

Article

Risk Mapping: Ranking and Analysis of Selected, Key Risk in Supply Chains

Maria Richert *  and Marek Dudek

Akademia Górniczo-Hutnicza w Krakowie, ul. Gramatyka 10, 30-067 Kraków, Poland

* Correspondence: mrichert@agh.edu.pl

Abstract: This study aimed to analyze the impact of key causes of external and internal risk on supply chains. The basic and most probable causes of the risk are listed, based on literature research and interviews with representatives of the metal industry. The analysis was carried out by semiquantitative assessment using risk maps. The relationship between the probability of an event occurrence and its impact on supply chains was tested. The study postulates that key risk factors can be controlled through risk monitoring. Attention was drawn to the beneficial aspects of using risk maps that enable a comprehensive assessment of the situation. Both external and internal risks can cause turmoil and disruption of the supply chain. The findings suggest that external uncertainty and crises have the most direct impact on supply chain risk and are the most dangerous. The work presents the possibility of practical application of risk maps for risk assessment and monitoring. The presented approach to risk assessment complements the methodology of risk assessment and monitoring. Risk maps were used as a basic tool in assessing the impact of individual risks on supply chains. It has been found that supply chains are subject to high risk, which can be monitored through risk matrix procedures. The conducted analysis showed that critical risk areas in supply chains are external crises, environmental uncertainty, supply chain relationships, and manufacturing and the most dangerous risks in supply chains are related to external conditions beyond the control of the participants in the supply chain. The article fills a gap in research on risk monitoring in supply chains by focusing on selected, generalized measures related to industrial supply.



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1. Introduction

The concept of the supply chain (SC) appeared in the second half of the 20th century, when there was a development of cooperation between manufacturers, producers, and sellers of consumer goods. The globalization of the world economy in the 21st century has led to the expansion of the range of contacts and services practically all over the world. Just before the COVID-19 crisis, there were no restrictions on business contacts, and the sourcing of raw materials and components was by no means restricted, nor were the distribution and sale of products (Xu et al. 2020). The free movement of goods and services has resulted in economic growth (Poutvaara et al. 2019). This manifested in an increase in GDP in many countries, improved quality of life, and increases in consumption, which stimulated good economic growth. Supply chains are essential to the smooth running of the economy (Goel et al. 2020). Any breakdown in this area results in unfavorable phenomena, such as reduced technical quality of the delivered goods or delayed/missed delivery. Any restrictions lead to disruptions, which propagate along the supply chain in the form of delays and downtime in the execution of production and distribution orders. The supply of raw materials, components, parts, and other accessories is usually well developed and smooth. The production of the final product runs smoothly when the supply chains are uninterrupted. With this in mind, when can a supply chain disruption occur? If external conditions such as the political, economic, and social situation are stable, disruptions in

the supply chains may only result from the loss of financial flow or the exhaustion of chain elements due to excessive demand relative to supply. Unstable economic conditions, along with political, social, and financial turmoil, may cause the collapse of supply chains and the emergence of turbulence in the global economy. Economic ties, now spanning almost all continents, may lose their smoothness or even be broken as a result of such phenomena. Supply chains are large logistical undertakings, especially when they involve large companies spanning several countries—or even continents. For the EU, disruption to supply, intermediate goods and production inputs means that exports shrank more than imports, negatively impacting its trade balance (BRIEFING 2020).

Supply chains are an integral part of the economy (Lu and Swaminathan 2015) and are well defined and characterized in the literature. They arouse interest because they are the basic element of economic development (Sisco et al. 2010). In particular, supply chain management is one of the most essential aspects of conducting business (Lu and Swaminathan 2015; Vidrova 2020; Mastos and Gotzamani 2022). Supply chain management is currently based on logistical activities and the coordination of individual links in the supply chain. An agile supply network can meet crisis challenges such as those faced during the COVID-19 pandemic and ensure customer retention and acquisition (Meško and Petrovic 2022; Çelikkol et al. 2021; Konecka 2010; Kulińska et al. 2021; Pató et al. 2022; Zahoor et al. 2022). Thanks to agile management, companies are able to skillfully move between global, local, and regional networks, ensuring the availability of supplies. Hybrid supply networks have been created to facilitate procurement. There is now a whole philosophy in modern supply chain management (SCM) aiming to make supply chains much more integrated than they used to be (Sweeney 2022).

Crisis events such as COVID-19 and the war in Ukraine have changed the view on the design and management of supply chains (Pujawan and Bah 2021). Firms face a range of international business challenges, from currency fluctuations to building global management teams. Today, uncertainty is a hallmark of business with respect to supply chains in crisis conditions (Niranjan et al. 2022; Russell et al. 2022). Therefore, enterprises devote special attention to the risk assessment and management of undertaken projects. A number of methodologies and tools have been developed to assess the potential impact of threats and implement mitigation strategies (Kurniawan et al. 2017; Ganeshan and Sivasamy 2018; Verheijen 2022). Global supply chains represent new challenges that need to be managed in such a way as to maximize opportunities and minimize risks (Vidrova 2020). Enterprises creating global supply chains make mistakes, as noted by Vidrova, who highlighted the advantages of global supply chains. The increase in the globalization of supply chains is associated with an increase in their complexity, which increases the likelihood of risk and management problems. Extending the supply chain by replacing a local supplier with a supplier, for example, from China may mean increase the volume of goods in the chain, but extend delivery times, the need to reassess stock levels, etc. The concept of a global supply chain network collapsed after the Russian attack on Ukraine. A small diversification of supplies is insufficient to avoid the threat of uncertainty or interruption of supplies (Ngoc et al. 2022). Working with one supplier may disrupt the supply chain in crisis conditions. Supply chains were disrupted as a result of the war in Ukraine. This is an example of the risk of non-diversification of supplies.

An example of change in the flexibility of supply chains is the automotive industry (Deloitte 2017; Ovens 2022). The delivery time of components imported from different parts of the world has been significantly delayed in the wake of the COVID-19 pandemic, and in some cases, there have been shortages of them. The most visible consequence of this disruption for car dealership customers was the increase in vehicle delivery times. In this case, external factors disrupted the supply chains. The broad impact of the semiconductor chip shortage during the pandemic exemplifies the pressure to shift supply chains (Shih 2022). Another example is the aviation industry (Karp 2022; Zakir et al. 2022). The construction of an Airbus aircraft in Toulouse requires the supply of approximately 1.5 million parts. This requires the existence of two logistics centers coordinating the deliveries. A

further example is IKEA (Shrum 2018; Jonsson et al. 2013). The task of supply chains is not only to supply raw materials products and to deliver the product to the customer but also to achieve the best economic effect, obtain the lowest cost of supplies while maintaining good-quality products, and provide the customer with the lowest price (Attinasi et al. 2021; Delautre 2019).

Frankowska notes that a company may be a participant in many different supply chains (Frankowska 2014). These can be internal supply chains or specially managed global supply chains. A balanced approach to the supply chain is of great importance (Kołosowski and Józwiak 2012). Modern supply chains are based on continuous modeling and implementation of optimized activities to improve delivery and distribution. Disruptions in supply chains are seen as the greatest threat to companies' operations (Konecka 2015). The analysis of the supply chain carried out in the work of Gajewska and Filina-Dawidowicz (2015) indicates the important role of warehousing, the implementation of comprehensive customer service, meeting consumer expectations, and creating a competitive advantage. Rising inflation may weaken supply chains (Albagli et al. 2022). Each company creates its own individual supply chain, consisting of several basic links, including obtaining raw materials or semifinished products or parts (depending on the industry and area in which the company or service is based), transport, warehousing, and the delivery of the product to consumers. In general, the supply chain is based on three main components:

1. Procurement—this refers to the method, place, and time of obtaining and delivering raw materials for the production of products.
2. Production—the transformation of raw materials into finished products.
3. Distribution—all activities enabling the delivery of products to their final destination, which is possible through a network of distributors, warehouses, and stationary or online stores (in the case of e-commerce activities).

Metal industry supply chains, despite the fact that they all consist of the aforementioned three basic components, may in fact differ in terms of the places from which they obtain raw materials and components, their methods of delivery, the distribution of the final product, and other components. In a period of globalization of the economy and often narrow specialization, in many cases, the sources of raw materials and components in numerous supply chains are the same. An example is electronic components produced in factories in Taiwan (Van der Steen and Soong 2022; The Project 2049 Institute 2022). It is obvious that there are specific places where raw materials exist on Earth, and there are good and proven companies that provide components and semifinished products that everyone wants to use (Inverto 2022). Price plays an important role, which, for example, meant that companies around the world used Chinese products, which were the most advantageous in terms of price (Lapinskaitė and Kuckailytė 2014; Seppälä et al. 2014). As a result of the long-term duplication of supply chains, in many cases—such as the automotive industry—there has been a strong dependence on specific sources of raw materials and components (Boranova et al. 2022). The effects of this phenomenon in situations of uncertainty and economic collapse in countries around the world can cause the breakdown of supply chains. At such times, there is the need to search for other suppliers or there are delays in delivering components, thereby changing the delivery conditions of the final product.

