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TRANSPORT RISKS IN THE SUPPLY CHAINS – POST COVID-19 CHALLENGES

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Abstract. The COVID-19 pandemic has caused major disruptions in global supply chains with unforeseen and unpredictable consequences. However, the pandemic was not the only reason why supply chain risk management has become more crucial than ever before. In the last decade, the occurrence of previously merely theoretical risks has emphasised the importance of risk management in supply chains. This has increased interest in risk assessment and management, COVID-19 and other disaster impact studies and proposals for more stable and resilient supply chains. This article addresses the problem of transport risk in supply chains in the context of COVID-19. Particular attention is paid to quantitative approaches. Identifying and quantifying risks and modelling their interdependencies contribute to the stability of the supply chains. The analysis presents the current state of knowledge and can serve as a guide for further research. It highlights transport risk management in supply chain management as an important area of investigation. In light of the challenges of the COVID-19 pandemic, the article proposes an approach to transportation risk assessment based on quantitative assessment and interconnection of risk factors.

Keywords: supply chain, logistics, risk, management, COVID-19, transport, assessment, Data Envelopment Analysis.

JEL Classification: R41, C44, D81.

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1. Introduction

Transport is a fundamental process in every supply chain, ensuring that products reach their destinations. Practitioners and researchers emphasise that effective transport in the supply chain is important in improving organisational performance and ensuring competitive advantage. Proper management of transportation risks contributes to supply chain quality and reduces overall risks in global logistics. The traditional concept of risks in transport relates to the probability of an uncertain situation or event occurring that would result in damage or loss to the transported cargo. However, the transport risk also concerns the drivers, passengers, information transmitted electronically and the means of transport, affecting all supply chain organisations and the environment. Transportation risk management in the supply chain is encompassed within supply management, which, in turn, together with demand management, product management, and information management implemented in a coordinated manner, allows for mitigating the risk effects associated with the entire supply chain (Tang, 2006). Like supply chain risk management, transportation risk management includes two primary dimensions: operational and disruption risks. Disruptions do not often occur in supply chains, but their negative impacts are deeper, and the recovery is slower (Azad et al., 2013; Bugert & Lasch, 2018). The severity of transport disruptions forces the development of appropriate risk mitigation strategies, which must consider the entire structure of the supply chain and the relationships between individual risks to develop appropriate risk management strategies and effectively mitigate them.

Disruption risk typically relates to natural (earthquakes, floods, hurricanes, tsunamis, wars, and others) or unnatural (e.g., Gulf War, Ukraine War, terrorist attacks including September 11, 2001, strikes, and others) disasters (Bugert & Lasch, 2018). In 2020, the outbreak of the COVID-19 pandemic had a significant impact on the global economy and all industries, including the transport and logistics sector (Xiang et al., 2021). It has been seen as an unprecedented disaster because of its duration, time, area, scope and magnitude (Xu et al., 2020). Considering transportation, each mode of transport (sea, rail, air, and road) has played different roles during the pandemic evolution stages (introduction, emergence, localised transmission, amplification, and reduced transmission) as a dependent, mediating, and moderating variable (Loske, 2020).

Although pandemic outbreaks, such as COVID-19, have a severe and comprehensive impact on society and the economy, including the transportation sector, operational risks resulting from inherent uncertainties, such as customer uncertainty, demand, supply, and cost, cannot be ignored when preparing for disruption risks. Emergency supply chain management also covers the demand and supply sides, regulatory and administrative, infrastructure, interoperability, storage and facility risks (Shareef et al., 2022). The growing need for sustainable development, actively counteracting climate change and saving resources (Nazarko et al., 2022) does not allow for ignoring the negative consequences of logistics, such as pollution, climate change and resource depletion, when determining the risks associated with global transport (Perkumienė et al., 2020).

