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Supply chain risk management in construction

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ABSTRACT

Risk and uncertainty in the supply chain have a direct impact on the profitability, operation, and competitiveness of the enterprise. Supply chain risk management allows for the reduction of the negative impact this risk may have on the enterprise, enabling quicker and more appropriate actions and responses. In the article, based on survey research, risk elements in the construction supply chain were identified. These risk elements were categorized into external risks, which are not directly dependent on the participants in the supply chain, and internal risks. Using the FMEA (failure modes and effects analysis) method, the risk of potential failures in both groups was assessed. The data analysis reveals that construction companies face significantly higher risks from external factors compared to internal ones. The greatest risk among external threats is attributed to changes in interest rates and issues with raw material suppliers. Among internal threats, the highest risk is related to workplace safety. Based on the analyses conducted, a risk management model for the construction supply chain was proposed.

Keywords: supply chain, construction industry, FMEA, risk management.

INTRODUCTION

The construction industry is one of the main sectors of the economy, playing a significant role in the economic growth of a country [1, 2]. It has faced numerous challenges due to the impacts of economic crises. These challenges include a reduction in the number of new projects, decreased investment, financing issues, and a decline in demand for construction services. Additionally, the sector must contend with rising costs of materials and labor, as well as increasing environmental and regulatory requirements. Despite these obstacles, the construction industry remains a crucial factor in the recovery and development of the economy, contributing to job creation and the development of infrastructure essential for future growth [3].

It is important to note that the construction industry has a significant impact on the built environment and its capacity to generate numerous employment opportunities for both skilled and unskilled workers, while simultaneously supporting economic growth is widely recognized [4]. Additionally, construction projects often have a hybrid nature, combining the use of both industrial products and essential resources such as raw materials and energy [5]. The construction industry also plays a crucial role in the development of social infrastructure, including roads, bridges, schools, and hospitals. This development contributes to improving the quality of life within communities and supports sustainable growth. As the construction industry can be a key social and economic activity for any country, the application of supply chain management (SCM) methods is recognized as valuable in achieving higher competitiveness for construction firms and the sector as a whole. Construction is a global activity with many unique characteristics, encompassing projects of varying types, sizes, and complexities [6]. Supply chain

management in construction is critical due to the sector's unique features, such as one-time projects, temporary organizations, and on-site production, which require precise coordination of resources, materials, and subcontractors. Effective supply chain management in construction ensures the smooth flow of information, materials, and capital, which is essential for the timely and budget- compliant completion of projects, especially in the face of economic and regulatory challenges.

The concept of supply chain management originates from modern approaches to managing logistics processes across various economic sectors and employs a range of management tools and methods. The topic of supply chain management is highly popular due to the substantial benefits it offers. As a result, it has been subject to numerous definitions. According to Jüttner et al. [7], supply chain management is defined as "the management of relationships with suppliers and customers to create maximum added value for the end customer at the lowest possible cost for the entire supply chain".

In construction projects, many different participants are involved throughout the execution of construction activities. A significant role in managing supply chains involves establishing proper relationships between the links in the supply chain. Uncoordinated, individual actions by companies to streamline flows within the supply chain are becoming increasingly ineffective, necessitating joint efforts by the companies forming the supply chain [8]. The lack of supply chain management can have catastrophic consequences [9]. Disasters in the construction sector have profound material effects and, more critically, impacts related to the loss of health or life of users [10]. Participants in the construction process are interconnected through various relationships. The execution of construction projects is characterized by the presence of multiple logistics chains, which aim to supply the construction site with physical resources such as raw materials, equipment, and energy, as well as informational and financial resources. Therefore, managing the logistics of construction projects can be considered as managing supply chains, where the efficiency of these chains determines the success of the construction endeavor. Addressing logistics issues in construction projects is possible through an understanding of supply chain management methodologies. The specificity of supply chains in construction is related to their low repetition or complete absence thereof. Often, these chains are created solely for the purpose of a single construction project. This results in inadequate information flow and short-sighted thinking, with companies primarily focused on achieving short-term goals and maximizing their own profits. Managing risk in the supply chain of construction processes is crucial due to its complexity, the number of components involved, and the dependencies between them. Risk permeates every aspect of life and is encountered and managed daily across various dimensions. It can encompass health, financial, environmental, or operational threats, influencing decisions at personal, organizational, and global levels. It is not surprising, therefore, that risk and risk management have garnered significant attention in academic discourse, where researchers analyze methods for identifying, assessing, and mitigating risk in different contexts. In most fields of management control and decision-making, risk management has emerged as a key component of modern construction management. In the construction industry, where projects are complex, involve numerous parties, and often entail substantial financial investments, risk management is particularly crucial. It involves identifying potential threats such as delivery delays, material quality issues, changes in legal regulations, or unforeseen weather conditions, and then developing strategies to mitigate their impact. Effective risk management in construction enables better planning, cost reduction, and ensures timely project completion. Through thorough risk analysis and the implementation of appropriate mitigation measures, construction firms can enhance their performance and competitiveness in the market. Consequently, risk management becomes an integral part of construction project management strategies, contributing to their success and sustainability. An essential element in reducing overall corporate risk is supply chain risk management [11] Proactive supply chain management can lead to greater customer satisfaction, lower total costs, improved delivery performance, and higher quality outcomes [12]. Sodhi et al. [12] note that there is an "absence of any consensus on a definition or scope for supply chain risk." Supply risk management is highly complex and typically includes: initial supplier assessments, evaluation of financial risks, supplier quality audits,

capacity and supplier planning, lead time analysis for project management, supplier scorecards, management reviews, supplier risk analysis based on accounts payable performance, contingency planning, forecasting techniques, safety stock, among others [13, 14]. The importance of project supply chains is also growing—these are chains that deliver products intended for a specific client and which often must be configured or even designed from scratch. The literature presents various approaches to supply risk management, ranging from a three-stage model [15] which includes identifying sources of risk and vulnerability, assessment, and mitigation; to a four-stage model [16, 17]; and even to five-stage frameworks, such as that proposed by Tummala and Schoenherr [18]. It is evident that there is no consensus on the components and definitions that constitute a "standard" supply chain risk management process. Sodhi et al. [12] also highlight the "lack of empirical research in the area of SCRM." Risk assessment must be a key part of supply chain management, and managers need easy access to risk-related information in order to make decisions. FMEA is a tool used to collect such information relevant to risk management decision-making [19–20]. FMEA is a long-established technique used to assess the risk of failure in product and process design projects.

