by the surveyed enterprises according to three criteria:

- severity (S) – indicating the importance of a given risk factor from the perspective of the surveyed enterprises,
- occurrence (O) – representing the probability of the risk factor occurring,
- detection (D) – reflecting the difficulty of identifying or detecting the given risk.

The potential effects of failures may have different levels of significance for customers, subsequent operational processes, or personnel. Therefore, the severity of failure is assessed on a scale from 1 to 10, where 1 indicates negligible significance (the failure is practically).

Table 2. Weights assigned to risk factors

Risk factor	Entity 1			Entity 2			Entity 3			Entity 4			Entity 5			Mean score – Severity (S)	Mean score – Occurrence (O)	Mean score – Detection (D)
	S	O	D	S	O	D	S	O	D	S	O	D	S	O	D			
Outdated infrastructure	7	4	5	7	5	5	6	5	5	7	6	4	6	5	4	6,6	5,0	4,6
Lack of system integration	9	4	3	6	5	4	5	6	4	8	5	5	7	5	5	7,0	5,0	4,2
Technology failures	8	5	4	9	6	5	7	6	5	6	5	5	7	5	6	7,4	5,4	5,0
Challenges in impementing new technologies	5	4	5	6	5	5	6	6	4	7	5	5	8	5	6	6,4	5,0	5,0
Insufficient employee training	6	6	4	6	5	5	5	4	5	8	6	6	7	5	5	6,4	5,2	5,0
Supply chain coplexity	8	5	5	7	6	5	6	5	4	9	7	6	8	6	5	7,6	5,8	5,0
Regulatory changes	8	6	5	7	7	5	7	6	4	8	7	6	7	7	5	7,4	6,6	5,0

Source: Own elaboration

Table 2 provides an overview of how the surveyed enterprises perceive the identified risk factors. The results allow the most significant risks to be identified and reveal differences in their assessment among companies. The mean scores indicate that risk prioritization should consider not only the severity of a given factor but also its likelihood of occurrence and the difficulty of detection.

Further analysis using the FMEA method enables the prioritization of risks and supports the development of risk management strategies for urban freight transport systems.

4. Risk factors in urban freight transport

The FMEA method applied in this study enables a systematic evaluation of risks using the Risk Priority Number (RPN), which incorporates three key parameters: severity, occurrence, and detection. The RPN value is calculated according to the following formula:

$$RPN = \text{Severity} \times \text{Occurrence} \times \text{Detection}$$

The results of the analysis indicate a number of risk factors with varying levels of significance and impact on the efficiency of urban freight transport. Table 8 presents the detailed results of the risk analysis, including the identification of potential failures, their effects, and proposed mitigation measures. This table constitutes a key element of the analysis, enabling the identification of risks with the highest RPN value.

Table 3. FMEA-Based Risk Analysis

Domain	Risk factor	Potential failure mode	Potential effect of failure	Severity	Potential causes	Occurrence	Preventive measures	Detection	RPN
Technological	Outdated infrastructure	Aging roads	vehicle breakdown	6,6	Lack of investment in road modernization	5,0	Regular investment in road infrastructure	4,6	151,8
		Poor condition of bridges	Delivery delays		Excessive urban traffic load		Regular maintenance of roads and bridges		
		Lack of dedicated delivery zones	Increased operating costs		Insufficient public funding		Planning alternative routes and infrastructure modernization		
		Lack of signage for heavy vehicles	Increased accident risk		Insufficient maintenance of road signage		Development of logistics zones in urban areas		
	Lack of system integration	Incompatibility of management systems	Errors in route planning	7,0	Use of outdated software	5,0	Regular inspections and renewal of road signs	4,2	147,0
		Lack of data exchange between systems	Loss of operational efficiency		Lack of common communication protocols		Standardization of used systems		
		Lack of integration with customer systems	Delays in order fulfillment		Systems not adapted to modern market requirements		Implementation of open APIs		

Source: Own elaboration

Based on the conducted analysis, the following priority categories were defined for the identified risk factors:

Low risk (RPN < 150):

Risks of minor significance that do not require immediate corrective actions. It is recommended to monitor the situation and conduct periodic reviews in order to identify any potential changes in their importance.

Medium risk (150 ≤ RPN < 300):

Risk factors of moderate significance that require the planning and implementation of corrective actions in the medium term. These actions should include the introduction of preventive measures and the improvement of existing detection processes.