The general definition of supply chain risk management can be applied to transport risk management, which is collaborative and coordinated efforts of all stakeholders to identify, assess, mitigate, and monitor risks to reduce vulnerability, increase robustness and resilience, and ensure profitability and continuity (Baryannis et al., 2019). The typical management risk framework is appropriate, consisting of scope establishment, risk identification, analysis, response planning, execution, and monitoring (Alhawari et al., 2012). Effective communication (understood as the process of obtaining and sharing risk information) is particularly an important part of risk management and assessment (Mansour et al., 2023). The main influencing factors are environmental, geopolitical, economic, and technological. Typical for transport are safety risks related to the mode of transport and accidents, route and infrastructure (Batarlienė, 2018). Since transportation is very sensitive to risk, the safety and security risks are traditionally treated separately (Fan & Yang, 2022).

The article aims to provide a literature review on transport risks in the supply chains and managerial challenges in post-COVID-19 times. It highlights selected quantity methods and proposes the reference common approach to transport risk assessment in the supply chain, resulting from risk management in the entire supply chain. The article consists of an introduction, a review of the literature on supply chain risk addressing transportation risks, and a proposal for risk assessment in transport. It ends with conclusions.

2. Literature review on transportation risks

The COVID-19 crisis was a major shock to the world economy, disrupting almost all sectors and organisations. In the case of supply chains, the pandemic exposed vulnerabilities in intercontinental logistics and exposed supply shortages for continuous mass production. The discussion of challenges posed by COVID-19 in transport mostly focuses on negative impacts and their mitigation. However, it is worth mentioning some unintended positive effects linked with transportation: reduction of pollution and waste (Erkhembayar et al., 2020; Haque et al., 2021), significant decline in traffic (Li et al., 2022), positive impact on road freight transport turnover (Ho et al., 2021), rapid progress in digitisation and implementation of innovations in the transport sector (Subramanya & Kermanshachi, 2021), and robotisation (Zeng et al., 2020). As a result of COVID-19's multifaced and severe implications, risk management in the supply chain has become an intensively explored area of scientific research.

Efficient transport has always been considered a logistics factor that enables achieving supply chain goals, and transport risk management is an integrated part of supply chain management. Many researchers focused on quantitative assessment, empirical studies and simulation analyses, and disruptions in supply chains. Analyses of papers on supply chain disruption risk models from 2001 to 2018 (Bugert & Lasch, 2018) identified the following modelling techniques: Petri net, system dynamics, discrete-event simulation, Bayesian belief network, agent-based modelling, interpretive structural modelling, Monte Carlo simulation, input-output modelling, and other approaches. According to a systematic review of maritime resilience based on articles from 2010 to 2022 (Gu & Liu, 2023), the dominant research methodologies are case study, empirical study, conceptual work, mathematical modelling and optimisation method, simulation, multi-criterion decision-making, Bayesian method, complex network, and game theory. Ivanov et al. (2017) classified existing quantitative analysis applications to a supply chain, considered three basic types of disruptive risks, i.e., production, supply, and transportation disruptions, and divided them into mixed-integer programming, stochastic programming, inventory management and contracting, simulation, system science, and control theory. The comprehensive modelling approaches to supply chains collected by Hosseini et al. (2019) divided them into deterministic, stochastic, and fuzzy. Fan and Yang (2022) classified research methods applied to safety and security in transportation into qualitative methods (including a case study and conceptual work) and quantitative methods (e.g., survey, modelling, experiment, and simulation). Artificial intelligence has recently been indicated as a promising research direction for supply chain resilience (Baryannis et al., 2019; Gupta et al., 2022).

Pandemics and other crises are believed to continue to disrupt the global economy, and supply chain disruptions are expected to evolve (Dunn, 2021). Therefore, supply chain resilience is particularly interesting in the literature (Ivanov & Das, 2020). Building and enhancing resilience to future crises includes preparedness, agility, elasticity, and redundancy (Rapaccini et al., 2020). Methods to quantify supply chain resilience are concentrated in three main modelling approaches: optimisation, simulation and decision analysis (Pires Ribeiro & Barbosa-Povoa, 2018). Regarding transport, there is a strong emphasis on quantitative risk assessments, including Big Data analysis (artificial intelligence and machine learning), simulation techniques, Bayesian networks and evidential reasoning to address unforeseen and significant uncertainties in transport modelling (Kiani Mavi et al., 2022). Table 1 contains selected research efforts on assessment methods for transport risks in supply chains.