The aim of the article is to analyze the internal and external risk factors that may negatively impact the construction supply chain. Through a survey conducted among construction companies, it was possible to identify the main risk factors affecting the construction supply chain. To assess the level of internal and external risk factors, the FMEA (Failure Modes and Effects Analysis) method was employed. The analysis conducted enabled the development of a risk management model for the construction supply chain, which can positively assist construction companies in minimizing the impact of risk on this chain.

BACKGROUND

The specifics of supply chain management in construction

Supply chain management can be defined as the management of activities, resources, and relationships between suppliers and consumers, from early stages to final stages, within the context of construction services [21]. In construction, the supply chain has also been defined as: "a supply chain in construction can be considered as a process of a series of activities transforming raw materials into finished products (e.g., roads or buildings) and services (e.g., design or budget) for use by a client, irrespective of organizational boundaries" [22]. Liao [23] defined the fundamental elements that should be included in the supply chain. In a broad sense, the construction supply chain begins with the specific needs of the project, encompassing preparation, execution, reception, delivery, and the usage phase, extending to the expansion and demolition of later stages of the building, as well as other related organizational activities. In a narrower sense, the supply chain focuses on the needs of the owner and emphasizes general contracting; it integrates the building material supplier, mechanical equipment supplier, designer, subcontractor, consulting firm, and owner into a network through the flow of information, materials, and capital. The construction supply chain has a unique structure because the construction industry is fundamentally different from other sectors and must develop distinct solutions and concepts to enhance performance and efficiency [24]. Consequently, Vrijhoef and Koskela [25] identified the following elements within the construction supply chain:

- the convergence on the construction site, where the structure is assembled from delivered materials;
- the temporary production of one-off construction projects through the repeated reconfiguration of project organizations, separate from the project;
- a typical make-to-order supply chain, where each project results in a new product or prototype.

Construction Supply Chain Management (CSCM) encompasses the key business processes of all participants involved in the investment process. CSCM is an operational and strategic cycle that includes personnel, materials, equipment, subcontracting, and project completion. These elements are interconnected through technology, safety, and communication. CSCM refers to the strategic management of the flow of information, activities, tasks, and processes involving various independent organizational networks and interaction relationships (both upstream and downstream), which add value through the completion of the project [21,26].

Key business processes in Construction Supply Chain Management include [27]:

- project/venture management,
- management of supplier and client/investor relationships,
- management of work flow/processes,
- environmental management and stakeholder relations,
- research and development,
- demand management/requirements of the investor and user,
- order fulfillment.

Quality management in the construction process is crucial, as it directly impacts the safety and comfort of the building's use. Construction quality encompasses safety, strength, durability, and functionality of building structures. Occasionally, buildings may fail to meet these standards, exposing occupants and other users to various risks. Ensuring high quality and safety is intrinsically linked to risk management within the supply chain. An example of the construction supply chain is illustrated in Figure 1.

Supply chains in the construction sector involve all participants of the project, including material manufacturers, subcontractors, architects, contractors, financial institutions, and clients. The construction site, or construction project, brings together all suppliers, forming a collaborative network. When managing logistics processes in construction projects, the following conditions must be considered [28]:

The construction site operates as a complex production system, where intricate tasks are performed within limited space and time constraints. This environment requires precise coordination and management to handle the complexities and ensure efficient execution. External deliveries are handled through numerous supply chains, which ultimately deliver materials that are assembled on-site. Effective coordination among these supply chains is crucial for ensuring that materials arrive on time and in proper condition.

Each contractor involved in construction works participates simultaneously in multiple projects and must manage the logistics of all these ventures, taking into account their diverse requirements. This necessitates robust logistics management to balance the demands of various projects and ensure smooth operation across all activities.

In Poland, the responsibility for ensuring construction quality is shared among various entities. Architects, developers, property owners, general

