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Supply Chain FMEA Risk Analysis for the Heavy Industry Sector

Małgorzata Dendera-Gruszka and Ewa Kulińska

Abstract Chopen

The discussed problem is associated with the analysis of risk factors affecting supply chain management in the heavy industry sector based on the analysis of entities operating in this industry. During the research, several aspects of key importance in supply chain management in the heavy industry sector were identified. The use of the failure mode and effects analysis (FMEA) method in research has enabled the detection of defects in supply chain management and analysis of factors that may negatively affect the flow of goods. During the research, potential design flaws and the effect of these flaws were identified, indicating the class, cause, and occurrence.

Keywords: heavy industry, supply chain, risk analysis FMEA

1. Introduction

The need for continuous improvement of processes taking place in enterprises in order to stay on the market in the era of globalization forced on organizations is requiring cooperation. Business-to-business cooperation has evolved considerably over the past few decades. It can be safely argued that the chains of service providers from the beginning of entrepreneurship. Over time, trade has appreciated the characteristics of the supply chain and its competitive advantage. They began to create conscious networks of companies for more efficient and easier loading of goods. Services related to data flow management are most often given a competitive advantage in a given market.

The term supply chain first appeared in the 1980s. The cooperation used alone was not sufficient. In order to efficiently, dynamically, and qualitatively optimize loading of goods, such as planning, decision-making, organizing, and turning over. Over time, various concepts of supply chain management were developed toward the rapid creation, which allow the flow of goods to take place in the most efficient way [1, 2].

Do business, follow the constant decision-making process that is affected by a situation that requires operations. Risk management is defined as a set of activities that include planning, organizing, flipping, controlling, and making decisions. These operations are aimed at protecting the organization against uncertain, unexpected, and dangerous events [3, 4]. Risk management is a multistage process that aims to monitor business transactions against broadly understood danger. Activities included in the risk management use also the analysis of risk sources and their elimination. It should be taken into account that it does not always mean a negative

situation and is increasingly seen as an opportunity for accessibility. Therefore, risk management may mean the elimination of the negative effects of a dangerous situation, but there may also be a chance to develop accessibility [5, 6]. The essence of risk management determines the maximum utilization of benefits by the company while minimizing possible losses [7].

The meaning of words often raises doubts, and it is impossible to change clearly. Defining keywords on the basis of various sciences and theories, such as economics, law, psychology, statistics, probability theory, systems theory, or behavioral sciences, and then explicitly worded contents of the word risk, extremely difficult tasks.

The risk mainly applies to everyone and situations that should be avoided. It is also identified with chance, courage, and fate. It is a collection of activities that cause material losses and damage to the body or cause other losses. It is primarily associated with human activity and behavior [8]. Processing the definition of risk associated with the risk of positive or negative effects, expected values, uncertainty of achieving the goal [9, 10].

The failure mode and effects analysis (FMEA) method is used to identify nonconformities together with the risk of their occurrence. The method is used to determine the risk assessment arising during production, management, organization planning, etc. of given products or processes. The FMEA method works best during implementation processes, planning processes, optimization elements, or improving unstable processes. The goal of the FMEA method is to systematically identify and recognize likely product or process incompatibilities. Then, take a step that minimizes the risks associated with them, and identify the factors that most threaten the success of the product/process [11].

2. Research goal and methodology

The FMEA method is designed to detect defects at the earliest stages of the process. The FMEA method is based on the analysis of factors that may affect the process under investigation and relate to process methods, instrumentation, and environmental impact along with the definition of control measures [12, 13].

The first stage of the FMEA method concerns the selection of operations that should be analyzed along with the definition of the scope of the analysis. The number of parts and levels of the method depends on the complexity of the process [14].

The second stage consists in specifying the activities related to the FMEA analysis. First of all, potential defects that can occur in the analyzed case should be defined. After determining the sequence of events, cause-defect-effect, each defect should be assessed with an integer ranging from 1 to 10, taking into account three criteria: risk, possible occurrence of a defect, and cause [15].

The final stage of risk analysis using the FMEA method describes the elements in which changes should be made to reduce the risk of defects.