Table 1. Assessment techniques for transport risks in supply chains

Title, Authors, Year	Method
Combining road safety information in a performance index (Hermans et al., 2008)	Five common methods for assigning weights to indicators: factor analysis, analytic hierarchy process, budget allocation, data envelopment analysis and equal weighting to assess European countries.
Designing a composite indicator for road safety (Gitelman et al., 2010)	A composite road safety indicator for benchmarking countries' road safety performance with principal component analysis and common factor analysis weighting to rank and group the countries.
Identification and assessment of supply chain risk: development of AHP model for supply chain risk prioritisation (Sharma & Bhat, 2012)	Analytic hierarchy process methodology to analyse the risk factors in the automotive industry.
The impact of COVID-19 on transport volume and freight capacity dynamics: An empirical analysis in German food retail logistics (Loske, 2020)	Linear regression analysis and correlation to assess volume in retail logistics.
A comprehensive mathematical model for quality integration in a project supply chain with concentrating on material flow and transportation (Abdzadeh et al., 2023)	A mixed-integer linear programming model for considering quality integration in a problem of material flow scheduling and transportation routing in the construction supply chain.
Lead time and quality driven transport strategies for the wood supply chain (Kogler & Rauch, 2023)	Discrete event simulation and regression analyses to evaluate transport strategies in the wood supply chain.
Two-stage risk-averse stochastic programming approach for multi-item single source ordering problem: CVaR minimisation with transportation cost (Taghizadeh & Venkatachalam, 2023)	Conditional value at risk approach for multi-item replenishment problem with a piece-wise linear transportation cost under demand uncertainty to simulation study on integrating inventory.
Stochastic optimization model for ship inspection planning under uncertainty in maritime transportation (Yan et al., 2023)	Stochastic optimisation model based on the k-nearest neighbour model for ship inspection on the example of data on ship control in Hong Kong.

A risk resulting from uncertainty evolves but remains a significant global logistics problem. Understanding and managing risks is assigned to all supply chain elements, and the goal is to minimise risks related to the entire supply chain and its elements. Many risks emerged as a result of COVID-19 and had long-lasting consequences, and risk analysis has become one of the key activities in transport planning. This increased importance is also reflected in the number of research efforts on identifying, measuring, and mitigating risks. Various risk assessment methods are proposed to assess potential problems and reduce transport risks.

3. Transport risks in the supply chains

3.1. Transport risk assessment methods

According to the International Organization for Standardization (2018), the risk management process starts from context establishment and consists of risk assessment (risk identification, analysis, and evaluation), and the output of the process is risk treatment. The risks could be expressed in terms of risk sources, potential events, consequences, and likelihood. The key business risk sources have internal or external origins and emerge from human behaviour, technology advancements, market and economic factors, policies and regulations, environmental hazards and natural disasters.

The following typologies could be considered in case of supply chains (Sharma & Bhat, 2012): 1) disruption, delays, systems, forecast, intellectual property, procurements receivables, inventory and capacity; 2) standards, suppliers, technology, and practices; 3) application level, organisational level, and inter-organisational level; 4) operational risks, external risks, strategic risks and external externalities; 5) operational accidents, operational catastrophes, and strategic uncertainty; and 6) supply side, demand side, process risks, environmental, logistics risks, and catastrophic. The classification of disruption risks in supply chains by Shekarian and Mellat Parast (2021) differentiates them into internal to the firm (process and control), external to the firm but internal to the supply chain network (demand and supply risk) and external to the network (environmental risk). Ulutaş et al. (2021) distinguished collaboration-based logistics risks (transportation-related risks, purchasing-related risks, inventory-related risks, information-related risks, packaging-related risks and operational-related risks) and non-collaboration-based risks (geographical location-related risks, natural disaster-related risks, and organisation-related risks). Batarlienė (2018) grouped the risks in carrying dangerous cargo into traditional, residential impact, accident, probable, and relative. During the risk prediction process, the following categories of risks are useful: supplier, demand, capacity, and process/product (Baryannis et al., 2019). In the case of specific risks related to road accidents while transporting dangerous freight, the environmental risks can be classified into direct and indirect (Batarlienė, 2018). Fan and Yang (2022) divided the hazards in container terminal operations into personal and technical.