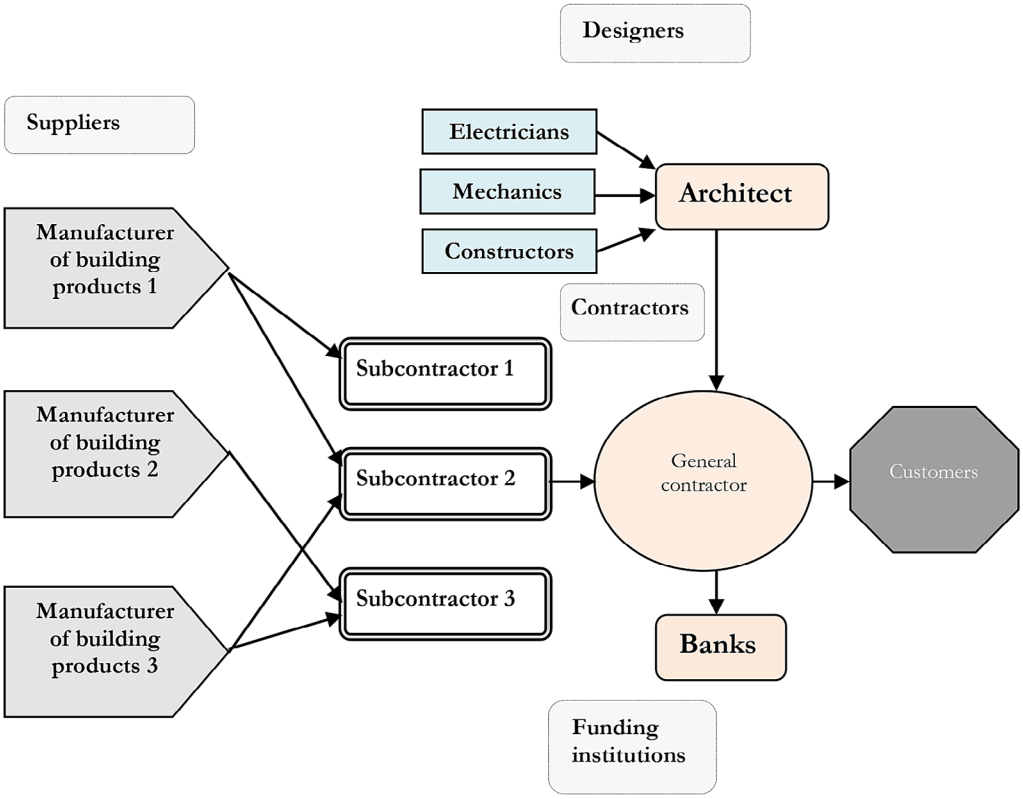

Figure 1. An example of a construction supply chain

contractors, and construction managers all play a role in the process aimed at ensuring high-quality construction and, above all, safety. There are numerous criteria for categorizing the elements of the construction supply chain. Figure 2 illustrates two of these criteria:

External and Internal Elements: This classification distinguishes between elements that are external to the construction process (such as suppliers and regulatory bodies) and those internal to the construction site (such as subcontractors and on-site workers).

Types of Supply Chains: This refers to different types of supply chains present in the construction industry, reflecting various ways in which materials, equipment, and services are organized and delivered to the construction site.

These categorizations help in understanding the complexity of the construction supply chain and in developing strategies to enhance efficiency and quality control.

The supply chain created for the purposes of executing a construction project is referred to as a project supply chain (or construction project supply chain) [30]. The term project supply chain is narrower than the general construction supply chain. Construction supply chains can start with designers and the general contractor, and end with manufacturers and specialists who are not part of the project team [31].

RISK MANAGEMENT

In recent years, there has been tremendous development in the area of supply chain risk management. In an increasingly uncertain world, the use of practical and effective tools for decision-making and risk mitigation has become more necessary than ever before. Every day, enterprises face a variety of risks that have the potential to affect the proper course of their operations. This is why risk management constitutes an effective approach that can reduce or limit the negative effects of risk [32].

Risk management identifies a key issue in relation to the enterprise's operations. By identifying and assessing risk factors, the enterprise can effectively evaluate risks and propose measures to eliminate or at least reduce them [33]. This process is crucial because it allows companies to operate more consciously and safely in markets, which can lead to greater stability and success in their operations. In many cases, risk management

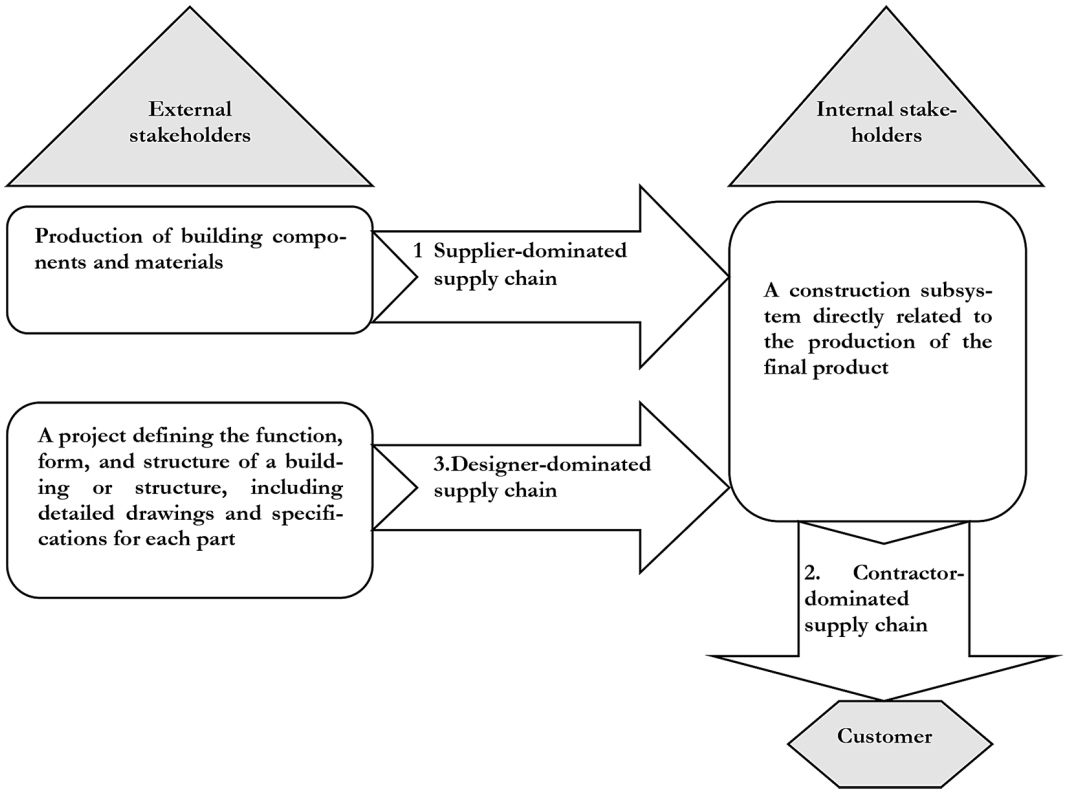

Figure 2. Elements of the construction supply chain [own study based on [29]