The individualization of supply chains is also related to the trust, reliability, and responsibility of suppliers and producers. This is the basis for consolidating the established path of activities in the supply chain. Any factors causing unexpected changes in this path lead to disturbances with far-reaching consequences. Currently, it is possible to select optimal supply chains thanks to numerous applications and the knowledge of experts who, based on existing logistical and organizational capabilities, are able to design the course of the supply chain.

Spectacular examples of supply chain modeling include e-commerce, which significantly increased and expanded the range of its offers during the COVID-19 pandemic. Depending on the e-commerce company, there is an immediate availability of goods and a quick way of delivering them to the customer. Therefore, for e-commerce, it is

important to have reliable suppliers to eliminate the risk of costly shortages in the product range (<https://www.experto24.pl/transport/logistyka/e-commerce-3-typowe-modele-lancuch-s-dostaw.html?cid=K000KN> (accessed on 14 November 2022)). Another delivery model for e-commerce is known as drop-shipping—the direct delivery model. This consists of a delivery to the target customer directly from the manufacturer/supplier, bypassing the seller's warehouse. Supply chains are now evolving towards logistic systems that are more dynamic, flexible, customizable, precise, and efficient (Tien et al. 2016). The essence of logistics is the flow of materials goods and services from their place of origin to the final customer (consumers) (Szymonik 2016).

The supply chains can operate within either a fully vertically integrated system or one where each channel member operates completely independently (Cooper and Ellram 1993). In a fully vertically integrated system, all of the functions are performed within one company. When functions are performed by independent entities with few or no ties to one another, the relationships are tenuous; the players can change from one transaction to the next. Demand is one of the most important factors in creating a supply chain (Chandra and Samerr 2000). Strategic alliances and partnerships are therefore critical to supply chains' success. Decreasing the number of vendors is beneficial in increasing flexibility and efficiency. It is important to establish strategic partnerships with suppliers for a successful supply chain. Corporations have started to limit the number of suppliers they do business with by implementing vendor review programs. These programs strive to find suppliers with operational excellence so that the customer can determine which supplier provides a better service.

According to Liu and Takala (2012), the critical factor index (CFI) is a measurement tool that can be used to determine the importance of an attribute for business performance based on the evaluation of employees, customers, and business partners. The level of importance can be grouped into three categories: most critical, soon to be critical, or noncritical. The following critical attributes have been presented as critical parameters for the calculation of future CFI: competence of organizational members; monitoring, control, and evaluation; communication; and leadership power. Meanwhile, soon-to-be-critical attributes include innovations and organizational structure (Sillanpaa et al. 2013). All factors influencing the effectiveness of supply chains have a specific level of risk, which is predictable when analyzed and monitored. These include such areas as environmental uncertainty, information technology, supply chain relationships, manufacturing, supply chain management performance, business management, and customer satisfaction (Ibrahim et al. 2015). Environmental uncertainty is an important factor in the realization of strategic supply plans.

The flexibility of supply chains is of great importance in the food industry (Gružasuskas and Burinskien 2022). Reducing the length of the supply chain would decrease food wastage; however, key issues related to system resilience and collaboration must be considered before redesigning the supply chain. One of the key strategies used in such cases is cooperation, which ensures an appropriate level of information exchange between the members of the supply chain. This study proposes a supply chain management framework, showing how information sharing can be achieved through collaboration. However, the increased information also increases the complexity of the supply chain, which can be managed by introducing innovative technologies.

The metallurgical industry is energy intensive and requires input materials for the production of metals (metal ores). The manufactured metals are used to produce various types of semifinished products and products that are used in everyday life, e.g., cars, tools, household appliances, etc. The specificity of this industry is the presence of metal ores in specific places on earth. The processing of metal ores consumes energy and water and requires special machinery. Metal industry chains are characterized by high management costs and high levels of risk (Kulińska et al. 2021). The risk for supply chains in the metallurgical and metal industries is high and requires attention, recognition and monitoring, in particular in crisis conditions, when supplies include raw materials obtained in dangerous

regions of the earth. Supply chains; therefore, the chains of this industry are crucial in the metallurgical and metal industries are complex and require considerable attention. The metallurgical sector is a very wide and demanding one. Nowadays, the biggest producer of iron and steel is China (Fregoso 2019). The other largest producers of metals are Russia, Australia, New Zealand, South Korea, the US, and Eurasia. Because energy is a main input to the basic metal industry, the energy intensity of the industry, or energy consumed per unit of output, is relatively high compared with other industries (Sendich 2019). Energy is a critical input for production industries. Strategic purchasing, such as energy purchasing, has a direct and considerable impact on supply chain performance (Mulhall and Bryson 2014). Nowadays, the market must generate flexible supply chains with the ability to change suppliers.

This paper analyzes the key causes of risk with a destructive effect on supply chains. External conditions were taken into account, as well as possible events within the supply chain affecting their course. Risk maps were used to determine the eventual effects of the emerging threats.

2. Theoretical Framework

“Risk is defined as the variation in the outcomes that could occur over a specified period. If only one outcome is possible, the variation and hence the risk is zero. If many outcomes are possible the risk is not null” (Outreville 1998). Next definition in the same publication: “Risk is defined as uncertainty concerning the occurrence of a loss.” Risk is incorporated into so many different disciplines from insurance to engineering to portfolio theory that it should come as no surprise that it is defined in different ways by each one (Chapter 1, *What Is Risk?* 1999). The review paper of Grima et al. on the concept of risk presents a historical view on its definition (Grima et al. 2021). Authors concluded “the evolution of research as the pandemic grows plays an important role in the definition and evolution of the word ‘risk’.” The 15th edition of the World Economic Forum’s Global Risks Report introduces the qualitative and quantitative study of global risks, conducted in partnership with members of the business, academic and public sector communities and others (Brende 2020). This study presents the probability of occurrence of a particular risk and its impact on the situation in the analyzed area. A global study of risk perception allowed for the formulation of its definition: a “global risk” is an uncertain event or condition that, if it occurs, can cause significant negative impact for several countries or industries within the next 10 years. Global risk affects supply chains, which are now also global (Kozłowski et al. 2022). Saliba (2022) lists six key global sources of risk in supply chains: labor shortages, ocean freight bottlenecks, increasing inflation, global port congestion, warehouse shortages, lack of sustainability, and resurgence of COVID-19. Global factors affect every business and source of supply.

The recent pandemic has affected every part of the value chain, from raw material sourcing to end customer. It is testing the commercial, operational, financial and organizational resilience of the majority of companies across the globe. COVID-19 has highlighted risks and resiliency gaps for many organizations. Companies are looking to build resilience in their supply chains (KPMG 2022). Serious sources of disturbance in the SC include logistics disruption, production delays, overreliance on a limited number of partners, reduction in technology investment, increase in the price of goods, workforce, and labor. The global world economy was already slowing down before the outbreak of the pandemic, it deepened during the pandemic and later after the outbreak of the war in Ukraine. After reaching an estimated 5.5 percent in 2021, global growth was expected to slow to 4.1 percent in 2022 and 3.2 percent in 2023 (Guénette et al. 2022). Supply chains are an integral part of the economy. Changes in supply chains caused by the COVID-19 pandemic and the war in Ukraine reflect the effects of the weakening economy. It is necessary to analyze new phenomena related to supply chains and risk factors affecting their resilience.

There are several considerations to assist companies as they face these challenges. Operations should be flexible and resilient enough to adapt in real time to changes in

trade flows, new regulations, the impact of COVID-19, climate change, trade tensions and other geopolitical movements (Durant 2022). Technology should be effectively utilized to help reduce operating costs, provide visibility, and diversify the way customer needs are met (Relich et al. 2022). Capability to adapt to digital operations and drive actionable improvements from data is important (Yu et al. 2022). Fleet management and supply chain networks should be responsive to increasing customer requirements (Alexander et al. 2022). Collaboration and supplier partnerships, and ongoing risk monitoring are all needed to “de-risk” the supply chain (Nagy and Kozma 2018).

Searching for alternative suppliers is a good solution when supply chains become unstable. Companies are looking for other options on how to restore manufacturing operations closer to their countries (Gembah 2022). It is crucial for companies to create a long-term supply chain strategy to bring the product to market while minimizing potentially catastrophic risks. The pandemic has completely changed the way contacts and interactions with other people operate. It limited contacts and meetings to video conferences. Companies began to develop an e-commerce sales strategy, which in this situation became a new commercial opportunity. Increased digital platforms have opened up the possibility of expanding supply chains around the world. Suppliers using digital interfaces are now able to do business directly with retailers or customers (Liddell et al. 2022). Market leaders should work with third parties as well as research partners to gain access to technical skills and gain experience needed to build new digital solutions, iterate platforms, increase data collection capabilities as streams become more and more complex, organize and plan the flow of goods, evaluate the efficiency and risk of deliveries, and maintain good relations with customers and contractors. Automation and digitization of the supply chain not only reduce costs but also increase efficiency, as well as generating huge amounts of digital information. All these activities will make supply chains more resilient to turbulence and disruption. Resilient supply chains create a sustainable vision for the company. They are as resilient as their weakest link. They affect people and the planet. Giovanni et al. (2022) indicated that growth in consumer spending merely brought economies back to prepandemic levels. This caused a rebound in economic activity, which however, coincided with problems with supply chains. Their slowdown resulted in a mismatch between demand and supply and led to higher-than-expected inflation. This illustrates the huge impact of supply chain resilience on the economics of an economy (Alshahrani and Asif 2022). The weakest places in supply chains correspond to critical risks. They are still vague and often poorly recognized. The division of risk into external and internal introduces the possibility of distinguishing key risks in these two areas related to SC (Figure 1).