Transport risk is associated with every type of transport (road, rail, air, maritime, and multimodal) and the digital network. The common aspects include physical risk and regulatory, market, environmental, and technological risks. Special attention should be paid to disruptions since they have significant consequences and impact all supply chain organisations' ability to deliver products or services effectively. Disruption risks specific to transportation are weather-related, natural disasters, infrastructure failures, accidents, health emergencies (pandemics), and terrorist and security threats, including cybersecurity.

The general supply chain risk assessment methodology consists of risk identification, classification and assessment phases (Sharma & Bhat, 2012). Implementing the approach could be extended to defining scope, identifying stakeholders, and gathering information before the risk identification phase and activities, such as risk mitigation, control monitoring, and review reporting after the assessment phase. The active data-driven risk prediction process could include risk management planning, establishing risk protection goals and prediction priorities, and decision-making (Baryannis et al., 2019). The specific classification and methodology used for transport risk assessment may vary depending on the organisation's industry, size, and unique risks. In each case, risk assessment should be an ongoing process that agilely adapts to changing circumstances and emerging risks in the transportation sector. As in any analysis the three fundamental stages are determining risk factors, describing relations between factors, identifying crucial factors (Nazarko et al., 2022).

Table 2 is an example of a broad approach to risk identification, summarising the transport risk factors. The listed 18 key transport risk factors could influence different load types in various regions and countries and affect local and international supply chains. Considering their importance, a great deal of attention should be paid to external factors, such as weather conditions, accidents, piracy, geopolitical and geoeconomic situations, natural disasters, sabotage, terrorist acts, crimes, and wars, as they could profoundly disrupt transport networks for a long time. Such factors make transport of loads particularly risky between countries and continents and when planning a new transportation route. However, when preparing preventive actions, internal factors cannot be neglected.

Table 2. Risk factors classification

Nr	Transport Supply Chain Risk Factors
1	Time zones
2	Weather conditions
3	Accidents, piracy
4	Mismatch of warehouse service types
5	Geopolitics and geo-economics situation
6	Social differences (culture, traditions, and customs)
7	Market and demand fluctuations
8	IT systems, failures, abruptness of technological changes, and lack of IT systems
9	Natural disasters, sabotage, terrorist acts, crimes, and wars
10	Political uncertainty, change in laws, and labour shortages
11	Cargo type or dimensions nod served, growth of cargo size or value, damage or theft
12	Defined responsibility, long time for handling complaints, and receiving compensation
13	Failure of customers and their suppliers to prepare cargo for the planned routes
14	Speed of execution of operations, accuracy, and quality of customer service
15	Planning problems, demand variability, and inconsistencies
16	Lagging of customers or partners in keeping up with new technology and market changes
17	Management of relations with customers, partners, and social favourability
18	Production, commercial, investment, financial, currency, systemic, percentage, stock market, selective, bankruptcy, liquidity, inflationary and deflationary, and speculative risks

The interdependence of global risks has been particularly exposed by COVID-19. Transportation risks cannot be analysed separately. Risks, as mentioned before, could be grouped or categorised according to different criteria. Interconnections, inevitable consequences, or mutual amplification or mitigation of certain risks must be considered in the risk analysis. Figure 1 presents the example of a graph of connections between risks.

Considering possible links between factors, the risk of delayed deliveries is a priority risk due to its probability of occurrence and the potential financial losses. Delays in deliveries are influenced by decision-making risks related to the choice of suppliers who may underperform or engage in partnerships, failure to comply with health and safety procedures, the lack of appropriate control equipment, machinery, and materials, and improper allocation of resources.