is often underestimated because many people are unaware of its necessity and consider it less important [34, 35]. Small businesses often show the greatest fluctuations in implementing risk management because they perceive it as costly and time-consuming. A common argument is that potential risks are already included in project management, and therefore there is no need for separate risk management [36]. However, the lack of dedicated risk management can lead to unforeseen problems that can have serious consequences for the company. Therefore, regardless of the size of the enterprise, investing in effective risk management is crucial to ensuring its stability and long-term success. In particular, small businesses should consider the benefits of risk management as a tool to protect against uncertainty and build market resilience.

Kayouh and Dkhissi [37] emphasize that risk management is one of the most fascinating areas of academic research, attracting significant attention from both specialists and practitioners. In the context of the supply chain, risk management can be described as the intersection of two key fields: risk management and supply chain management.

Supply chain risk management involves the coordination of collaborators to ensure profitability and continuity while addressing economic, environmental, and social threats [38]. Risk in supply chain management is perceived as potential adverse effects [39, 40] that can lead to the inability to meet customer needs. Supply chain risk involves vulnerabilities to threats, disruptions, and uncertainties, and sometimes also includes supply chain security issues [41, 42]. It can be defined as "the variability in the distribution of supply chain outcomes, their probabilities, and subjective values" [43] or as "the expected outcome of an uncertain event, meaning uncertain events lead to the emergence of risk" [44]. Risk management is a decision-making process that involves identifying, assessing, controlling, and responding to risks that could threaten the achievement of planned economic or social goals. Risk management should encompass actions both within and outside companies to identify and address major threats, ensuring the company's sustainability and goal achievement [45]. Actions taken should be systematic and long-term, with a planned and purposeful nature. Kisperska-Moroń distinguishes three categories of risk [46], presented in Table 1:

- Specific risk for supply chains, arising from their complex structure and interactions among multiple entities,
- External risk, related to the occurrence of random events independent of economic entities,
- Related risk, which may arise in the supply chain as a result of economic actions and decisions, as well as external factors.

Authors [38, 39] have identified three basic stages of risk management: risk identification, risk assessment and measurement, and risk monitoring and control. Other authors point to four stages, which makes the process more comprehensible (Figure 3).

The individual stages of risk management which was presented in Figure 3 can be utilized as follows [50]:

- Step 1. Risk identification – This involves identifying individual risk factors, considering both external factors independent of the examined object and internal factors over which the object may have some influence. In supply chain risk identification in construction, this means analyzing potential threats that could impact the delivery of materials and services necessary for construction projects. Based on industry reports and analyses, factors such as delivery delays, material quality, resource availability, economic conditions of suppliers, and logistical issues are identified.
- Step 2. Threat classification – Threat classification is based on the causes of problems

Table 1. Risk categories [47]

Specific risk for supply chains	External risk	Related risk
• risk related to decision-making processes, • lack of a single owner, • lack of coordination (risk of chaos).	• natural disasters and catastrophes (fires, floods, hurricanes, earthquakes, etc.), • international terrorism, sabotage, • extraordinary environmental threats, as well as some events related to technical and military threats of an anthropogenic nature.	• linked to the environment and conditions of business operations (resources and relationships, organizational and legal issues, etc.), • threats that may directly impact the execution of operational processes (financial problems, breakdowns, accidents, etc.), • arising from market mechanisms (demand fluctuations, currency exchange rates, competition, etc.).

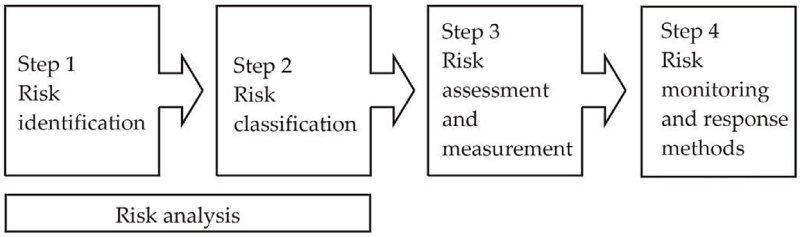

Figure 3. Risk management – stages [48, 49, 50]

in the supply chain. External threats, such as changes in legal regulations, political situations, and natural disasters, are distinguished from internal threats, such as supplier management issues, errors in logistical processes, improper planning, and coordination. These threats can be further divided into those occurring at different stages of the supply chain, from material ordering, through transportation, to delivery at the construction site.

- Step 3. Risk assessment and measurement – This stage involves assessing and measuring risk to determine its potential impacts and likelihood of occurrence. This assessment helps identify the most significant threats that could affect the supply chain and assign them appropriate priorities. Based on this assessment, it can be determined which threats require immediate intervention and which can be monitored over time.
- Step 4. Risk monitoring and response methods – In this stage, proposed corrective measures (preventive actions) are needed to reduce the impact of individual risk factors. Risk monitoring involves continuously observing and analyzing conditions that may affect the supply chain and responding to any alarming signals. Response methods may include actions such as negotiating contracts with alternative suppliers, creating stockpiles of critical materials, implementing delivery monitoring systems, training employees responsible for supply chain management, and conducting regular supplier audits. The goal of these actions is to minimize the risk of disruptions in the supply chain and ensure that potential threats are quickly identified and effectively mitigated.