Rosenhead et al. were the first to classify a decision process according to the available information into three categories: certainty, risk and uncertainty (Rosenhead et al. 1972). Under certainty, all parameters are deterministic and known. The relations between information (input) and the decision (output) are unambiguous. Situations that are not certain involve some kind of fortuity. Reasons for the need to make decisions under these circumstances vary from lacking time and resources to collect, process and evaluate information to the inherent complexity of systems that forestalls predicting the consequences of a decision (Comes et al. 2011; Lempert and Groves 2010). Under conditions of uncertainty and risk, it is necessary to identify them as closely as possible (Grzybowska and Stachowiak 2022). Each decision made by the managing persons is subject to high risk, which is greater the less recognizable are variables affecting supply chains (Heckmann et al. 2014). Under conditions of uncertainty and risk, it is necessary to identify them as closely as possible (Foli et al. 2022). This is when various types of risk identification and assessment tools are useful. In particular, the categorization of risks makes it possible to assess them and influence the decisions made.

The cooperation of supply chain participants is usually complicated and is based on internal and external cooperation (Zhong et al. 2022). This involves external and internal risks that may affect deliveries and logistics.

Various sources of risk related to external and internal conditions pose a challenge to managing supply chains that are individual and specific to each company. Therefore, against the background of global supply conditions, individual phenomena and causes threatening the smooth supply of the company are important. Identification of risk causes is one of the most important activities enabling its assessment, probability of occurrence and impact on the supply chain. Azizsafaei et al. presents a review of the literature identifying the main risk factors that have been evaluated in recent years in food supply chains (Azizsafaei et al. 2022). The authors introduced several degrees of risk and numbered them. The number they assigned to a given risk immediately identified the degree of risk.

Risk assessment consists of three steps: risk identification, risk analysis and risk evaluation (Le Guenan et al. 2022). Qualitative or semiquantitative methods are used in risk assessment, e.g., risk maps. Qualitative risk analysis means that the likelihood and severity of risk are assessed using an ordinal scale such as 1 to 5, where 1 is least likely and 5 is most probably. A similar scale can be used to assess the severity of the risk. Risk is the possibility of losing something valuable. Therefore, quantifying the risk is to show the probability distribution of that loss. The main difficulty of quantitative methods is to be able to “find the numbers” (Hubbard 2009). Numbers must come from experts, particularly when there are few data. The second important aspect is the need for modeling and probability analysis. The risk assessment should include analysis risk factors, potential causes, actions needed, etc. The framework for risk management must identify and characterize the risks associated with the analyzed area of interest. It should include an assessment of the potential impacts for each hazard identified. It is necessary to create a risk ranking. Risks should be prioritized and characterized for each identified case. They must be entered as categories ordering information about the risk. The definition of risk as significant or insignificant should be introduced. Risk management measures should be defined, such as identification and evaluation of risk management measures, including monitoring activities, preventive and corrective measures that may be implemented, or planning contingency measures to reduce risks or related uncertainties, and should assess the resulting risk reduction.

The global economy was already slowing before the outbreak of hostilities in Ukraine. After reaching an estimated 5.5 percent in 2021, global growth was expected to slow to 4.1 percent in 2022 and 3.2 percent in 2023 (Guénette et al. 2022). Supply chains are an integral part of the economy. Changes in supply chains caused by the COVID-19 pandemic and the war in Ukraine reflect the effects of the weakening economy. It is necessary to analyze new phenomena related to supply chains and risk factors affecting their resilience.

Today's supply chains are more complex as ever. It is imperative to build a framework to manage supply chain risks, both known and unknown. Risk assessment is never once and done. It is a repetitive process that involves different types of changing data. Organizations that seek to reduce supply chain disruptions must find ways to reduce their risk, using actionable, predictive intelligence as their foundation. A typical approach for risk identification is to map out and assess the value chains of all major products. Each node of the supply chain—suppliers, plants, warehouses, and transport routes—is then assessed in detail. Risks are entered in a risk register and tracked rigorously on an ongoing basis. In this step, parts of the supply chain where no data exist and further investigation is required should also be recorded (Bailey et al. 2019). Strong plans need to survive contact with the real world. That requires manufacturing and warehouse operations that work efficiently, reliably and quickly. The best companies achieve those goals through a combination of new technologies and old-fashioned discipline. They use lean methods and other performance improvement techniques to streamline activities, cut error rates and boost reliability. They invest in robotics and automation, especially in warehouse processes, to accelerate the handling of complex orders. They use smart IT tools to track performance against targets in real time (Kuntze et al. 2018). Very important in risk assessment are risk maps in various graphical forms containing risk levels, their impact and the scope of necessary intervention and risk prevention (Solistica 2022; Le Guenan et al. 2022; Hubbard 2009).

Globalization and trade openness have amplified the vulnerability in supply chain management and increased the risks. The monetary value of supply chain expenses is the highest in manufacturing organizations (Dey et al. 2011; Gurtu and Jestin 2021). Managing risks allows the decision-maker to understand and assess the impact of risk in a supply chain network. The estimation of risk can lead to better risk management, reduce the extent of damage, and improve supply chain resilience. Risk detection plays a pivotal role before disruption occurs. Force majeure disruptions are challenging to manage, but can be estimated through conscious risk assessment strategies. Strategies to control risk may be divided into seven categories: prevention, rescheduling, conjecture, numeric and economic, vertical integration, risk sharing, and technology and security (Jüttner et al. 2010; Gurtu and Jestin 2021). The article covers the prevention category. By classifying the risk and assessing it, it is possible to highlight critical elements in the supply chain and such activities that may lead to the emergence of critical points.

Despite the rich literature on supply chain issues, changing external conditions and internal problems arising in workplaces, there is still no clear assessment of some emerging risk situations. Research focuses on selected cases and specific sectors of the economy, an example of which is Pató et al. (2022). The article attempts to generalize the main causes of risk in supply chains, based on the experience of the metal industry sector. Despite some differences, the main sources of risk in crisis conditions, regardless of the industry, often have the same sources.

The aim of this article is to contribute to the science and practice of risk assessment and prevention methods in supply chains. The issues considered are based on risk visualization through risk maps. The characteristics of the causes of possible threats were carried out on the basis of literature data and opinions of managers from the metal industry. The causes of risk have been divided into groups arranged with an increasing probability of increasing the risk. Locating the potential cause of risk in a specific risk group allows one to make appropriate decisions to prevent the threat. The research was inspired by the changes, events and phenomena that have affected the metal industry in the last three years.

This study contributes to expanding the literature on risk related to supply chains by analyzing the key factors affecting their interruption or disruption. In the context of this study, some areas related to the resilience of supply chains were also addressed. A literature framework revealed data on key aspects of risk and its impact on supply chains. The study deepens understanding of the role of the supply chain on company performance and risks. The goal of this paper is to quantify key risk influence on supply chains in industry. On the basis of a case study in the metal industry and literature review, a matrix model of main risk influencing on supply chains has been constructed. The practical aspect of these studies is to determine the possibility of risk assessment and its current assessment by assigning numerical coefficients from the risk matrix (probability $\times$ impact). The presented approach to risk assessment in supply chains is a new look at the possibility of assessing the effects of risk on the basis of identifying and monitoring selected, key areas of threats by fixing data in a risk matrix, which should be modified by experienced experts related to industrial economy.

The article has the following structure. Part 1—Introduction—presents an introduction to the article, discusses and cites articles on issues related to supply chain. Characterization. Part 2—Theoretical Framework—contains the research framework of the literature covering the issues of risk in supply chains, their resilience and key causes of disruption. Part 3—Methodology—research methodologies used for this study are discussed. Part 4—Results—presents the research results. Part 5—Discussion—the applied methodological approach is discussed and the obtained results characterized in the context of literature data. Part 6—Conclusion—the study findings are summarized.

3. Methodology

Case study research can be based on any combination of quantitative and qualitative approaches. This research typically uses multiple sources of data: direct in-depth

observations, interviews, and documents/literature (Rowley 2002; Johansson 2003). The pooled case study aims to provide a general understanding of a phenomenon by using a series of instrumental case studies that either take place in the same place or come from multiple places. Harling described this as an analytic generalization, as opposed to a statistical generalization (Harling 2018). The case study approach is particularly useful to employ when there is a need to obtain an in-depth appreciation of an issue, event or phenomenon of interest, in its natural real-life context. In this study, a deep literature review and interviews were used to scientific analysis. Based on these data, a scientific analysis to assess the impact of crisis conditions on supply chains was conducted. The main features of supply chains were exposed, along with their characteristics and elements influencing their course. Tools enabling the control and management of supply chains were investigated. The simplest procedure for identifying risk factors (RFs) in a production supply chain (PSC) is the checklist (Vujović et al. 2017). A growing number of authors and managers are interested in identifying critical RFs, especially when resources are limited. Potential sources of risk were analyzed using risk maps, revealing the main critical reasons for the impacts of unfavorable phenomena on supply chains. The studies on the impact of threats on supply chains took into account the disruptions resulting from the impact of the COVID-19 pandemic, as well as armed conflicts and economic turmoil. Risk and supply chain management is discussed here in relation to the results of the analysis carried out on the basis of a risk map, as well as discussions and interviews with representatives of the industrial sector.