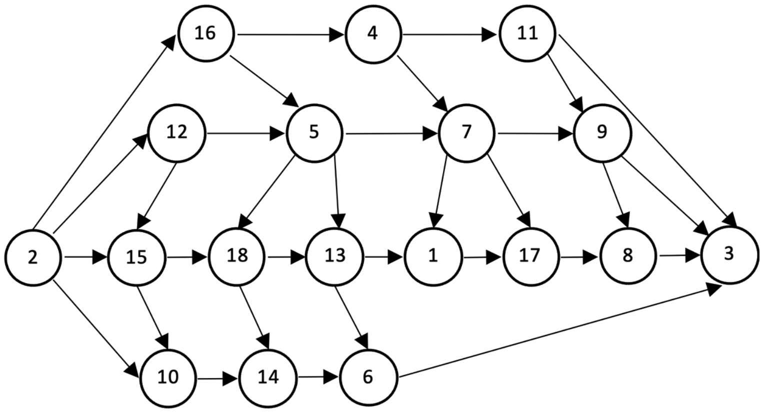

Figure 1. Risk interconnection models

The risk of failure during the logistics flows results from links with logistic service providers, as more and more supply chain enterprises entrust logistics processes to companies that specialise in this area. The risk can also be caused by fluctuations in demand, human errors, sudden changes in customer orders, inventory deficits, relying on only one supplier, reduction of the production capacity of suppliers, random events, the lack of raw materials, errors in transport orders and waybills, improper protection and packaging of goods, insufficient number of transport vehicles, unloading ramps, and insufficient warehouse volume, equipment failures, delays in payment of fees, discontinuities in technical infrastructure, the lack of production synchronisation and communication, especially when the company's logistics procedures are in another country. In addition, risks associated with changing economic factors, geopolitical, environmental, and technological issues, and external random events, such as accidents and catastrophes, can also contribute to delivery delays. To effectively address the identified risks, risk assessment techniques can be used to estimate their probability and impact.

3.2. Transport risk assessment techniques

Traditionally, risks are described in two dimensions: impact (estimating the possible effect) and probability (addressing how likely the risk event is to occur). The lesson from COVID-19 is that risks can be marked as the most severe in the short and long term World Economic Forum (2023). There are many transport risk assessment techniques: quantitative, based on relevant data of effect and occurrence, and qualitative, based on expert opinions. Integrating quantitative and qualitative data, the hybrid models allow for taking advantage of both (Chodakowska & Nazarko, 2020). Like risk identification, risk assessment should also be a continuous process. Drawing from the experience of COVID-19, it is worth analysing the impact and probabilities as the disruption process expands or breaks down.

Transport risk assessment can be performed based on simple formulas and data on the number of accidents, damage, and financial deterioration. To determine a transport safety problem, one can multiply risk, exposure (e.g., passenger kilometres, number of registered vehicles), and consequences (Al Haji, 2005). Risk probability of, e.g., road accidents can be described as a number of accidents, *A*, per number of frights, *F* (Batarlienė, 2008):

$$\frac{A}{F}. \tag{1}$$

Similarly, the amount of freight transported affected by an accident, Q, per total quantity of freight, T, can be utilised (Batarlienė, 2008):

$$\frac{Q}{T}. \tag{2}$$

Taking the ecological perspective, the risk severity associated with environmental damage can be described as (Batarlienė, 2018):

$$N_t^a = N_t^{al} K_{kat}. \tag{3}$$

where: N_t^a – the extent of damage to assess; N_t^{al} – the constant indicating the damage type; K_{kat} – the coefficient describing the category.

The approaches to assessing dangerous cargo by land and water contamination, originally proposed by Batarlienė (2018), can be successfully applied to any type of transport. In many cases, it is convenient to use models that consider overall costs:

$$C = k_1 k_2 \left(C_{at} + C_{ant}\right), \tag{4}$$

where: C – the cost of an accident; C_{at} – direct costs of an accident (e.g., cost of road infrastructure, cost of transport means); C_{ant} – indirect costs of an accident (e.g., number of affected people, financial losses); k_1 – coefficient related to general areas; k_2 – coefficient related to urban areas.