Research is based on the use of FMEA risk analysis in supply chain management in the heavy industry sector. The research lasted from 2016 to 2019. Nine business entities involved in steel production, trade, and processing were subject to examination. The entities were divided into three groups, and each group included three economic entities. The first group concerned steel companies. The headquarters of the enterprises are located in Poland, the Netherlands, and Germany. The next group concerned enterprises dealing in steel trade in Poland. The last group of enterprises is engaged in steel processing. Based on the industry analysis and intelligence in business entities, FMEA risk analysis has been developed [14]. In the studies presented, the FMEA analysis concerns industry analysis, not the process or product so far. This is an innovative use of FMEA risk analysis. No risk analysis has yet been developed for the industry in the context of supply chain management.

3. FMEA risk analysis

The FMEA analysis (**Table 1**) covers such areas of activity of the heavy industry sector as technological, time, location, political and legal, economic, social, and environmental area. Determinants affecting supply chains in the heavy industry sector were subjected to risk analysis.

Table 1 presents all aspects that may affect supply chain management in the heavy industry sector. In the table above, individual areas of activity of business entities involved in the flow of goods in the heavy industry sector have been analyzed. The potential type of defect was defined along with its effect. The probability of occurrence of a defect is determined on a scale of 1–10. The value of 1 is assigned to an unlikely situation, while 10 to a very likely situation. The details of the value assignment are set out in **Table 2**.

The next step is to determine the cause of the defect along with determining its value. Also in this case, the cause of the defect is determined on a scale of 1–10. The value of 1 is assigned to an improbable situation and 10 to a very likely situation. The details of the value assignment are set out in **Table 3**.

In the next step, you need to specify preventive measures and estimate the detection parameters, based on **Table 4**.

The final stage of FMEA analysis is the assignment of the RPN parameter. Assigning the above parameters to the FMEA spreadsheet allows you to specify the priority number of RPN risk, which is calculated according to the following formula:

$$RPN = Meaning (I) \times Occurrence (P) \times Detection (D)$$
(1)

RPN makes it possible to determine which threats carry the highest risk and the hierarchy in which order preventive actions should start.

FMEA analysis is a method of identifying and preventing problems related to the analyzed process before its implementation. It is focused on preventing process or product defects, increasing process security, financial security of the project, work safety, and environmental protection [14]. FMEA analysis is carried out at the design stage of the process or product to avoid the biggest threats and flaws in the implementation phase. This is an important technique for identifying and eliminating potential defects and errors in processes and products.

4. Conclusion

The research aimed to show the sources of risk in supply chain management in the heavy industry sector. During the analysis, RPN = 100 was determined below which the impact of factors on supply chain management is insignificant. For the industry studied, the greatest impact of risk on supply chain management has social aspects, primarily related to the lack of qualified staff, an increase in labor costs and social benefits, and the need to meet staffing needs with foreign personnel. Further aspects affecting supply chain risk management include an increase in energy and raw material prices, business relationships with customers, expansion of emerging markets, and reduction of spatial barriers.

КРИ	42	(4 V	280	288	192	168	70	48	32
Detection	7		~	8	8	8	7	5	4	4
Preventive measures	Analysis of the current machine park and	process factures in terms of implementing innovations. Economic analysis of the implementation of innovations		Getting new customers. Negotiating new rates for purchasing raw material. Increasing the number of suppliers	Getting new customers. Negotiating new rates for purchasing raw material. Increasing the number of suppliers		Extending the sales and purchasing offer to other countries	Transfer of the workplace. Acquiring suppliers from the local enterprise environment		1
Occurrence	7		N	2	9	3	9		4	4
1 1	Difficulties with implementing innovations Lack of patience of the management regarding the effects of implemented innovations	High costs of implementing innovations	Employees' concerns related to implementing innovations No interest in new technological solutions	More attractive supplier offer from the emerging market	Distraction of employees. Too little employee involvement. Employee overload. Hiring employees with insufficient skills and experience		Accession of the country to the economic union	Location of the plant in an area underdeveloped in economic terms		
Reaning	3		m l	~	9	8	4	2	3	2
Potential effect of the defect	Loss of capital	Lack of technological	development of the organization	Increased competition Loss of customers	Loss of potential customer	Loss of customer	Increased competition	Lack of access to seaports, river, air ports, roads, highways, rail networks	Lack of adequate transport or communication network	Bad condition of the road
Potential type of defect	Incorrect implementation of innovations	Lack of orientation of the organization on innovative activities	Lengthening during the implementation of innovative investments	Emerging markets expansion	Too late response to customer queries and wishes	No response to customer inquiries and wishes	Reduction of spatial barriers	Transport network		
Area		L Majogan	ТээТ		əm	ïT '		ation	zilsəc	PI