High risk (RPN ≥ 300):

The highest priority in risk management. These factors are critical for transport operations and require immediate corrective actions. The implementation of risk mitigation measures should be carried out as a priority, and the progress in their elimination should be continuously monitored.

5. Discussion

The results of the FMEA-based analysis indicate that the most significant risk factors affecting urban freight transport in the analyzed system are primarily related to infrastructural limitations, technological integration, and regulatory conditions. In particular, risks associated with outdated infrastructure, lack of system integration, technological failures, and regulatory changes were identified as having the greatest impact on operational efficiency. These findings are consistent with the literature on urban freight transport, which emphasizes the multidimensional character of risks in urban logistics systems and the strong influence of infrastructural capacity, technological coordination, and regulatory frameworks on freight operations (Behrends, Lindholm & Woxenius, 2008).

The importance assigned to risks related to outdated infrastructure corresponds with conclusions presented in earlier studies on urban freight systems. Cherrett et al. (2012) demonstrated that urban freight activities generate a significant number of delivery movements, which place considerable pressure on transport infrastructure. Similarly, Dablanc (2007) emphasized that freight transport occupies a substantial share of urban road space and that insufficient loading and unloading infrastructure contributes directly to congestion and delivery inefficiencies. In this context, the identification of outdated infrastructure as a priority risk factor confirms observations widely reported in the literature.

Risks associated with insufficient system integration also play an important role in the analyzed system. The results indicate that incompatibility between logistics management systems and limited data exchange may lead to route planning errors, delays in order fulfillment, and reduced operational efficiency. Similar conclusions were presented by Vieira et al. (2015), who showed that the logistics performance of freight operators depends strongly on coordination between information systems and operational conditions within urban environments. Furthermore, Bosona (2020) identified technological integration and digital coordination as key challenges for sustainable urban last-mile logistics.

Temporal and spatial constraints, particularly those related to road congestion and the limited availability of loading and unloading zones, were also identified as significant sources of risk. Previous research consistently indicates that congestion represents one of the main operational barriers in urban logistics. Comi (2022) showed that insufficient availability of delivery bays often forces freight vehicles to park in unauthorized locations, which contributes to additional congestion and operational inefficiencies. Similarly, Vieira et al. (2015) reported that congestion, access restrictions, and inadequate loading infrastructure significantly increase delivery times and operational costs.

Regulatory risks constitute another important dimension of the analyzed system. Increasing environmental requirements and the implementation of transport policies aimed at reducing emissions have significantly changed the operating conditions of freight carriers. Muñuzuri et al. (2012) indicated that urban logistics policies may fail to achieve their intended objectives if they are not aligned with the operational realities of freight operators. Likewise, Kin et al. (2017) emphasized that the effectiveness of urban freight policies depends on stakeholder cooperation and the integration of freight considerations into urban planning processes.

Environmental regulations and decarbonization policies have also become increasingly important sources of operational risk. The introduction of low-emission zones and stricter emission standards often requires significant investments in fleet modernization. Savadogo, Gardrat, and Koning (2023) demonstrated that although environmental regulations can improve air quality, they may also generate substantial costs for freight operators. The findings of the present study are consistent with this perspective, as enterprises identified regulatory and environmental pressures as important drivers of operational uncertainty.

An important observation emerging from the analysis is that the risk structure of urban freight transport is characterized by the coexistence of several medium- and high-priority risks rather than a single dominant factor. Similar conclusions were presented by Shankar, Choudhary, and Jharkharia (2018), who emphasized that freight transportation systems are exposed to complex and interconnected risks involving technological, economic, and environmental dimensions. Consequently, effective risk management requires a comprehensive and integrated approach.

The results also demonstrate that risk patterns commonly identified in large metropolitan areas are present in medium-sized cities as well. Although many studies focus on large urban agglomerations, the case analyzed in this research indicates that similar challenges related to infrastructure, congestion, regulatory pressure, and technological integration also occur in smaller urban systems. This suggests that structured risk assessment methods, such as FMEA, can serve as a useful analytical tool for improving the resilience and sustainability of urban freight transport not only in large metropolitan areas but also in medium-sized cities.