Classical time series methods can also be applied in the quantification of transportation risks. Auto regression integrated moving average (ARIMA) models were proposed by Allach et al. (2019) for the safety classification of intercity routes. ARIMA consist of a regression model of lagged time series values and moving average, which involves error term as the linear combination of the previous error terms (Chodakowska et al., 2023; Nazarko et al., 2005):

$$y_t = \sum_{i=1}^{p} \phi_i y_{t-i} + \sum_{j=1}^{q} \theta_j e_{t-j}. \tag{5}$$

In the model, y_{t-i} and e_{t-j} are the lagged past values and errors, ϕ_i and θ_j are the coefficients for the autoregressive and the moving average term, and p and q are orders (number of coefficients' parameters).

Data Envelopment Analysis (DEA) allows for multidimensional assessment. It is considered a comprehensive and useful assessment of supply chain risk (Kraude et al., 2022). DEA is commonly used in many areas, including supply chain management (Azadi et al., 2022) and transport (Akbar et al., 2020). When mentioning the applications of the DEA method, it is worth emphasising its particular usefulness for assessing objects and processes that cannot be characterised in financial terms, e.g., the public sector: foundations, education institutions, and, e.g., technology (Nazarko & Chodakowska, 2020). The DEA method relies on solving linear programming tasks for n units, uses m inputs x_j and $i \in I = \{1, \dots, m\}$, produces s outputs y_j, $r \in O = \{1, \dots, s\}$ as follows:

$$\begin{gathered} \min \theta, \\ \sum_{j=1}^{n} \lambda_j x_{ij} \le \theta x_{ij_O}, \quad i \in I, \\ \sum_{j=1}^{n} \lambda_j y_{rj} \ge y_{rj_O}, \quad r \in O, \\ \lambda_j \ge 0. \end{gathered} \tag{6}$$

The score θ ranges from 0 to 100% for the best ones. The symbol λ_j represents the weights.

A recently promising direction in risk assessment is machine learning (ML) technology that includes deep learning, support vector machines, decision trees, neural networks, Bayesian networks, logistic regression, random forest, ensemble learning, clustering, extreme learning machine, and naive Bayes (Emrouznejad et al., 2023; Yang et al., 2023). The problem in using ML algorithms is the preparation of data sets and the difficulty of interpreting the results.

The key goal in risk management is to reduce the risk and mitigate the consequences. Understanding different types of risks and their likelihood of occurrence, along with relevant data, is the starting point for companies to develop effective risk management strategies. It is generally acknowledged that the types of risks, and hence the corresponding mitigation measures, vary across supply chains and business sectors.

3.3. Effect of the COVID-19 pandemic on road safety – a comparative study

It is important to consider transport risks when conducting risk analysis in supply chains. While restrictions and lockdowns are generally believed to have a negative impact on the entire supply chain, the effect of COVID-19 on transport risk is not as straightforward.

Road safety in the EU is improved yearly, taking various actions to reduce transport risks. The COVID-19 pandemic restrictions affected road safety, measured by people killed, resulting in an unprecedented decline in 2020. However, there was an increase in 2021, but the level of 2019 was not reached (Table 3). Therefore, it is necessary to update the risk assessment systematically.

Table 3. Road fatalities in the EU

Year	2000	2001	2002	2003	2004	2005	2006	2007
People killed in road accidents	53 410	51 282	50 343	47 331	44 466	42 552	40 365	40 038
Year	2008	2009	2010	2011	2012	2013	2014	2015
People killed in road accidents	36 880	32 978	29 576	28 730	26 487	24 213	24 132	24 358
Year	2016	2017	2018	2019	2020	2021		
People killed in road accidents	23 808	23 392	23 328	22 756	18 835	19 917		

An example of using a quantitative approach in risk assessment can be a risk evaluation performed by the DEA method in an input-oriented model (6), where the minimised input is the number of people killed in road accidents, and the outputs are the population and the number of passenger cars in 2021 and 2020. The following hypothesis by the DEA model was tested H_0: set of EU countries is homogeneous in terms of the number of people killed, when adjusted by the population and the number of vehicles, and the alternative hypothesis H_1: set of EU countries is heterogeneous. In addition, it was analysed whether there was a significant change in the efficiency of individual countries in 2021 compared to 2020.