MATERIALS AND METHODS

The first element of the conducted analysis was identifying the most important risk factors related to the functioning of the supply chain in construction. These factors were identified based on surveys conducted between 2021 and 2023 among participants in the construction supply chain. Respondents answered the open-ended question, "What are the risk factors threatening the success of construction enterprises?" by pointing out problems they encountered in their work. Among the respondents were construction material producers (123 responses), subcontractors (118), contractors (185), designers (138), and clients (93). The survey involved 421 individuals who provided a total of 657 responses to the open-ended question. Some responses were obtained from online questionnaires (112 people), while others came from paper surveys (309 people). The profile of the companies participating in the survey from 2021–2023 was as follows: contractor companies 52%, design firms 18%, construction material producers 16%, and investors 14%. The projects mainly concerned tasks related to residential and multi-family construction, and the number of employees was not considered.

According to Statistics Poland [51], the construction sector employed over 400,000 people during the period from 2021 to 2023. Using a sample size calculator [52], it was determined that the minimum number of responses needed was 384, which indicates that a sufficient number of respondents participated in the survey.

The responses obtained from the survey formed the basis for identifying the main factors affecting the supply chain in construction. The analysis allowed for grouping the responses based on similarities, and then dividing them into two categories: external factors and internal factors. Next, an analysis of individual risk factors was conducted using the FMEA method. There are various methods that can be used for risk analysis, including those related to sustainable development. The FMEA method allows for identifying actions to minimize the risk of various types of problems [53]. It is a technique that enables the

identification of errors and aids in their elimination. FMEA is used to recognize and assess the risk of potential errors and their consequences. The method involves analytically establishing cause-and-effect relationships leading to potential product defects and considering the factor of criticality (risk) in the analysis [54]. Wolniak [55] emphasizes that FMEA is particularly recommended during the development and production of a new product because it allows for the identification of potential defects early enough to be eliminated through preventive measures before production begins. He also notes that this method can be used not only to analyze the causes of already identified defects but also to prevent defects that might occur in the product. Nedeliaková and co-authors [56] highlighted that FMEA is a straightforward procedure that can be extended to other types of risks [57,58]. FMEA also helps prioritize risk areas in the production process steps and develop effective corrective and preventive actions [59]. Therefore, it was decided to use the FMEA method for risk analysis in the construction supply chain.

At the outset, the causes and effects of different types of risk were identified. For these causes, three numbers were determined based on expert judgment collected through interviews with engineers, using standardized rating scales to ensure consistency:

- P (probability) – the likelihood of the given risk factor occurring in the construction supply chain (how often the defect can appear: 1 – improbable, 10 – very probable),
- S (severity) – the significance of the risk factor for the participants in the construction supply chain (how important the defect can be for the customer, how much it can disturb: 1 – not important, 10 – very important),
- D (detection) – the likelihood of detecting the given risk factor in the construction supply chain (how easy it is to discover the defect: 1 – very easy to be detected, 10 – impossible to be detected).

Based on these numbers, the Risk Priority Number (RPN) was calculated as the product of the previously determined numbers. This allowed for identifying the most critical risk factors. The analysis also enabled the development of a risk management model for the supply chain, which can be utilized in various types of construction companies.

RESULTS AND DISCUSSIONS

The analysis of respondents' answers allowed for the identification of the most important risk factors affecting the functioning of the supply chain in construction (the most frequently mentioned answers). Internal risks refer to factors originating from within the construction company, while external risks are linked to the broader environment. The answers were clustered by thematic similarity. A total of 17 external risk factors and 11 internal risk factors were identified (Table 2).

The risk analysis for the construction supply chain was conducted using the FMEA method (Table 3). The classification of risk types was based on the analysis of the survey conducted.

Table 2. External and internal risk factors according to respondents

External risk factors	Internal risk factors
• fluctuations in raw material prices, • unavailability of materials, • logistical problems, • high inflation, • changes in interest rates, • issues with project approval, • low quality of construction materials, • lack of advanced technology in construction production, • demand variability, • problems with raw material suppliers, • risks related to pandemics and public health, • damage to materials (improper loading, unloading, transport), • shortage of drivers in the market, • high prices, • loss of customers purchasing construction materials, • changes in customer preferences, • lack of skilled professionals.	• limited warehouse space, • theft of materials, • damage to construction materials due to improper storage or expiration, • problems with inventory management in the warehouse, • reliability issues with machinery and equipment on the construction site, • risks related to workplace safety, • risk of negative events affecting the environment (fire, noise, work near areas of special environmental value), • transportation delays, • high transportation costs, • lack of transportation flexibility, • access restrictions to the construction site.

Table 3. FMEA method for external and internal risk factors in the construction process