A scientific synthesis method was used to find links between the various phenomena influencing the development or breakdown of supply chains. Important building blocks for supply chains were identified, along with opportunities to rebuild them. The influence of particular unfavorable phenomena on supply chains was examined, defining their basic features and dependences. The synthesis entailed combining the knowledge obtained from the analysis of the research subject and summarizing it into a rational whole, as presented in Section 5.

Numerous risk assessment methods are known. Methods included in ISO 31010-2009, Risk Assessment Techniques and ANSI = ASSE Z690.3-2011, Risk Assessment Techniques are listed in Luko's article (Luko 2014). However, the most friendly graphical form are risk matrices, which can quickly assess risky situations and decisions. These were used to assess risk and estimate its impact on supply chains in article. The risk matrix is a combination of risk probability and its impact, and is beneficial in finding and assessing critical risks (Markowski and Mannan 2008). Risk matrices were used to assess risk and estimate its impact on supply chains. Risk matrices are a commonly used tool for risk assessment and have different forms depending on the research need (Dehkhoda 2016; Ale et al. 2016). A risk matrix contains the probability of events and their consequence. Probability (p) is the chance that the event will occur. Probability is a number between 0 and 1. Consequence/impact (c) is the outcome of an event. Risk point is the combination of the outcome and the probability/frequency of an event. Risk set is the set of risk points of all possible events of a decision. The risk matrix is a clear picture of the situation, the occurrence of the probability of events, and their consequences. This is a very useful risk assessment tool. Risk (R) is the magnitude of risk set. R can be evaluated in various ways. In its simplest form, the risk dimension is a value defined as the product of the probability and the impact of the threat.

$$R = p \times c \quad (1)$$

Methodology of risk map construction: the construction of a risk map requires the creation of a risk register by determining the degree of risk and the effects of the risk. There are numerous examples of the use of this type of risk visualization and attempts to modify risk maps in various ways (Leniart 2022; Ali 2018; Richert et al. 2022). A risk map is a simple diagram that very quickly highlights the key risks to programs or projects. This is an advantage of the risk map over other risk assessment methods. The occurrence of a given risk—that is, the likelihood that the risk will materialize and become an issue—is

located on the vertical axis, while the horizontal axis denotes the impact that the risk will have on the project or program should it materialize (Table 1). Numbers are assigned to each probability and risk impact from 1 to 5. Multiplying these values fills the tables. The values obtained by multiplying the probability and the impact of risk illustrate the scale of danger resulting from a particular source of risk.

Table 1. Risk map with the probability of risk events' occurrence and their impacts on a project.

Impact	5	Catastrophic	5	10	15	20	25
	4	High	4	8	12	16	20
	3	Medium	3	6	9	12	15
	2	Small	2	4	6	8	10
	1	Very small	1	2	3	4	5
			Very small	Small	Medium	High	Catastrophic
			1	2	3	4	5
Probability of risk							

Next, it is necessary to determine the key risks in supply chains. These could include technology risks, market risks, organizational risks, and/or exterior environmental risks (Gurtu and Jestin 2021; Arabshahi and Hamed 2019). Risks in supply chains may also be related to the time of delivery or part of the delivery, the timely receipt of correct orders, and the costs of order fulfillment. There are also external risks, such as market demand for a manufactured product or technology. The established supply chain is related to the cost-effectiveness, which must also be taken into account. The following risk ranges have been proposed for individual levels in relation to supply chains:

1. Very small risk—events that can be removed in a short time and do not cause changes in supply chains;
2. Small risk—events that influence the supply chains but do not cause significant changes and fall within the limits of the allowed changes;
3. Medium risk—events or obstacles affecting the changes in supply chains, e.g., those requiring annexes to the contract;
4. High risk—events posing a threat to the timely implementation of supply chains (e.g., withdrawal of a partner, staff shortages making it impossible to perform the intended works, random accidents disrupting the work schedule);
5. Catastrophic risk—events leading to interruption or noncompletion of supply chains (e.g., withholding the payment of funds, inability to apply for further tranches of funds, withdrawal of one or more partners, and changes in the external conditions resulting in an interruption of the supply chain).

Each category in the risk register can be assigned a probability assessment for a given event (Table 2). The construction of the risk map requires multiplication of the point values of the probability and effect of a given event (Table 3). The red indicates the most dangerous situations, and this level of risk should not be allowed. Intervention is necessary in such circumstances. The blue range is medium risk, but also requiring intervention. Green is small risk and to some extent possible to miss.

Table 2. Point-based assessment of the probability of a given event.

Points	1	2	3	4	5
Risk level	Very small	Small	Medium	High	Catastrophic
Probability range	0–20%	21–40%	41–60%	61–80%	81–100%

Table 3. Risk map scheme filled with numerical values of the probability of risk occurrence.

Impact	Catastrophic	5	10	15	20	25
	High	4	8	12	16	20
	Medium	3	6	9	12	15
	Small	2	4	6	8	10
	Very small	1	2	3	4	5
		Very small	Small	Medium	High	Catastrophic
Probability of risk						
Levels of risk impact on supply chains:						
1	Very small risk					
2	Small risk					
3	Medium risk					
4	High risk					
5	Catastrophic risk					

Notes: Red indicates high danger and requires action and interference, blue indicates medium risk and requires intervention, green indicates the possibility of refraining from interference and assuming risk.

4. Results

Risks can be associated with almost every step in the supply chain (Kundu 2015; Zandhessami and Savoji 2011). Suppliers' reliability is often unknown in the early stages of a business relationship. Accordingly, the delivery time may vary, as may the quality of the product, depending on the contractor. The likelihood of differences in quality and delivery times may necessitate increasing inventory and lowering the level of customer service. These negative factors may not be taken into account in the preliminary analysis or, if taken into account, their effects may be underestimated (Howells 2022). The era of mass production has focused on producing large quantities of standard products at low cost and with varying quality, although the quality of the goods is generally increasing. This has reduced the risk associated with deliveries. Achieving the assumed standards of goods has been made possible through the use of higher levels of automation of devices, which have become more specialized in terms of their design and operation. The shift from mass production to mass customization has accelerated the demand for flexibility and agility in supply chains (Jafari et al. 2022). Supply chains also contain links between companies that work together.

As supply chains expand, the number of entities cooperating with them increases. Supply chains are becoming more complex, and the risks associated with their operation are increasing (Verwijmeren 2017; Trent 2020; Gružas and Burinskien 2022). Supply chains carry risks associated with fluctuating demand, as well as less tangible risks related to social, political, and environmental issues. One way to reduce these risks is to move from a production-oriented model to a service-oriented one. Outsourcing can not only provide savings but also streamline processes, increase efficiency, and strategically reorient supply chains (Bretton 2008). Risk management in supply chains has become a problem for all types of organizations. As companies move to loosely coupled networks of customers and suppliers spread over wide geographic areas and diverse business environments, the level of potential supply chain disruptions increases dramatically. Internal risks in supply chains can arise from the activities of customers, suppliers, or internal components of any participating company; they can also result from the relationships established during the creation of the supply chain. Operating in an open-system environment causes a number of disruptions in the supply chain. While some of these changes are predictable, their timing and magnitude are often unpredictable. The destructive influence of various factors may range from minimal to severe. The role of supply chain managers is to monitor the situation and react in a timely manner. Above all, supervision is critical. Supply chain managers also need to more carefully consider the processes of transporting products over long distances. In such cases, attention should be paid to reducing carbon dioxide

emissions, among other things. Supply chains are becoming greener as companies work more intensively to implement changes that will reduce the negative impact on the Earth's natural environment, but at the same time maintain a competitive advantage.