Overall, the findings confirm that improving the efficiency and resilience of urban freight transport requires coordinated actions involving infrastructure development, technological integration, regulatory adaptation, and stakeholder cooperation. The application of systematic risk assessment methods can therefore support evidence-based decision-making and help identify priority areas for intervention in urban logistics systems.

6. Conclusion

The analysis of risk factors in urban freight transport made it possible to identify key challenges and priorities in risk management. The application of the FMEA method enabled a systematic assessment of threats based on the Risk Priority Number (RPN), which helped determine which factors require immediate action and which can be managed in the long term.

In the technological domain, the highest risk is associated with cyber threats, such as hacking attacks and data breaches, reflected in a high RPN value of 280.8. These problems result from insufficient technological safeguards and inadequate data management. The implementation of data protection policies and regular cybersecurity training are key recommendations for reducing this risk.

In the temporal domain, the main challenges include emergency situations in warehouses and long order fulfillment times, with RPN values of 252.7 and 236.8, respectively. These problems stem from equipment failures, limited warehouse space, and the lack of appropriate procedures. To mitigate these threats, it is necessary to conduct regular inspections and maintenance of equipment, expand warehouse space, and optimize warehouse processes.

In the locational domain, the most critical risk is urban road congestion, where the RPN reached 415.0. This issue requires the construction of bypass roads and dedicated freight transport lanes. A high value was also recorded for increased traffic intensity resulting from special events (RPN = 361.8). An additional threat is the insufficient number of loading and unloading zones (RPN = 352.2), indicating the need for investments in dedicated logistics infrastructure.

In the economic domain, the increase in fuel costs (RPN = 507.9) and the shortage of drivers (RPN = 408.6) represent the main challenges. Addressing these problems should involve investments in fuel-efficient vehicles, route optimization, and improvements in working conditions within the logistics sector, which may help reduce costs and increase operational efficiency.

The environmental domain also presents significant challenges, such as climate change (RPN = 423.8) and growing requirements for CO₂ emission reductions (RPN = 361.9). The development of low-emission fleets, investments in renewable energy sources, and the construction of infrastructure resilient to extreme weather conditions are key elements of the adaptation strategy for this area.

In conclusion, effective risk management in urban freight transport requires a holistic approach that combines technological innovation, process optimization, and cooperation at both local and global levels. Integrated risk monitoring systems, the development of dedicated infrastructure, and technological support are essential not only for reducing risk but also for improving operational efficiency and contributing to the development of a sustainable logistics system. The implementation of environmental initiatives and cooperation between the public and private sectors constitute further steps toward a more efficient and sustainable urban transport system.

References

- Barhoumi, T., Frikha, M. A., & Boujelbène, Y. (2026). Data-driven optimisation of urban freight transport using the Six Sigma DMAIC methodology. *Urban Science*, 10(3), 144. <https://doi.org/10.3390/urbansci10030144>
- Behrends, S., Lindholm, M. i Woxenius, J. (2008). The Impact of Urban Freight Transport: A Definition of Sustainability from an Actor's Perspective. *Transportation Planning and Technology*, 31(6), 693–713. <http://hdl.handle.net/10.1080/03081060802493247>
- Bjørgen, A., & Ryghaug, M. (2022). Integration of urban freight transport in city planning: Lesson learned. *Transportation Research Part D: Transport and Environment*, 107, 103310. <https://doi.org/10.1016/j.trd.2022.103310>
- Bondyra, K., Zagierski, B., (2019). Przemysł 4.0. Na jakim etapie przemysłowej rewolucji znajduje się województwo wielkopolskie? *Wielkopolskie Regionalne Obserwatorium Terytorialne*,