	network							
Limited spatial mobility	Lack of suitable transport rolling stock	4	No business entity investment in transport means	2	Using the services of shipping companies	6	72	
Lack of qualified labor force	Staff shortages	~	Unemployment. Migration of population.	8	Employment of foreigners	5	112	
	Lack of appropriate staff	~	High level of emigration. Aging of the society.	10		1	70	
	Hiring employees with insufficient qualifications, exnerience and skills		LAUN ULIADUL III WULINIIS ASC	6		3	189	
Changes in global markets	Financial crisis	5	International economic situation. Conflicts between countries	5	Transfer production to stable areas of the world	3	30	
Changes in the stock exchange listing	Loss of potential shareholders	4	Crisis on global stock exchanges. Company bankruptcy. Speculative bubble	3		0	24	
Exchange rate changes	A drop in the value of shares	0	4 4	2		6	24	
	The inflow of external capital	3		3		5	45	
	Inflation	3		5		5	30	
Changes in legal and social relations	Unfavorable legal and social relations	4	Professional groups strikes. Social policy of the state	5		4	80	
Changes in tax rates	Unfavorable tax regulations		Income load					
Changes in tax regulations	Lack of funds for enterprise development	Ŋ		~		ŝ	105	
No possibility of assistance from public funds	Rejection of the application for investment co-financing	2	No public funds for the area. Lack of classification of the entity to obtain assistance	5		5	50	
-	Insufficient funds for the investment	1	from public funds. Insufficient pool of public funds. Insufficient reasoning in requesting	7		~	49	
	Lack of adequate transport or communication network	1	assistance. No proper support program available	6	Acquiring new contractors, new production orders	8	72	
	Lack of creditworthiness	4		6		5	48	
Changes in economic	Inability to repay the loan	3	Other credit obligations. Loss of production	2		5	12	
conditions	The need to introduce	-	orders. Enterprise debt	-		6	0	
	foreign capital	-		-		J	4	
Unfavorable policy of state	administration	1	Lack of understanding of the situation by	8		9	48	
authorities towards enterprises	Complicated and time- consuming administrative procedures	0	state administration offices. Handling specific and rigid procedures	6	Joining the business association	3	54	
		1						
	Limited spatial mobility Lack of qualified labor force Changes in global markets Changes in the stock exchange listing Exchange rate changes Exchanges in tax rates Changes in tax rates from public funds from pu		network Lack of suitable transport rolling stock Staff shortages Lack of appropriate staff Hiring employees with insufficient qualifications, experience and skills Financial crisis Enaction of appropriate staff Hiring employees with insufficient qualifications, experience and skills Financial crisis Enancial crisis Financial crisis Ioss of potential shareholders A drop in the value of shareholders A drop in the value of shares The inflow of external capital Inflation Unfavorable legal and social relations Unfavorable tax regulations Lack of funds for enterprise development Rejection of the application for investment Lack of adequate transport or communication network Insufficient funds for the investment Lack of adequate transport or communication	networknetworkLack of suitable transport4Lack of appropriate staff7Lack of appropriate staff7Lack of appropriate staff7Hiring employees with insufficient qualifications,7Financial crisis5Financial crisis5Loss of potential3Financial crisis3Inflation3Unfavorable legal and4Social relations2Inflation3Unfavorable legal and4Social relations2financial crisis3Unfavorable legal