Industry 4.0 is a technological combination of CPS with logistics and production using the internet of services and things in the industrial process (Patil 2020). This has an impact on downstream services, value creation, workflow, and business models. Industry 4.0 is an ongoing transformation that changes traditional manufacturing and industrial practice to intelligent manufacturing and industrial practice using the latest smart technologies. The Industry 4.0 concept changes the perception of products in a key way. There is now a strong trend towards agile management of supply chains. Agile management is about driving a diversification strategy to deliver a product that consumers cannot find anywhere else (Konecka 2010; Çelikkol et al. 2021). The most important thing is to react quickly to changes in demand. The lean concept can be successfully applied in the event of stable demand. This enables businesses to increase the efficiency of their operations by applying a continuous flow. In the event of changes in demand due to promotional or seasonal periods, the concept of agile management is a better solution. Companies that focus their actions on responding to risk (i.e., coping with its consequences) usually adopt an agile strategy. It should be noted that there are different strategies for reducing risk in the supply chain (Evans 2019). Moreover, an appropriate risk reduction strategy is not always adopted. There are four main risk strategies to choose from: transfer (e.g., insurance of freight, transport, and infrastructure, contractual penalties), retention (e.g., preparation of funds to cover possible damages, preparation of scenarios for unforeseen events, such as strikes, blockades, or border crossings), reduction and limitations (e.g., quality control of goods and processes, selection of suppliers and subcontractors), and avoiding the risk (e.g., hang up of investments) (Konecka 2010). The concept of lean and agile supply chain management in terms of risk management (Klimarczyk et al. 2010) entails exploring the supplier market in order to search for potential suppliers or avoid risk (e.g., suspension of investments). In addition to these methods, there are other viable strategies to protect supply chains against various types of risks. Risks in supply chains affect their performance. Among other things, risks may potentially arise in the event of dishonesty, opportunistic behavior of supply chain partners, or misuse of information. Information sharing sometimes may not influence supply chain performance. As a result, companies may be uncertain or suspect that information will be used unfairly to their disadvantage, and this may cause divergent interests and opportunistic behavior of supply chain partners (Baihaqi and Beaumont 2005). This informational asymmetry has potential negative effects on the supply chain's performance (Ibrahim and Hamid 2014; Varma and Khan 2014). Identifying the root causes of risk in supply chains is crucial to their effective management. Based on our literature review and discussions with management personnel from the metal industry, we were able to distinguish some major sources of risk related to the following areas of supply chain activity:

- Environmental uncertainty, especially in times of crises, pandemics, and armed conflicts.
- Competence of organizational members in terms of their modern management skills and the use of the latest scientific achievements.
- Monitoring based on continuous risk monitoring and prevention.
- Control and evaluation related to risk monitoring, the quality of delivered components, goods, and services, time of delivery, cost of delivery; etc.
- Communication, i.e., constant and responsible communication between partners, preventing supply downtime, quick response in case of unexpected events.
- Organizational structure, i.e., streamlining and modernizing the organization of the supply chain structure and information flow between partners, openness to innovation.
- Management based on strong, highly competent leadership with great experience, striving for innovative changes conducive to the improvement of supply chains.

- Consumer satisfaction, e.g., by meeting delivery dates, ensuring the quality of goods, and complying with contracts.

A literature review was carried out to obtain information on the key risks and causes of risk (Table 4). Insight into the information presented by other authors and experts analyzing the effects of the COVID-19 pandemic and the war in Ukraine pointed to the causes of risk in supply chains. Each of the seven main basic causes causing disturbances in supply chains and their interruption results from a set of unfavorable phenomena occurring in the economy. Phenomena that occurred sporadically during the period of prosperity have now intensified and led to a significant deterioration in the supply of raw materials and components. It is also an opinion expressed by people from the metal industry with whom the authors conducted discussions and interviews on this subject (Supply Chain Risks 2022).

Table 4. Literature sources of risk causes in supply chains.

Main Risk	Cause of Risk	Literature
External crises	Pandemic; armed conflict; global economic crisis; local economic crisis	(Ide 2020; Zhu and Wu 2022; Albagli et al. 2022; Brende 2020; BRIEFING 2020; Boranova et al. 2022; Çelikkol et al. 2021; De Vet et al. 2021; Deloitte 2022; Durant 2022; Foli et al. 2022; Trax 2022; Giovanni et al. 2022; Global Report on Food Crises 2022; Gurtu and Jestin 2021; Goel et al. 2020; Grima et al. 2021; Guénette et al. 2022; Howells 2022; Koç et al. 2022; Mastos and Gotzamani 2022; Liddell et al. 2022; Committee for the Coordination of Statistical Activities 2020; Niranjana et al. 2022; Ngoc et al. 2022; Nuyts and Berard 2022; Pató et al. 2022; Pujawan and Bah 2021; Russell et al. 2022; Saliba 2022; Silva et al. 2022; KPMG 2022; Supply Chain Risks 2022; GMK Center 2022; Sweeney 2022; Schiller et al. 2018; Xu et al. 2020; Zhong et al. 2022)
Environmental uncertainty	No suppliers; bankruptcy of the supplier; limitations in the extraction of raw materials; striking workers; increasing prices of goods	(Alonso et al. 2007; Alves et al. 2022; Ekinici et al. 2022; Inverto 2022; Liddell et al. 2022; McKinsey Global Institute 2020; Paramasivam et al. 2022; Pinaud 2021; KPMG 2022; Srivastava et al. 2022; Sweeney 2022; Willox 2022; Supply Chain Risks 2022)
Supply chain relationships	Changes and complexity related to new technologies; increases in delivery and collaboration costs; increases in the complexity of products; poor cooperation between partners	(Huddinia and ER 2019; Elsayed and Abdelmajied 2022; Brende 2020; Deloitte 2017; Jongbae and Wilemon 2012; Alkan et al. 2018; Haynes and Alemna 2022; Ko et al. 2018; Bean and Joubert 2020)
Manufacturing	Lack of components; lack of raw materials; new technologies of greater complexity; insufficient training of employees; production delays; machine failures; reduced quality of products	(Beer and Mulder 2020; Brende 2020; Arabshahi and Hamed 2019; Fregoso 2019; Verheijen 2022; Abdel-Malek 2015; Supply Chain Risks 2022; Wahid et al. 2022; Bragagni and Xhaferaj 2021; Breton 2022; Hocker et al. 2022)

Table 4. Cont.

Main Risk	Cause of Risk	Literature
Supply chain management performance	Extension of the supply chain; IT attacks; inefficiency in logistical management; errors in supply chain management; lack of coordination; poor cooperation with suppliers; excessively long supply chain and a large number of partners	(Asan and Tanyas 2012; Akin Ateş et al. 2021; Furusawa and Ing 2022; Grant et al. 2017; Gružasuskas and Burinskien 2022; Shraah et al. 2022; Zhang et al. 2022; Foli et al. 2022; Cooper and Ellram 1993; Perkumienė et al. 2022; Supply Chain Risks 2022)
Business management	Lack of managerial knowledge and skills; time pressures; lack of information and recognition of cooperating units; lack or underestimation of financial control; lack of flexibility in management; errors in assessing the situation	(Li 2022; McKinsey and Company 2016; Benedito et al. 2020; World Economic Forum 2022; Trax 2022; Crandall et al. 2015; Abrudan et al. 2022)
Customer satisfaction	Low quality of deliveries; failure to meet the delivery date; overstated cost of deliveries	(MacIntire 2016; Wen and Wang 2022; Rice et al. 2022; Melián-González 2022)

The weakest places in supply chains correspond to critical risks. They are still vague and often poorly recognized. The division of risk into external and internal introduces the possibility of distinguishing key risks in these two areas related to SC (Figure 1). Identification and assessment of risk in supply chains was carried out using a risk matrix. Possible causes identified on the basis of a literature review and the industry expert experience were assigned to the key risk sources.

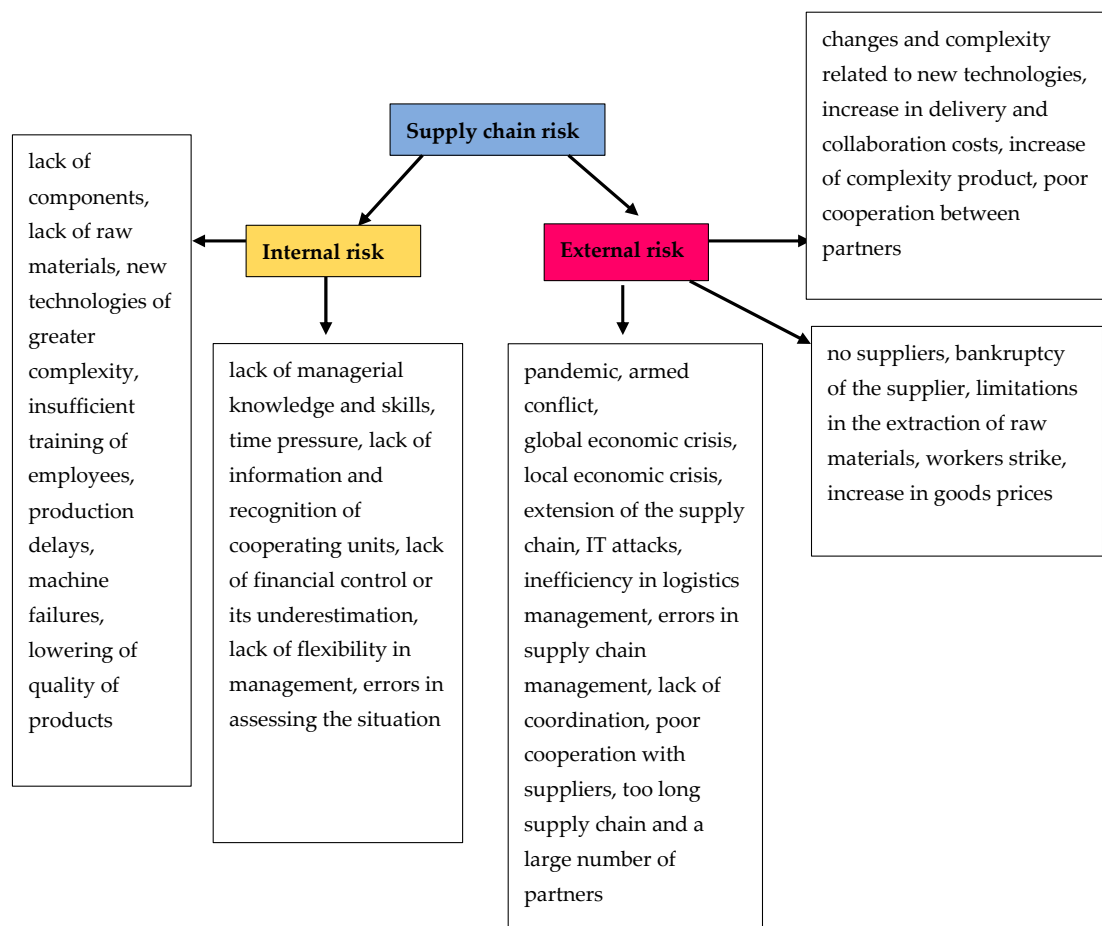


Figure 1. Scheme of risk sharing in supply chains into external and internal risk. Source: (own performance).