- Bosona, T. (2020). Urban Freight Last Mile Logistics—Challenges and Opportunities to Improve Sustainability: A Literature Review. *Sustainability*, 12(21), 8769. <https://doi.org/10.3390/su12218769>
- Bukhari, J., Somanagoudar, A. G., Hou, L., Herrera, O., & Mérida, W. (2023). Zero-emission delivery for logistics and transportation. In R. Brinkmann (Ed.), *The Palgrave handbook of global sustainability* (Chapter 107). Palgrave Macmillan. https://doi.org/10.1007/978-3-031-01949-4_107
- Campisi, T., Russo, A., Bouhouras, E., Tesoriere, G., & Basbas, S. (2023). The increase in e-commerce purchases and the impact on the newest European city logistics development. *The Open Transportation Journal*, 17, e26671212279047. <https://doi.org/10.2174/0126671212279047231128105715>
- Comi, A. (2022). A methodology for assessing the urban supply of on-street delivery bays. *Results in Engineering / Elsevier platform*. <https://doi.org/10.1016/j.geits.2022.100024>
- Corchado, J. M., Mehmood, R., Li, R. Y. M., Mossberger, M., & Desouza, K. (2021). Responsible urban innovation with local government artificial intelligence (AI): A conceptual framework and research agenda. *Journal of Open Innovation: Technology, Market, and Complexity*, 7(1), 71, 1–16.
- Chen, G., Han, J., Yuan, H., (2022). Urban digital economy development, enterprise innovation, and ESG performance in China, *Environmental Economics and Management Vol. 10*, 1-15.
- Cherrett, T., Allen, J., McLeod, F., Maynard, S., Hickford, A. i Browne, M. (2012). Understanding urban freight activity – key issues for freight planning. *Journal of Transport Geography*, 24, 22–32. <https://doi.org/10.1016/j.jtrangeo.2012.05.008>
- Gatta, V., Marcucci, E., & Le Pira, M. (2023). E-commerce and urban logistics: Trends, challenges, and opportunities. In *Handbook on city logistics and urban freight* (Chapter 21). Edward Elgar Publishing. <https://doi.org/10.4337/9781800370173.00033>
- Hu, K.-C., & Salim, V. (2023). Combining Kano’s model, IPA, and FMEA to evaluate service quality risk for bus service: Case of Bangkok bus service. *Applied Sciences*, 13(10), 5960. <https://doi.org/10.3390/app13105960>
- Kaimuri, B., Kosimbei G., (2017). Determinants of Sustainable Development in Kenya, *Journal of Economics and Sustainable Development, Vol.8, No.24*, 17-36.
- Kin, B., Verlinde, S., Mommens, K. i Macharis, C. (2017). A stakeholder-based methodology to enhance the success of urban freight transport measures in a multi-level governance context. *Research in Transportation Economics*, 65, 10–23. DOI: 10.1016/j.retrec.2017.08.003. <https://doi.org/10.1016/j.retrec.2017.08.003>
- Kulińska, E., Masłowski, D., (2020). Zarządzanie bezpieczeństwem miejskiej komunikacji zbiorowej, *DIFIN*
- Kütahya, C. K., & Kanmaz, U. (2025). Prioritizing risk mitigation strategies in air cargo freight operations: A fuzzy TOPSIS approach. *Journal of Aviation*, 9(1), 181–195. <https://doi.org/10.30518/jav.1599331>
- Li, Z., Chen, H., Mo, B., (2023). Can digital finance promote urban innovation? Evidence from China, *Borsa Istanbul Review, Vol. 23 I. 2*, 285-296.
- Lindholm, M. (2010). A sustainable perspective on urban freight transport: Factors affecting local authorities in the planning procedures. *Procedia Social and Behavioral Sciences*, 2, 6205–6216, <https://doi.org/10.1016/j.sbspro.2010.04.031>
- Liou, J. J. H., Liu, P. C. Y., Luo, S. S., et al. (2022). A hybrid model integrating FMEA and HFACS to assess the risk of inter-city bus accidents. *Complex & Intelligent Systems*, 8, 2451–2470. <https://doi.org/10.1007/s40747-022-00657-1>
- Ma, Y., Ampong, D. K., & Mészáros, F. (2025). Access restrictions in urban logistics: A systematic review of policy effectiveness and sustainability. *Future Business Journal*, 11, Article 259. <https://doi.org/10.1186/s43093-025-00675-8>
- Manglano-Redondo, P., Paricio-Garcia, A., & Lopez-Carmona, M. A. (2025). Dynamic low-emission zones for urban mobility: A systematic review. *Applied Sciences*, 15(6), 2915. <https://doi.org/10.3390/app15062915>
- Masłowski, D., Dendera-Gruszka, M., Kulińska, E., Rut, J., (2020). Decision Model for Planning the Transport of Goods in The International Aspect, *Education Excellence and Innovation Management*, 9279-9291.
- Muñuzuri, J., Guadix, J., Cortés, P. i Onieva, L. (2012). City logistics in Spain: Why it might never work. *Cities*, 29, 133–141. <https://doi.org/10.1016/j.cities.2011.03.004>
- Maxner, T., Rula, K., Rosenblatt, B., Paulsen, J., Esmaili, A., & Goodchild, A. (2025). Advancing zero- and low-emission zones: Local levers to decarbonize urban freight using existing authority. *Urban Freight Lab*, University of Washington.
- Morgado, D., Pereira, L. F., Dias, Á. L., & Crespo de Carvalho, J. (2026). Adaptive resilience in freight: Problem-solving strategies for the unexpected. *Transportation Research Interdisciplinary Perspectives*, 36, 101746. <https://doi.org/10.1016/j.trip.2025.101746>
- Nilssen, M., Hanssen, G., S., (2022). Institutional innovation for more involving urban transformations: Comparing Danish and Dutch experiences, *Cities 131 103845*, 2-10.
- Patnala, P. K., Regehr, J. D., Mehran, B., & Regoui, C. (2024). Resilience for freight transportation systems to disruptive events: A review of concepts and metrics. *Canadian Journal of Civil Engineering*, 51(3), 237–263. <https://doi.org/10.1139/cjce-2023-0187>