Symbol	External risk factors	Reason	Cause	P	S	D	RPN
R_{o1}	Fluctuations in raw material prices	Trade policy, inflation, supply, demand, or exchange rate fluctuations	Increases in construction material costs, supply chain destabilization	6	9	8	432
R_{o2}	Unavailability of materials	Limited production, transportation bans	Downtime, project delays, necessity to purchase lower-quality materials or at higher prices	6	8	5	240
R_{o3}	Logistical problems	Lack of material availability, disruptions in delivery schedules, project delays	Searching for alternative suppliers, higher costs, delays	6	7	7	294
R_{o4}	High inflation	Increased consumer demand, unbalanced budget	Delays or stoppages on the construction site, rising material costs affecting the project budget	6	8	7	384
R_{o5}	Changes in interest rates	Countering inflation	Lack of creditworthiness, abandonment of construction projects	8	8	7	448
R_{o6}	Issues with project approval	Errors	Delays, loss of customers	4	6	3	72
R_{o7}	Low quality of construction materials	High prices lead to the selection of lower-quality materials	Reduction in building safety and durability, loss of customer trust	6	9	6	324
R_{o8}	Lack of advanced technology in construction production	High costs	Reduction in flexibility and efficiency of construction production, project delays, increase in operational costs	5	7	6	210
R_{o9}	Demand variability	Inflation, rising interest rates, price volatility	Increased demand may lead to unnecessary downtime if materials are not available on time, and storing excess materials generates additional warehousing costs	7	8	7	392
R_{o10}	Problems with raw material suppliers	Market instability of raw materials, logistical issues related to transportation delays or stock shortages	Project delays, breach of contract, difficulties in maintaining financial liquidity, loss of clients and reputation	8	8	7	448
R_{o11}	Risks related to pandemics and public health	Random causes	Decline in demand for construction services, health issues among workers, additional costs for ensuring sanitary safety	9	8	4	288
R_{o12}	Damage to materials (improper loading, unloading, transport)	Improper loading, unloading, transport	Financial losses, decreased profitability, delays in construction projects	6	8	4	192
R_{o13}	Shortage of drivers in the market	Offering low wages	Project delays, reduced quality, decreased productivity, increased risk of accidents, impact on other projects	4	6	4	96
R_{o14}	High prices	Unstable raw material market, unstable energy market, high demand	Reduced quality, instability of suppliers, decreased wages for employees	7	7	7	343
R_{o15}	Loss of customers purchasing construction materials	Lack of proper material quality, delivery delays, delays in project completion	Excess inventory, financial losses, fluctuations in demand for the company's services or products, weakening market position	7	8	5	280
R_{o16}	Changes in customer preferences	Design and architectural trends, market competition, effective marketing strategies of companies	Decrease in demand for existing products, risk of material obsolescence	7	7	4	196
R_{o17}	Lack of skilled professionals	Low wages, poor working conditions, job cuts, economic crises, seasonality of work	Project delays, loss of competitiveness and client trust, contractual penalties, difficulty recruiting new employees or issues with potential investors	7	7	6	294
Symbol	Internal risk factors	Reason	Cause	P	S	D	RPN
R_{i1}	Limited warehouse space	Suboptimal supply planning, lack of synchronization between suppliers and construction, seasonality in construction	Delays in material deliveries to the construction site, risk of material damage, errors in project execution	5	7	4	140

R_{i2}	Theft of materials	Lack of adequate security	Financial losses, as well as delays in project completion	4	8	4	128
R_{i3}	Damage to construction materials due to improper storage or expiration	Inappropriate weather conditions, exposure to sunlight, rain, snow, and frost, improper inventory management	Financial losses, decreased profitability, delays in construction projects	4	8	5	160
R_{i4}	Problems with inventory management in the warehouse	Inadequate quantity of ordered materials	The need for rapid replenishment of missing materials, safety hazards caused by damaged or outdated materials	6	6	5	180
R_{i5}	Reliability issues with machinery and equipment on the construction site	Using old machinery, cutting costs on technical infrastructure	Delays, higher costs related to machine repairs and maintenance, reduced product quality, increased safety risks	4	7	4	112
R_{i6}	Risks related to workplace safety	Non-compliance with safety regulations, attempts to cut costs at the expense of workers	Decreased work efficiency, lack of staff, sanctions and penalties, loss of client trust, and deterioration of the company's reputation	7	10	6	420
R_{i7}	Risk of negative events affecting the environment (fire, noise, work near areas of special environmental value)	Lack of adequate investment protection	Sanctions and penalties imposed on the company due to noise and environmental pollution	7	7	3	147
R_{i8}	Transportation delays	Traffic accidents, weather conditions, road repairs	Project delays, additional labor costs, extra expenses	7	7	3	147
R_{i9}	High transportation costs	Rising fuel prices, toll fees, transportation taxes	Decreased profit, reduced project profitability	6	6	4	144
R_{i10}	Lack of transportation flexibility	Failure to adapt to changing project needs	The need to use more expensive transportation services, delays, higher costs	7	5	4	140
R_{i11}	Access restrictions to the construction site	Narrow streets, entry restrictions, weight limits, and height restrictions for heavy vehicles	Higher costs, delays, reduced productivity	7	8	4	224

Note: R_o – risk of external factors; R_i – risk of internal factors.

The final results, including the Risk Priority Number (RPN), are presented graphically (Figure 3) to highlight those factors for which the risk is high. The graphical presentation of the results allows for better visualization of the findings.

The sequence of the analyzed risks in both groups was arbitrary, and the items were numbered based on their position in the table, without implying any prioritization. Each group was numbered independently, with the external risks labeled as R_o and the internal risks as R_i.

The analysis of the data presented in Figure 3 indicates that construction companies face significantly greater risk from external factors than from internal ones. This is because external factors are less controllable compared to internal ones. Among the external factors, the dominant ones are:

- R_{o1}: fluctuations in raw material prices,
- R_{o4}: high inflation,
- R_{o5}: changes in interest rates,
- R_{o9}: demand variability,
- R_{o10}: problems with raw material suppliers.