It has been established that serious effects in the disorder of the articular chain may have external causes that are difficult or impossible to avoid (Kundu 2015). The external causes of risk—especially at present—are often related to pandemics and armed conflicts. The environmental uncertainty is also an especially important factor in the realization of strategic supply plans. These factors affect the economy and create more sources of risk in the supply chains. An example may be the energy crisis and its consequences for the development of production (Nuyts and Berard 2022; De Vet et al. 2021). European companies limit production to reduce costs, thereby reducing the supply of manufactured products to the market (GMK Center 2022). This can result in shortages of goods and limited supplies. In such conditions, bankruptcies, reduced production, economic slowdown, and recession are possible. In 2019, there was a global downward trend in the economy (Committee for the Coordination of Statistical Activities 2020). The risk table includes the most important possible causes of the emergence of key risks leading to complications or disruptions in supply chains. Possible causes of the identified risks are presented, along with their possible consequences. The probability of their impacts on supply chains and the global risk levels were also assessed. Possible remedial measures to prevent the risks are presented in the last column of Table 5. Table 5 estimates the levels of risks caused by external phenomena and internal activities of the supply chains. The risk level scores presented in Table 5 were plotted on a risk map (Table 6). The fields with the risk level values are marked, and the risk area associated with these fields is delimited. The locations of the risk levels in the areas of catastrophic, high, and medium risk are visible. This suggests that threats to supply chains carry a serious level of risk and require considerable attention and tracking of any changes that could disrupt them.

Properly managed supply chains in which risk is monitored become resistant to turmoil and crises. Studies have shown that logistic flows in practice can reduce overall delivery costs and delivery times. This requires the use of electronic ordering systems and reducing waiting times in the supply chain, which entails a change in working methods (Van der Vorst 2004; Abrudan et al. 2022). Most deliveries are characterized by a lack of transparency in the supply chain and cooperation. Usually supply chain management (SCM) projects concern only part of the supply chain. Supply chain risks are either under control or out of control. Those beyond control include external risks. Risk management and business impact analysis prepares the company for any potential business disruption (Business Queensland 2022). Institutional uncertainty is one of the main threats to supply chains (Wang et al. 2022). Behaviors against business ethics mainly refer to corruption, bribery, child labor, price manipulation, fraud, patent infringement, etc. Properly managed supply chains, in which risk is monitored, become resistant to turmoil and crises (Figure 2a). In supply chains where risk is not monitored, destruction and interruption of supplies occur (Figure 2b).

Figure 3 presents a graphical map of the risk levels in supply chains. The structure of the chart reflects the results of the analysis carried out on the basis of the risk maps. All positions requiring a risk response strategy are placed inside the dangerous ranges.

The components that are involved in risk assessment have a high degree of uncertainty. The weakest point relates to catastrophic levels of risk. In such cases, it is necessary to react immediately to the situation that has arisen; therefore, they are situated in the unacceptable range of risk. The proper response to risk cannot be determined until the risk has been analyzed to see how it compares to the organization's risk tolerance. Risk reduction or mitigation is a choice that can be complex or simple as a decision to cease an action. The basic risk response strategies include avoiding, reducing, transferring, accepting, or *taking risks*.

Table 5. Assessment of the possibility of key risks in supply chains.

No.	Main Risk	Cause of Risk	Result	Risk Assessment			Risk Response Strategy	Cost of the Recovery Strategy
				Probability of Risk	Impact	Risk Level		
1.	External crises	Pandemic; armed conflict; global economic crisis; local economic crisis	Disruption of supply chains; high uncertainty in maintaining the supply chain	Catastrophic (81–100%)	Catastrophic, 5 points	Catastrophic (25 points in risk matrix)	Insurance of freight, transport, and infrastructure; contractual penalties; reacting quickly to changes in demand; creating new supply chains; crisis management	Very high
2	Environmental uncertainty	No suppliers; bankruptcy of the supplier; limitations in the extraction of raw materials; striking workers; increasing prices of goods	Disruption of supply chains; delays in deliveries; disruption of the flexibility of supplies; extension of the supply chain	High (61–80%)	High, 4 points	High (16 points in risk matrix)	Insurance; preparation of funds to cover possible damages; preparation of scenarios for unforeseen events, such as strikes, blockades, or border crossings; looking for new suppliers; changing the path of the supply chain	High
3	Supply chain relationships	Changes and complexity related to new technologies; increases in delivery and collaboration costs; increases in the complexity of products; poor cooperation between partners	Complexity of the supply chain; extension of the supply chain; failure to meet contracts and deadlines; need for changes in supply chains	Medium (41–60%)	High, 4 points	Medium (12 points in risk matrix)	Reducing product complexity; reducing strategic inventory levels; improving supply forecasting or finding new sources of supply—especially those closer to home; increasing transparency and tracking of deliveries	Medium
4	Manufacturing	Lack of components; lack of raw materials; new technologies of greater complexity; insufficient training of employees; production delays; machine failures; reduced quality of products	Delays in deliveries; deterioration of the quality of goods; failure to meet contracts; reducing the quality of manufactured goods; loss of brand quality	Medium (41–60%)	High, 4 points	Medium (12 points in risk matrix)	Quality control of goods and processes; careful selection of suppliers and subcontractors; reducing product complexity; reducing strategic inventory levels; improving supply forecasting or finding new sources of supply—especially those closer to home; increasing transparency and tracking of deliveries	Medium

Table 5. *Cont.*

Risk Assessment								
5	Supply chain management performance	Extension of the supply chain; IT attacks; inefficiency in logistical management; errors in supply chain management; lack of coordination; poor cooperation with suppliers; excessively long supply chain and a large number of partners	Delays in deliveries; slowdowns; shortages in deliveries	Small (21–40%)	Medium, 3 points	Medium (6 points in risk matrix)	Employee training; supply chain control; risk monitoring; improvement of logistical operations; reducing the length of supply chains	Medium
6	Business management	Lack of managerial knowledge and skills; time pressures; lack of information and recognition of cooperating units; lack or underestimation of financial control; lack of flexibility in management; errors in assessing the situation	Overstated delivery costs; disrupting the flexibility of deliveries; reducing the quality of goods	Small (21–40%)	Medium, 3 points	Medium (6 points in risk matrix)	Staff training; expert assistance; cooperation with logistics centers; flexible solutions; cost supervision	Small
7	Customer satisfaction	Low quality of deliveries; failure to meet the delivery date; overstated cost of deliveries	Production downtime; production stoppage; quality reduction; delays; failure to deliver to contractors	Small (21–40%)	High, 4 points	High (8 points in risk matrix)	Quality control of deliveries; quick response to the sender of the goods; penalties for non-compliance with quality; alternative orders	Small