- Patterson, J., J., Huitema, D., (2019). Institutional innovation in urban governance: The case of climate change adaptation, *Journal of Environmental Planning and Management, Volume 62*, 374-398
- Peng, Q., Wang, W., Yang, X., Wang, Y., & Chen, J. (2023). Research on affective interaction in mini public transport based on IPA-FMEA. *Sustainability*, 15(9), 7033. <https://doi.org/10.3390/su15097033>
- Phimphanthavong H., (2014). The Determinants of Sustainable Development in Laos. *International Journal of Academic Research in Management, Vol. 3, No. 1*, 51-75.
- Ramírez-Villamil, A., Montoya-Torres, J. R., & Jaegler, A. (2025). Trends and advances in urban logistics research: A systematic literature review. *Journal of Advanced Transportation*, 2025, 8859606. <https://doi.org/10.1155/atr/8859606>
- Ridaoui, H., Moufad, I., Jawab, F., & Arif, J. (2024). Artificial intelligence: A key to smart and sustainable urban freight transport. In 2024 IEEE 15th International Colloquium on Logistics and Supply Chain Management (LOGISTIQUA) (pp. 1–7). IEEE. <https://doi.org/10.1109/LOGISTIQUA61063.2024.10571498> Yigitcanlar,
- Rześny-Cieplińska, J., Tomaszewski, T., Piecyk-Ouellet, M., & Kiba-Janiak, M. (2023). Emerging trends for urban freight transport—The potential for sustainable micromobility. *PLOS ONE*, 18(9), e0289915. <https://doi.org/10.1371/journal.pone.0289915>
- Savadogo, I., Gardrat, M. i Koning, M. (2023). Environmental and economic evaluation of a low emission zone for urban freight transport. *Research in Transportation Economics*, 101369. <https://doi.org/10.1016/j.retrec.2023.101369>
- Shankar, R., Choudhary, D. i Jharkharia, S. (2018). An integrated risk assessment model: A case of sustainable freight transportation systems. *Transportation Research Part D: Transport and Environment*, 63, 362–376. <https://doi.org/10.1016/j.trd.2018.07.003>
- Tabatabaei, S. M. (2024). Sustainable supply chain design: Integrating risk management, resilient multimodal transportation, and production strategic. SSRN. <https://doi.org/10.2139/ssrn.5003804>
- Orłowska, M. (2024). E-commerce customer service a challenge for city logistics. *Scientific Papers of Silesian University of Technology. Organization and Management Series*, 207, 419–434. <https://doi.org/10.29119/1641-3466.2024.207.23>
- Vieira, J.G.V. i Fransoo, J.C. (2015). How logistics performance of freight operators is affected by urban freight distribution issues. *Transport Policy*, 44, 37–47. <https://doi.org/10.1016/j.tranpol.2015.06.007>
- Williamsson, J., & Moen, O. (2022). Barriers to business model innovation in the Swedish urban freight transport sector. *Research in Transportation Business & Management*, 45(Part A), 100799. <https://doi.org/10.1016/j.rtbm.2022.100799>