and4Social relations2for investment1Inflation3Unfavorable legal and4Social relations2for investment1Inflation3Unfavorable tax regulations1Inflation3Unfavorable tax regulations1Inflation3Unfavorable tax regulations1Inflation1Insufficient funds for enterprise1Insufficient funds for enterprise1Insufficient funds for the application1Insufficient funds for the application3for investment1Insufficient funds for the application1Insufficient funds for the application1Insufficient funds for the application1Insufficient funds for the application1Insufficient funds for the applic	network network Lack of suitable transport 4 No business entity investment in transport Lack of suitable transport 4 No business entity investment in transport Staff shortages 7 Unemployment. Migration of population. Lack of appropriate staff 7 Unemployment. Migration of population. Itining supployes with 7 Unemployment. Migration. Aging of the society. Itack of appropriate staff 7 Lack of labor in working age insufficient qualifications, 5 International economic situation. Conflicts Experience and skills 5 between countries Lack of labor in working age Loss of potential 4 Denomic situation. Conflicts Denomic situation. Conflicts Lack of the society. 2 Crisis on global stock exchanges. Company shareholders Denomic situation. Conflicts Lack of tractal 3 Drivorable staft 1 Denomic situation. Conflicts Unfavorable legal and 2 Crisis on global stock exchanges. Company shares. Social policy of shareholders Lack of the state Unfavorable legal and 3 Professinal groups strikes. Social po	network network Lack of suitable transport 4 No business entity investment in transport 2 Valid shortages 7 Unemployment. Migration of population. 8 Eack of appropriate staff 7 Unemployment. Migration. Aging of the society. 10 Hiring genolyces with insufficient qualifications, 7 Unemployment. Migration. Aging of the society. 8 Financial crisis 5 between countries 9 9 Lack of labor in working age Lack of labor in working age 9 9 Financial crisis 5 between countries 2 2 Loss of potential 4 bankruptcy. Speculative bubble 2 2 Morpin the value of 3 Adropin the value of 5 2 Inflation 3 Inflation 4 the state 2 Unfavorable legal and 4 the state 5 2 Unfavorable tax regulations 5 development 7 Reveation 4 the state 5 development	network network Listing of suitable transport 2 Using the services of shipping companies Lakef shortages 7 Unpublic formation of the society. 10 Lakef shortages with 7 Unpublic formation of the society. 10 Hithing employees with 7 Unpublic formation of the society. 10 Hithing employees with 7 Unpublic formation of the society. 10 Ethancial crisis 5 between countries it and the society. 2 World Lass of potential 4 4 between countries it and the society. 2 10 Lass of potential 1 A trop in the society. 10 2 10 Lass of potential 2 2 World 2 10 Lass of potential 3 2 2 Atop in the society. 1 2 2 Atop in the society of the society of the area. Lack of a transformer countractors. 2 Atop in therestice 1 2	Intervolution Intervolution Distinguistic of stringbing companies 9 Staff shortages 7 Unsupply investment. Migration of population. 8 Employment of foreignets 2 Barff shortages 7 High physics 7 Unsupplying companies 3 Lack of appropriate staff 7 High physics 8 Employment of foreignets 2 Hinding employees with 7 High physics 9 Employment of foreignets 2 Ethandcient and skifts 5 High physics 9 Employment of foreignets 2 Ethandcient and skifts 4 Chisto in working age 0 9 2 2 Loss of potential 4 Chisto foreignets 2 2 2 2 Aldrop in the value of 2 Particupters 3 2 2 2 2 Aldrop in the value of 2 Particupters 2 2 2 2 2 2 2 2 2 2 2 2 2