All these elements are interconnected. They are consequences of the pandemic, the war in Ukraine, and geopolitical instability, which lead to fluctuations in raw material and energy carrier prices, significantly impacting business operations. Raw material price changes are not cyclical and are difficult to predict. Recently, the pandemic-induced increase in raw material prices has caused numerous problems, significantly affecting the operations of construction contractors engaged in long-term contracts. As is well known, the price set at the time of the agreement generally binds the parties despite fluctuations in the prices of raw materials necessary for producing the product or completing the work. In such situations, the financial burden of macroeconomic changes falls on only one party to the contract. This leads to many negative consequences, ranging from substantial losses related to the project to the risk of bankruptcy. Construction contracts usually include a clause adjusting the payment amount in case of changes in production costs, known as an indexation clause. The contractor

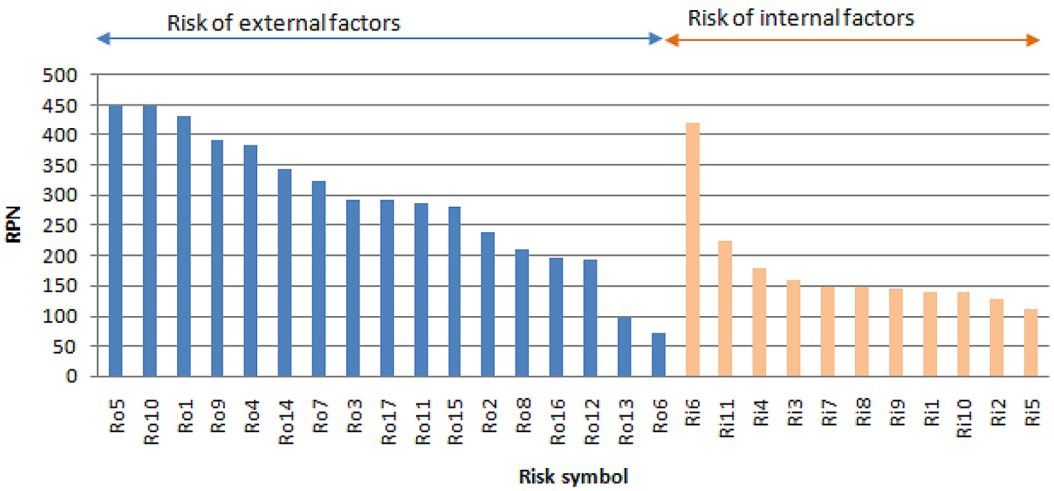

Figure 4. Graphical interpretation of risk priority number for external and internal risk factors

may also use the clause rebus sic stantibus or claim damages. Alternatively, the contractor can stipulate in the contract a recalculation of costs depending on the increase in material prices above a level set by the contractor. The prices of raw materials and energy lead to increased prices of construction products and labor. The result of inflation is both increased costs and a growing sense of unpredictability in the market, which effectively deters many entrepreneurs from making decisions about new investments. A high consumer price index (CPI) is a significant investment deterrent for both entrepreneurs and investors. High inflation restricts the scale of investments in construction sector enterprises. High commodity and service prices, combined with high interest rates, also reduce investment demand, especially visible in the residential construction sector.

In Poland, in 2022, there was a 27.8% decrease in the number of new residential construction projects started, and a 12.8% decrease in building permits issued compared to 2021 [60]. When price increases affect buyers, demand typically falls, and consequently, producers may offer fewer goods or services. Investors do not feel secure and stable in a high-inflation environment, which impacts interest rates and limits credit capacities. This situation affects demand volatility, often restricting it and destabilizing the construction market. Dramatic cost increases, delays in investment decisions, and growing concerns about a market slowdown are just a few of the long list of problems in the construction sector caused by inflation. Inflation in the supply chain manifests as increased logistical and production costs. This results in higher prices for raw materials, energy, and transportation. Unfortunately, in a rising inflation scenario, there are often disruptions in supply chains, such as delays, bottlenecks in production lines, or stock shortages. Therefore, it is crucial for companies, being aware of the types of risks, to implement technological solutions that improve planning to anticipate possible disruptions in advance or to have better control over inventory levels to ensure an adequate supply. By understanding the risks associated with supply disruptions, businesses can maintain competitiveness by enhancing inventory control, streamlining logistical planning, and reducing production costs. There are tools available for forecasting, planning, and managing in an inflationary environment. These typically cover two aspects:

Forecasting, which involves simulating the operation of the supply chain under conditions of high inflation or significant unpredictability. By conducting such activities, companies can better prepare for market changes and improve their responsiveness in situations of increased uncertainty.

Flexibility, which involves logistics that include maintaining a list of alternative suppliers and developing alternative logistics networks. This allows companies to adjust their resources to potential changes.

As for internal risk factors in the supply chain, their level is significantly lower. The dominant factor here is R_{i6}: risks related to workplace safety. Unfortunately, accidents on construction sites remain very common, with approximately 2.500 to 3.000 incidents per season, from January to September.

Directive 92/57/EEC of the Council on minimum safety and health requirements at construction sites, incorporated into the Building Law, emphasizes the importance of safety planning (risk identification, risk assessment, and measures to prevent possible accidents) during the phases of design, commencement, and execution of construction works. In practice, the construction manager is required to prepare or ensure the preparation of a safety and health protection plan if the work involves exceptionally high risk and is expected to last more than 30 working days, employ at least 20 workers, or involve high labor intensity (more than 500 person-days). Understanding risks is crucial for the functioning of a company. Risks need to be identified and monitored. A risk management model for the supply chain should include four main steps: 1. risk identification, 2. risk assessment, 3. risk treatment, and 4. monitoring and reporting, as presented in Figure 4. Each of these four main steps includes detailed actions to be taken, based on the procedures used in the FMEA method. When using the model, it is important to adhere to the concept of continuous improvement and repeat the cycle.

In developing the risk management model for the supply chain, the authors decided to modify the previously described risk management model by changing its stages. The first two stages were combined as they both pertain to the identification of risk factors. The significance of stage 4 was changed to reflect that it should occur periodically; the analysis should be repeated and newly identified factors should be added, while also checking whether the actions intended to minimize the impact of specific risk factors are effective. Stage 3, risk treatment, was highlighted, which refers to preventive and, if necessary, corrective actions.