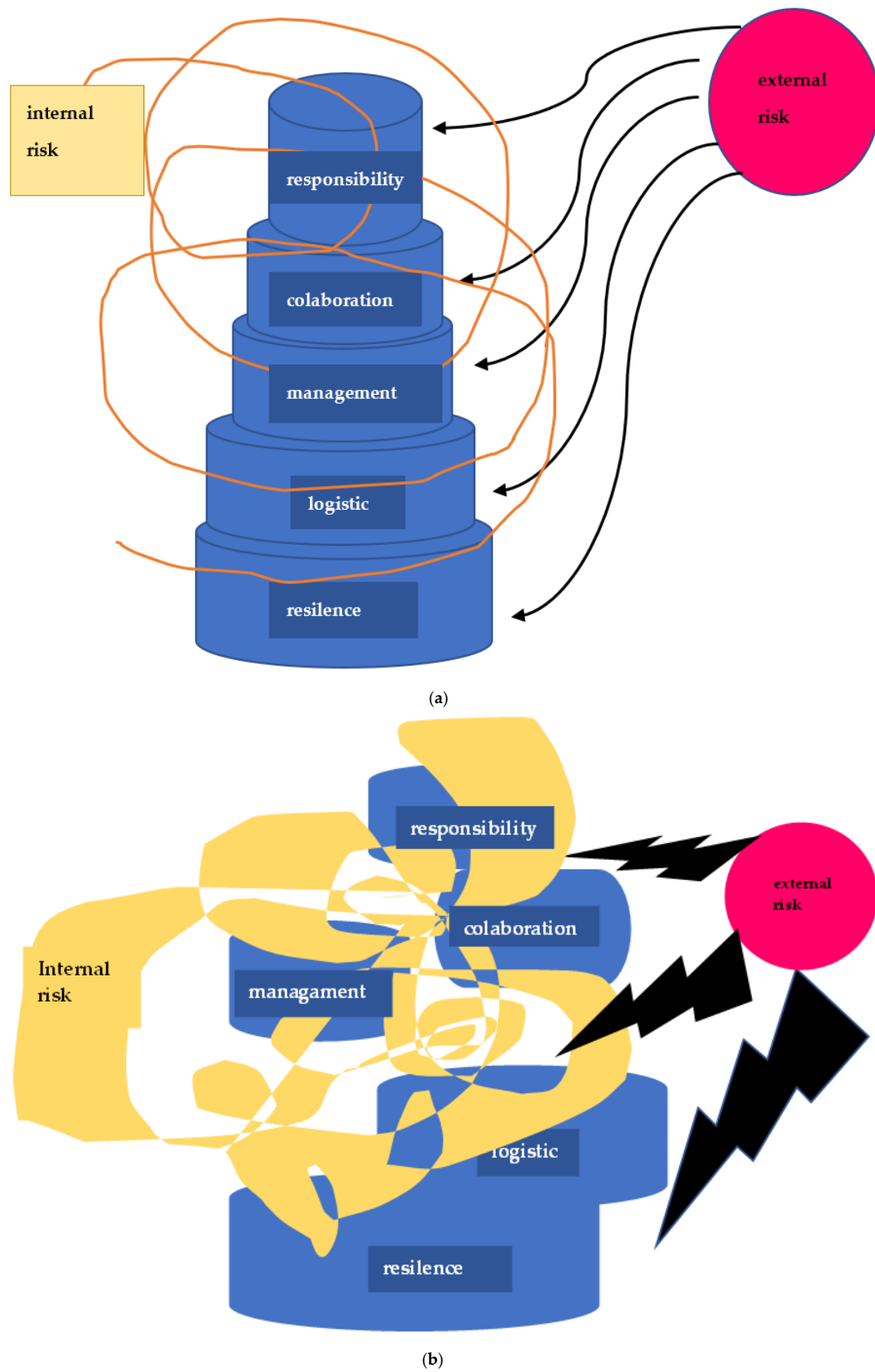
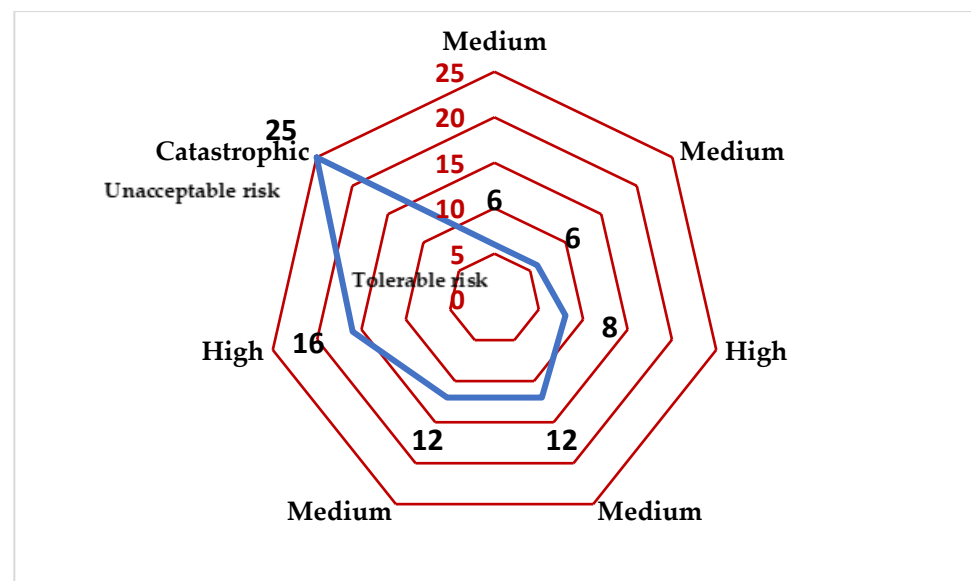


Figure 2. (a) A diagram of the balanced behavior of the main attributes of the supply chain as part of risk monitoring. Source: (own performance). (b) An unbalanced supply chain arrangement resulting from the turmoil that arose due to the lack of risk monitoring. Source: (own performance).

Table 6. Risk map with marked fields of the estimated risk of supply chains.

Impact	Catastrophic	5	10	15	20	25
	High	4	8	12	16	20
	Medium	3	6	9	12	15
	Small	2	4	6	8	10
	Very small	1	2	3	4	5
		Very small	Small	Medium	High	Catastrophic
		Probability				

Notes: Red indicates high danger and requires action and interference, gray indicates medium risk and requires intervention, green indicates the possibility of refraining from interference and assuming risk.

**Figure 3.** Graphical representation of the risk levels in supply chains. Source: (own performance).

The analysis of the literature and data from the metal industry indicates the existence of unavoidable risks that may disrupt supply chains. One of the preventive factors that warns about possible sources of risk is its monitoring, inter alia, by drawing up risk maps. This tool perfectly reveals vulnerabilities and key risks, as well as informs about the scope of potential danger (Table 6). The practical use of risk maps introduces the possibility of quick orientation in a crisis situation and supports the identification of its causes, which enables the introduction of changes and improvements. Risk maps should be considered an additional source of protection to a wide range of other risk monitoring possibilities. Therefore, certain limitations of this study pave the way for future research. This study considered only one method of risk assessment. A relatively small number of respondents were analyzed in the research. This was compensated by a significant number of literature items. Future-proof, broader research of industry representatives and deeper recognition of risk phenomena in supply chains would improve the objectivity and produce more accurate results.

5. Discussion

A high level of risk requires concentrated action by supply chain management personnel. It is necessary to constantly monitor the risk and react to the emerging obstacles and causes of disorders. In such cases, it is not possible to refrain from corrective actions. Preventive measures in this case include insurance, good knowledge, and recognition of the reliability of suppliers—especially the brand awareness of the supplier. Securing recognition of other delivery paths in the event of crisis situations is crucial to crisis management. Similar actions must also be anticipated in medium-risk conditions, as shown in the

analysis in Table 5. The least favorable are catastrophic risk conditions, which are related mainly to external factors, such as pandemics or armed conflicts. The negligible influence of the participants in the supply chain on the external conditions makes it necessary to increase vigilance and secure the possibility of alternative supplies. Risk analysis is an essential tool in supply chains. Cost of risk is $\text{Risk Value} = \text{Probability of Event} \times \text{Cost of Event}$. By carrying out a risk analysis, monitoring risks, identifying hazards and estimating the likelihood of their implementation, the cost of risk can be prevented. External risk events, such as the COVID-19 pandemic, point to the increasing need for businesses to develop a risk assessment plan that helps industry managers execute strategy and achieve objectives. Risk assessment matrix, also known as a probability and severity risk matrix, is a visual tool that depicts the potential risks affecting a business. The risk matrix is based on two intersecting factors: the likelihood that the risk event will occur, and the potential impact that the risk event will have on the business. It is a tool that helps you visualize the probability vs. the severity of a potential risk. The risk assessment matrix can help companies gain a thorough understanding of their risk environment, helping them manage risk before an event occurs. The scale and complexity of business risk is constantly growing. Literature on the subject refers to uncertainty and complex environmental conditions affecting risk assessment (Emblemsvåg 2020). In this situation, the monitoring and testing of key risks identified in Table 5 are a sensitive indicator of the ongoing changes and enable a quick response. Key risk areas related to the ongoing COVID-19 pandemic, war in Ukraine, natural disasters and global social unrest have created a new reality that will have a colossal impact on business in the coming years. Businesses must meet the challenges of today—and tomorrow—by quickly identifying, analyzing and mitigating risk. The risk assessment matrix is a crucial tool in risk management for three reasons: easy prioritization of risks, targeted strategy for managing risks and real-time view of the evolving risk environment. The impacts of the COVID-19 pandemic and the war in Ukraine have translated into shortages of raw materials and components, which relate to points 2, 4 and 5 in Table 5 (Allam et al. 2022; Vlachos 2022). The coronavirus pandemic has strained or broken many supply chains, as many industries lack the means of production (Table 5—points 1, 2, 3). An example is the automotive industry, as mentioned above (Pató et al. 2022). It is likely that deficiencies in one industry can lead to delays in other industries. In particular, there are shortages of microchips and control device components—some new cars need over 1000 of these components (Ovens 2022). There are also problems with plastics, packaging, and other products. The lack of energy resources and the universal need to obtain them, even in very remote places, have a great impact on the economy (Deloitte 2022; IEA 2022). The interconnectedness of economies makes breakdowns in supply chains affect everyone, which relates to point 1 in Table 5. Worldwide supply is affected not only by the political situation but also by catastrophic weather events, fires, maritime disasters, and other disasters that block or destroy supplies, such as floods. It is obvious that the potential of the global economy is enormous and, despite the unfavorable situation, production is constantly growing (Grzybowska and Stachowiak 2022). The potential for maintaining, creating, and developing supply chains is therefore great (Christopher and Pec 2004; Zhu and Wu 2022). In the current technological and economic conditions, there are no obstacles to rapid changes or new organization of supply chains. An example can be found in the maintenance of supply levels and the absence of signs of crisis in many areas of the economy that are essential for everyday functioning, including the food industry, household appliance industry, textile industry, etc. (Howells 2022; Alshahrani and Asif 2022; Albagli et al. 2022; Bretton 2008; Karp 2022; Global Report on Food Crises 2022; Supply Chain Risks 2022; Fregoso 2019; Mastos and Gotzamani 2022). Furthermore, a significant increase in production is visible in the military sector (Sani et al. 2022). The resourcefulness and effectiveness of human resources operating in the supply chains should be emphasized. In all conditions, on the basis of modern IT technologies and available transport routes, it is possible to obtain effective supply solutions. However, it is difficult to change the supply paths that have been built over the years. Therefore, the European Union plans to reduce