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2 48	2 24	1 24	3 12	4 360	4 144	9 288	2 98	3 126		3 45	3 36	5 105	-
Starting cooperation with new suppliers	Use of outsourcing. Signing a contract with a subcontractor		Acquiring strategic investment and implementing smaller production orders		Breaking cooperation	Development of customer service standards. Hiring the right people to contact customers. Staff training	Analyzing projects with department managers and production employees	Improving the information flow process	Confirmation of payment and economic credibility of the customer		Checking the quality of delivered goods. Change of supplier	Control of manufactured products	
6	4	4	2	10	6	8	7	7		5	4	с С	
Low attractiveness of enterprises abroad	100% production in one place	Sales regress	Directing production only to one specific type of product and cooperation with only one final customer	Increase in prices of energy, raw materials, labor costs	Competition development, globalization	Disregarding the customer, improper customer service, lack of developed and implemented customer service standards	Lack of communication between the management and the lowest level employees	Interference during the information flow		Too much trade credit	Poor quality of purchased goods and services Poor quality of goods and services sold	The impact of globalization, a decrease in the share of international investments, the long- term nature of investments, changes in international economic conditions	
4	3	9	5	6	4	4	7	9		3	3	~	
Lack of support from government institutions for scientific research and production development	Increased competition	Low export rate	No strategic transactions carried out	Low level of profitability of production	Unfair commercial practices	Loss of customer	Loss of employees	Bad quality of information flow	No payment within the prescribed period	Counterparty's bankruptcy Too much debt of the organization Payment period too long	Breaking relations with the supplier No supply source	Loss of customer	
Low innovation of the economy	Degree of concentration of production	Export Rate	The level of strategic transaction execution	Costs increase	Competitiveness Policy	Business relations with clients	The quality of communication	Information flow quality	Customer insolvency		The quality of purchased goods and services	Quality of goods and services sold	-
	Lack of support from government institutions for scientific research and production developmentLow attractiveness of enterprises abroad6Starting cooperation with new suppliers2	Lack of support from government institutions for scientific research and production developmentLow attractiveness of enterprises abroad6Starting cooperation with new suppliers2scientific research and production development100% production in one place4Use of outsourcing. Signing a contract2	Lack of support from government institutions for scientific research and production development4Low attractiveness of enterprises abroad be6Starting cooperation with new suppliers 22Increased competition3100% production in one place4Use of outsourcing. Signing a contract with a subcontractor2Increased competition6Sales regress4Use of outsourcing. 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N ir ir irvestment	No participation in						
	international investments	9	Giobalization, imperfection of manufacturing processes, low quality of manufactured components, various cultural conditions affecting the production process, communication problem and changing time zones, long transport time	7		5	210
ion fragmentation	No possibility for fragmentation of production	n	Poor quality of purchased goods and services	4		4	48
capacity N	No international division of labor is possible	4		5	cooperation with international contractors who are able to provide the	4	32
Access to international raw L materials, capital and la	Lack of access to the global labor market and sales	9		2	required quanty of goods	2	60
esources f storage of the	market Too large inventory	∞		~		9	336
	Steel oversupply	L	Global steel overproduction	9		4	168
Steel supply \overline{V} tr	Volatility of energy and transport prices	8	4	10		- 7	160
Degree of production P profitability st	Price discrepancy between steel and raw material price	2	High level of raw material prices. Steel unprofitability.	9		2	24
cy of mining	Inability to meet demand	3	T ave 1 ave a dama and a	e C	Searching for new deposits of raw	4	36
Inaccurate estimates of D mine life	Depletion of resources	1	row rever of deposits	1	material	<i>ი</i>	с С
Drilling failure L	Loss of raw material	5	Errors during drilling processes	5	Toilum and weight Inn and in a competition	3	12
Errors during production F. processes 0	Failure to complete the order	5	Loss of capital. Loss of customer	5	ranure analysis, miprementing corrective actions	5	8
Export Capabilities C tr	Changes in the steel mill's trade policy	8		4		5	64
E	Embargo	L	Lack of conviction to export goods. Too much competition. Temporary or permanent ban on the event of moods	y	Verification of foreign contractors. Acquiring opinions about a contractor in	c	
		c		>		N	8
Steel Import	Material losses	4	Increasing costs of raw material extraction.	7		3	84
II	Increase in transport costs	3	Too low prices for steel and iron ore. Chronic	8		3	72