Figure 2 shows the risk efficiency assessment in 2020 and 2021. Norway, Iceland, Malta, and Sweden were the best countries with lowest risk measured by the number of road fatalities. Most EU countries performed better during COVID-19, while Norway maintained the same result. Some countries reduced risk slightly in 2021 compared to 2020, namely, Denmark, Lithuania, Malta and Poland. However, no significant changes were observed in the assessment of individual countries in 2020 and 2021. The largest difference was observed in Slovenia – 18%, but on average the absolute difference is only 7%. The linear correlation of results measured by the Pearson coefficient is 0.96, by the Spearman coefficient is 0.95. It can be inferred that countries have been consistent in their positions over the analysed years.

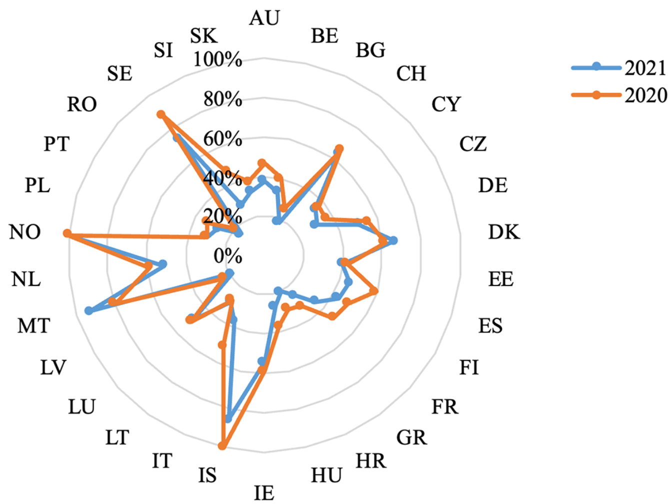

Figure 2. DEA in the assessment of transport risk of EU countries in 2020 and 2021 (based on Eurostat, n.d.)

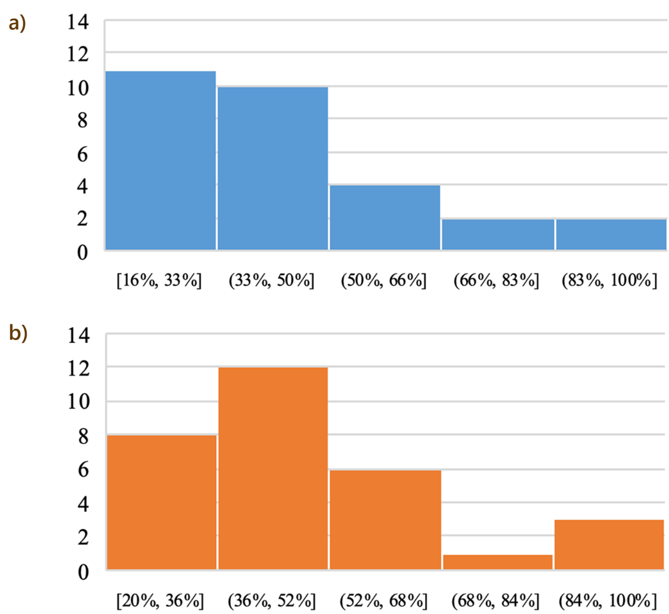

Figure 3. Histogram of EU countries' performance in: a – 2021; b – 2020

In the post-2020 period, the challenge is to maintain the positive impact on the number of accidents caused by COVID-19, despite the rise in road traffic.