The authors have chosen to present the described risk analysis process in the form of a boundary framework, which is intended to streamline and simplify its implementation for other researchers and practitioners (Figure 5). By

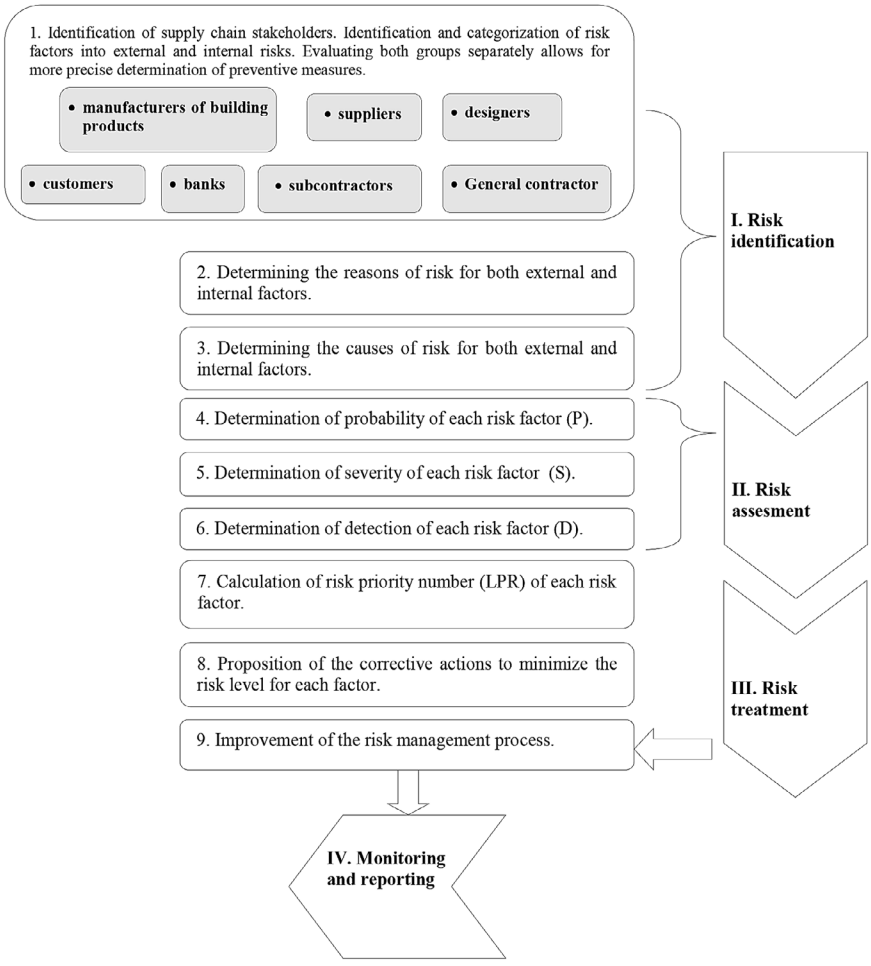

Figure 5. Proposed risk management model for the construction supply chain

structuring the model within clear boundaries, they aim to make the risk management process more accessible, replicable, and adaptable across different contexts. This approach enhances its practical utility, ensuring that it can be easily applied to similar research or real-world construction projects. To reflect its purpose and scope, the authors have named it the 'Proposed Risk Management Model for the Construction Supply Chain,' highlighting its specific focus on managing risks within the construction sector's complex and dynamic supply chain environment.

The proposed model was developed based on a thorough analysis of the data and relevant factors, though it has not yet been fully validated. Despite this, it offers a valuable framework for conducting similar studies and could serve as a useful tool for future research in this area. Due to time constraints, limited access to real-world data, or the exploratory nature of the research, the model has not yet undergone a full validation process. However, it provides a solid foundation for further exploration and validation in future studies.

Risk analysis enables companies to understand and, through appropriate actions, avoid or minimize the negative impacts of events that affect their operations. Identifying risks and their nature allows for the implementation of tools that can mitigate their adverse effects on investment success. These tools may include specific contractual provisions and, most importantly, actions aimed at preparing for market changes and improving the ability to respond to increased uncertainty.

Properly selecting tools according to the nature of the business and associated risks enables full control over the supply chain, facilitating the detection of errors and inefficiencies before they develop into problems for the entire chain.

The benefits of risk analysis include:

- reduction of time and costs: decreases the time and costs required for risk analysis of new ventures,
- increased efficiency: accelerates the pace of risk analysis due to a smaller volume of data to process,
- risk forecasting: allows for anticipating the significance of risks at subsequent stages of the project,
- weak point identification: identifies and enables the minimization or elimination of weaknesses in the investment process,
- optimal resource utilization: ensures the optimal use of resources at each stage of the investment process,
- enhanced competitiveness: increases the company's competitiveness in the market,
- building prestige: contributes to building the company's reputation.

CONCLUSIONS

Risk management in construction is increasingly essential for minimizing risks in the supply chain, ensuring efficient execution, and reducing costs. In the construction supply chain, key internal and external risks were identified using FMEA analysis. External risks, such as raw material price fluctuations and supply chain disruptions, were found to be more significant, while internal risks, particularly related to workplace safety (Ri6), were lower in level.

The article proposes a model for managing supply chain risk, based on four steps: risk identification, assessment, management, and monitoring. FMEA analysis plays a central role in assessing and prioritizing risks, allowing for targeted corrective actions. The model is applicable across industries and emphasizes the need for continuous monitoring in dynamic environments.

The research highlights significant threats to construction operations, such as inflation and interest rate changes, while emphasizing the importance of flexibility and diversified suppliers. Safety risks in the construction sector require ongoing attention to minimize accidents and ensure compliance with safety regulations. Effective risk management contributes to smoother project execution, reduces disruptions, and enhances overall competitiveness and sustainability in the construction industry.

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