dependence on foreign suppliers in important economic areas. The draft of the new EU industrial strategy covers six sectors of particular importance: semiconductors, raw materials, pharmaceutical active substances, batteries, hydrogen, and internet cloud technologies. In addition, cooperation between EU countries on important projects is to be strengthened in order to minimize the risk of dependence on supplies. The practice-based view (PBV) is a relatively new perspective proposed by [Bromiley and Rau \(2014\)](#) as an alternative approach to the resource-based view (RBV) ([Barney 1991](#)), which is implemented in supply chain management theory ([Silva et al. 2022](#)). They focus on the practice theories, since these underexplored theories can support further implications in the supply chain management (SCM) field, as well as further theorization. This approach is related to global supply risks. Supply chains operate on the basis of constantly evolving methods of maintaining a competitive advantage in a highly dynamic or turbulent environment.

The greatest risk for companies today is the extreme uncertainty caused by inflation, rising commodity prices, the COVID-19 pandemic, and broken supply chains, marked in Table 5 in points 1 and 2 ([Brende 2020](#); [Rice et al. 2022](#)). A gradual worsening of payments in certain economic sectors is becoming noticeable. Companies that are directly exposed to rising energy costs are hit the hardest. An increase in the number of bankruptcies is forecast, which is also associated with an increase in risk to supply chains ([Paramasivam et al. 2022](#)). It is necessary to check the credibility of contractors, demand prepayment, and insure trade credit. Logistics centers are important links in supply chains that can contribute to improvement in the flow of goods and services ([Gajewska and Filina-Dawidowicz 2015](#)); they cooperate with various suppliers and recipients of goods, offering a wide range of services tailored to the expectations of customers. As independent economic entities, these centers participate in the integration of transport sectors, deal with comprehensive goods and services from many suppliers and intended for different recipients, redirect cargo flows within the available nodes of logistics networks, etc. ([Russell et al. 2022](#); [Ovens 2022](#)). The use of such centers by companies is beneficial; for example, the possibility of lowering prices by importing more goods (e.g., from China) reduces the cost of transport. The recent rise in inflation has started to gradually reduce consumption, which will affect the levels of production. This phenomenon corresponds to points 3 and 4 in Table 5. The biggest drops have been recorded in the automotive industry, with car sales having fallen ([Deloitte 2017](#)). The main problems in this industry are declining demand and supply disruptions. The reduction in production in the automotive industry, among others—e.g., in the production of bicycles—is the result of problems with the supply of components from China ([Moore and Boger 2022](#); [Schiller et al. 2018](#)). Some spare parts now cost as much as double their previous price. This is the result of broken supply chains in Asia, which have caused shortages of components in factories in China and Germany. Broken supply chains have also caused problems with the delivery of other components—for example, to Tesla factories. The situation in the construction market is not very interesting. A significant drop in demand for construction loans is visible, related to the increase in interest rates. The prices of building materials have increased, and many developers have suspended new construction projects due to the unpredictable situation and the slowdown in the growth of housing prices.

Analysts are starting to assert that another global economic crisis is rapidly approaching ([Supply Chain Risks 2022](#)). The main reason is expected to be the actions of central banks, whose decision to increase interest rates will stifle economic growth. At the beginning, the slowdown is mainly expected to affect the real estate market, which is heavily dependent on lending; indeed, such signs are already visible. Another problem is with food ([Magdoff 2008](#); [Global Report on Food Crises 2022](#)). The increase in global food prices started as early as mid-2020, and since then nothing has been able to break this trend ([von Braun 2007](#)). This spring, the World Bank's Global Food Price Index reached an all-time high, and it has doubled since the spring of 2020. Lockdowns related to COVID-19 disrupted the smooth functioning of global supply chains, increasing costs in areas such as deep sea transport. Rising fuel costs also have an impact on transportation costs. Another

important factor behind the increase in food prices is the rising price of fertilizers, the main exporters of which are Russia and Ukraine. On top of that, climate change is already creating visible problems for global food security. This situation is forecast to worsen even further. Some analysts also point to the role of entities speculating on food prices in the world markets in triggering and maintaining the current price bubble. The scale of the energy crisis and economic problems resulting from the invasion of Ukraine is probably greater than the decline in oil supply on the markets. The energy crisis will continue to drive up food prices, because ~70% of food costs are energy-related. The costs of food include not only fertilizers but also transport, fuel for machines, and food processing, and each of these elements requires energy. Therefore, the food crisis and the energy crisis are closely related phenomena.

The resulting situation has and will continue to have significant negative social and political consequences, the resolution of which will be neither quick nor simple. The outlook is not optimistic for the development of the global economy. The resulting disturbances and breaks in supply chains have effectively weakened the cooperation of economic units, which was comparatively smooth not long ago. It would be wise for companies that continuously produce goods to maintain or quickly modify many supply chains (Liddell et al. 2022; Trax 2022). Numerous industries have been able to deal with emergencies and emerge unscathed from the shortages of raw materials, components, and parts. This is possible due to well-developed activities in the areas of creating and maintaining supply chains, efficient operation of logistics centers, and the experience and efficiency of teams servicing supply chains. It is worth noting that in every dire situation humanity has ever found itself in, there was ultimately a return to a stable economy thanks to the constant improvements in possibilities and knowledge regarding the control and management of crisis situations (Sachs 2022). In recent years, and in particular during the pandemic and war in Ukraine, the tendency for supply chains to evolve towards the idea of “lean manufacturing” and “just in time” deliveries. There has also been a growing trend towards sourcing worldwide in reducing costs as much as possible along the entire chain (Supply Chain Risks 2022). Managers perceive disruption of the supply chain as the greatest threat. This also points to problems related to the recovery of compensation. However, they do not seem to have a thorough understanding of supply risks. Research conducted by key experts showed that many respondents had experienced supply chain disruptions and found that the removal of disruptions did not go smoothly. This suggests not only a lack of good identification of supply risks but also a lack of risk monitoring. In this light, the creation of up-to-date risk matrices would be a good tool for monitoring and preventing crisis situations. Interruption of supply chains or other perturbations leading to their disruption have financial and organizational consequences for enterprises. This article draws attention to dangerous phenomena in areas with the greatest threat to the smooth course of supplies. Highlighting the risk areas affecting supply chains is practical guidance for supply managers and supports their vigilance in monitoring risk.

6. Conclusions

This study shows the key factors that contribute to supply chain uncertainty and risks. The growing effect of risk on firm performance highlights the importance of processes meant to reduce the likelihood of supply chain risk. Environmental uncertainty means frequent changes in production, demand, supplies and technologies that impede companies to anticipate future changes in supply and delivery. Increasing environmental uncertainty leads to disruption and delay in the entire range or in some segments of the supply chain. Ultimately, the supply chain is interrupted. This study draws attention to the process of risk monitoring, the neglect of which contributes to the catastrophic consequences of the collapse of the supply chain. In addition to factors related to external risk, internal factors affecting the resilience of supply chains were also analyzed. Risk maps were used as a basic tool in assessing the impact of individual risks on supply chains. In summary, the following conclusions were drawn.

1. Supply chains are subject to high risk, which can be monitored through risk matrix procedures.
2. Our analysis showed that the critical risk areas in supply chains are external crises, environmental uncertainty, supply chain relationships, and manufacturing.
3. The most dangerous risks in supply chains are related to external conditions beyond the control of the participants in the supply chain. These can lead to disruption of the supply chain, which is seen as posing the greatest risk with the worst consequences for the company.
4. Awareness of the existence of risk and the possibility of its classification on the risk matrix are a great help in easy assessment of threats, which can be useful in practice, e.g., through the numerical coding of cases, they can be located and generalized on the risk matrix, leading to the possibility of risk analysis and prevention.

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