The distribution of results in 2020 and 2021 is shown in Figure 3. There is considerable variation in the assessment of individual EU countries. The scores in 2020 range from 20% to 100%, and in 2021 range from 16% to 100%. Large variation is observed in both 2020 and 2021, the coefficients of variation are 42.85% and 51.01%, respectively. To sum up, the hypothesis about the homogeneity of the set of EU countries should be rejected.

The DEA models offer simultaneously analyse of numerous impact factors and their outcomes. They enable the multidimensional assessment and results to be corrected using independent, exogenous variables. Future studies might consider infrastructure, road maintenance expenses, as well as tourist and transit traffic. Additionally, it is essential to differentiate between fatalities and injuries, the types of road accidents with their short- and long-term consequences to account for them appropriately. To address interconnections between risks DEA network models can be used. A limitation of using the DEA method is the need to have a set of comparable units described by the same output and input variables. The relative results of the DEA method are only interpreted by comparing them with the results of benchmarking units.

4. Discussion

Based on the above presented analysis on risks in the supply chain and its challenges due to COVID-19, there are few main points to be broadly discussed. The results of the research show in theoretical and in empirical part the main gaps in the field of transport and supply chain risk management. Analysis has demonstrated an approach to transportation risk assessment based on quantitative assessment and interconnection of risk factor. Under the background of literature review on transportation risks, the scientists presented different risk assessment methods to solve various issues in the period of COVID-19 and diminish transport risks. In this regard, in order to effectively implement transport risks in supply chain management it is important to revise carefully transport risks assessment methods and its assessment techniques. Under the background of research on transport risk management is important to pay attention to transport safety problems and its evaluation approaches. The present empirical research infused the calculation of road accidents, risk probability on the roads and dangerous cargo prevent occured risks for more stable and resilient transport supply chain management. This research prominently proves several contributions based on effect of the COVID-19 pandemic on road safety using a quantitative approach in risk assessment can be a risk evaluation performed by the DEA method in an input-oriented model, where the minimised input is the number of people killed in road accidents, and the outputs are the population and the number of passengers. Future research possibilities and findings will invite researchers to focus on road safety principles challenges, transport risk assessment methods and techniques offers valuable insights for practitioners in transport global supply chain the COVID-19 pandemic caused by major disruptions.

5. Conclusions and directions for future research

The COVID-19 pandemic was unprecedented, posed new challenges that had not previously been considered in transport (like shortages of goods and growing interest in deglobalisation of the supply chain), and increased the likelihood of previously ignored threats and exposed their interdependence. Risk management has become an even more critical factor in organisations as it can minimise the likelihood and impact of threats and capture opportunities that may arise in the global supply chain. It is worth emphasising that when COVID seemed to be easing, further global threats emerged, such as war in Ukraine. To face the upcoming global challenges and the scope of instability, cooperation is necessary between all supply chain elements, including transport.

Transportation risk cannot be analysis in isolation from the entire supply chain risk analysis. The consequences of interconnected of risk sources that, when combined, can increase or mitigate risk are multidimensional. A quantitative risk assessment might consider various perspectives and, as demonstrated in the article, uncertainty can lead to positive effect.

At the risk recognition stage, it is worth using a broad approach. Possible risk factors should be analysed, but the links between them are equally important. Besides qualitative and expert assessments, mathematical methods should also be used. They can be both simple and complex. Recently, machine learning algorithms are considered to have excellent risk identification and assessment features. As the article proves, operations research methods are also useful. Without a doubt, transport security is a global problem. Remedial actions should increase visibility and response speed to mitigate disruptions. Identifying and quantifying critical risks, modelling their interdependencies, and involving all stakeholders in the decision-making process contribute to the stability of the supply chain. Further research should delve deeper into the relationship between various risk assessment concepts and models. The resilience of transportation supply chains to sudden large-scale disruptions may be another interesting area for future research in the context of disaster events.

The authors hope their work will give readers a better understanding of different approaches to risk assessment in transportation supply chains by laying the groundwork for further substantive discussion of this issue.

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