Supply Chain FMEA Risk Analysis for the Heavy Industry Sector DOI: http://dx.doi.org/10.5772/intechopen.91042

	Steel price increase	4	low steel and iron ore prices	9		3	108
	The use of steel substitutes	6	Development of competition of other	8	Acquiring new quetomore Accortment	2	96
Decrease in steel demand	Loss of customers	9	attractiveness of other materials	8	flexibility. The rate at which primary	2	144
Seasonality of sales			Loss of standing production orders		production is transformed		
Addiction to suppliers	potential supplier Production stoppages	1	Supplier's bankruptcy. Delays in the implementation of supply orders. No constant flow of raw material. Supply order execution	7	Securing the source of supply from several suppliers	5	35
	Loss of production orders	1	problem with a potential new supplier	3		4	12
	Loss of a key customer						
Relationship with entities	Loss of subcontractor		Too much trust No lovalty Business fraud	1		6	18
Telutionship with entities	Transfer of production to Asian markets		100 much frust. No toyarty. Dusiness fruud	1			
	Loss of regular customers	6	Global steel overproduction. The inflow of	10		2	120
The impact of globalization	Price drop	2	raw material from Asian markets. Low price	2		2	8
	Material losses	3	level. Low quality	4		3	36
	Increase in transport costs						
The amount of the minimum wage		9	Loss of price attractiveness on the international and national arena. Increase in prices of manufactured products	10		6	540
	Labor cost increase						
Environmental degradation	Adaptation of production plants to strict restrictions and environmental regulations High penalties for non- compliance with environmental regulations Inability to adapt production plants to environmental requirements	2	Steel cost increase. The need to modernize the workplace to meet environmental standards. High investment costs. Lack of government programs supporting the adaptation of workplaces to environmental conditions.	6	Gradual adaptation of the workplace to environmental standards	3	36
	Addiction to suppliers Addiction to suppliers Relationship with entities The impact of globalization The amount of the minimum wage	Decrease in steel demandThe use of steel substitutesSeasonality of salesLimited cooperation with a potential supplier Production stoppagesAddiction to suppliersLoss of production ordersRelationship with entitiesLoss of a key customer Loss of subcontractor Transfer of production to Asian marketsThe impact of globalizationDiscover and the second Price dropThe amount of the minimum wageIncrease in transport costsThe amount of the minimum wageLabor cost increase Adaptation of production plants to strict restrictions and environmental regulationsEnvironmental degradationHigh penalties for non- compliance with environmental regulationsInability to adapt production plants to environmentalHigh penalties for non- compliance with environmental regulations	Decrease in steel demandThe use of steel substitutes6Decrease in steel demandLoss of customers9Seasonality of salesLimited cooperation with a potential supplier Production stoppages1Addiction to suppliersLimited cooperation with a potential supplier Production stoppages1Relationship with entitiesLoss of production orders Loss of subcontractor Transfer of production to Asian markets3The impact of globalizationLoss of regular customers Price drop6The amount of the minimum wageIncrease in transport costs3The amount of the 	Decrease in steel demandThe use of steel substitutes6 bDevelopment of competition of other materials. 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 Table 1.

 FMEA analysis sheet for the industry studied [own study].

Supply Chain FMEA Risk Analysis for the Heavy Industry Sector DOI: http://dx.doi.org/10.5772/intechopen.91042

Ι	Importance	FMEA services/constructions
1	Unbelievable	An imperceptible impact on the service
2–3	Little	The defect is small and has little impact on customer satisfaction
4–6	Average	Average defect, felt customer dissatisfaction
7–8	Important	The defect happens cyclically and has a big impact on customer dissatisfaction
9–10	Extremely important	An extremely important defect, which affects further work, safety and is contrary to the law

Table 2.

Determining the significance of the occurrence of a defect [own study].

Р	Probability of occurrence of a defect	FMEA service/construction/process
1	Unbelievable	No defect can occur
2	Very low	Very low probability of occurrence of a defect. Defects occur individually and very rarely
3	Low	Low probability of occurrence of individual defects
4–6	Average	Defects occur on average in small quantities
7–8	High	Disadvantages occur very often
9–10	Very high	Very high probability of a defect

Table 3.

Determining the probability of occurrence of a defect [own study].

D	Detection	FMEA service/construction/process
1–2	Very big	Some defect detection
3–4	Large	The chances of detecting a defect are high, a test or functional check is used
5–6	Average	Defect control can detect average detectability
7–8	Small	Defect detection difficult
9–10	Very small	Detection of a defect is difficult or impossible to detect

Table 4.

Determining the probability of detection [own study].

Risk analysis has been created for a specific industry. Based on the analysis, the values included in **Table 1** have emerged. The RPN value presented in **Table 1** identifies the greatest threats to the process under study. A detailed analysis of all RPN values above 100 identifies the greatest threat to supply chain management in the heavy industry sector. At the same time, analyzing the results contained in **Table 1**, you can simultaneously create and implement appropriate preventive measures described in the column "Current preventive measures in the process." Disregarding the results of risk analysis using the FMEA method may lead to negative effects on the functioning of enterprises operating within the analyzed supply chain.

The FMEA risk analysis itself can be used for different cases. The studied problem concerns threats and uncertainty in the supply chain in the heavy industry sector. Each risk analysis based on a given problem is individual. Risk factors may vary on each enterprise that is technologically similar, and it is not possible to use risk analysis prepared for entity A for entity B. Even more, the risk analysis considered in the context of one industry may differ for other industries. The impact of risk factors may be the same in some respects, but it will be different even if it is personal or environmental. Risk analysis is always created with a specific enterprise, process, product, or industry in mind. The scheme of risk analysis using the FMEA method can be used for each individual problem.

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