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Analysis of supply chain risks by structural equation model and fuzzy analytical hierarchy process

Tedarik zinciri risklerinin yapısal eşitlik modeli ve bulanık analitik hiyerarşi süreci ile analizi

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Abstract

Supply chain risk management activities attempt to eliminate or minimize the effects of risks that businesses face or may encounter within the scope of supply chain activities. The main aim of this study is to define, decide, and prioritize the supply chain risk factors. In the content of the study, first, supply chain risks from the literature were gathered and then the obtained risks were grouped and combined and a summary risk table to be considered in the study was created. Second, a questionnaire was created to evaluate the risks in the created risk table, and evaluations were received from 391 users. According to the collected results, the main risks were evaluated statistically with the help of the Structural Equation Model (SEM), and then sub-risks were prioritized by the Fuzzy Analytical Hierarchy Process (Fuzzy AHP) method according to the model results. With the help of obtained results, action plan suggestions were developed for individuals and/or businesses in the supply chain over prioritized risks. Pareto Analysis was used to determine which of the sub-risks hosted by the main risks and the sub-risks will be included in the action plan. According to the results of the study, supply and demand risks are obtained as the most important main risks; procurement cost; frequency of material design changes, inaccurate demand forecasts, risks arising from supplier, risks arising from the costumer, transit time variability risks are identified as the most important sub-risks in the action plan.

Keywords: Supply chain risks, Structural equation model, Fuzzy, Analytical hierarchy process, Pareto analysis.

Öz

Tedarik zinciri risk yönetimi faaliyetleri, işletmelerin tedarik zinciri faaliyetleri kapsamında karşılaştıkları veya karşılaşabilecekleri riskleri ortadan kaldırmaya veya en aza indirmeye çalışır. Bu çalışmanın temel amacı tedarik zinciri risk faktörlerini tanımlamak ve önceliklendirmektir. Çalışmanın içeriğinde ilk olarak literatürden tedarik zinciri riskleri elde edilmiş, daha sonra elde edilen riskler gruplandırılmış ve birleştirilmiş ve çalışmada dikkate alınacak bir özet risk tablosu oluşturulmuştur. İkinci olarak, oluşturulan risk tablosundaki riskleri değerlendirmek için bir anket oluşturulmuş ve 391 kullanıcıdan değerlendirmeler alınmıştır. Toplanan sonuçlara göre temel riskler, Yapısal Eşitlik Modeli (YEM) yardımıyla istatistiksel olarak değerlendirilmiş ve model sonuçlarına göre Bulanık Analitik Hiyerarşi Süreci (Bulanık AHP) yöntemi ile alt riskler önceliklendirilmiştir. Elde edilen sonuçların yardımıyla, tedarik zincirindeki bireyler ve/veya işletmeler için öncelikli riskler konusunda eylem planı önerileri geliştirilmiştir. Eylem planına dahil edilecek ana riskler ve alt risklerden hangilerinin barındırdığını belirlemek için Pareto Analizi kullanılmıştır. Çalışmanın sonuçlarına göre, en önemli ana risk olarak arz ve talep riskleri olarak belirlenirken; satın alma maliyeti; materyal dizayn değişiklikleri; düzensiz talep tahminleri; tedarikçi kaynaklı riskler; transit zaman değişkenliği; müşteriden kaynaklı riskler; kısıtlı teslimat zamanları ve ürün yaşam döngüsü riskleri eylem planında en önemli alt riskler olarak belirlenmiştir.

Anahtar kelimeler: Tedarik zinciri riskleri, Yapısal eşitlik modeli, Bulanık analitik hiyerarşi prosesi, Pareto analizi.

1 Introduction

The supply chain is rapidly transforming into a complex structure in global markets [1]. Supply chain risks cause some disruptions [2]. We need to manage these risks. Supply chain risk management aims to reduce the likelihood of risks occurring and to ensure that risks are managed most properly. Therefore, it ensures the resolution of raw material waste, production errors, and events that can lead to important results [3]. Corporate reputation, decrease in debts, employee health and safety, decrease in costs, legal compliance, efficient supplier and customer relationships are defined as some of the advantages that can be achieved with effective supply chain risk management. For companies to survive in a competitive environment, they must recognize the risks they face or will face during the supply chain process. Since supply chain risks are defined as the negative deviation in the results of a performance measure determined for an organization [4]; successful execution of supply chain risk management depends on identifying risks and minimizing the effects of identified risks. However, after the risks are defined in the supply chain processes, they need to be prioritized to create action plans. Since it is not possible to handle all the risks in the processes at the same time due to resource, budget, and labor constraints, it is important to handle the prioritization analysis with a correct approach.

In the literature, there are studies to define supply chain risks and to create strategies for identified risks. Needham and Evers [5] provided an approach to analyze the costs resulting from risk management practices and their suitability. In this study, the simulation method and meta-model were used. Chopra and Sodhi [6] studied supply chain risks and risk management by identifying supply chain risks, they researched to prevent their destructive effects on the supply chain. In the study of Kleindorfer and Saad [7], the aim was to evaluate the risks arising from factors such as natural disasters, strikes, economic

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failures, and terrorist attacks in the US Chemical Industry and present a conceptual study on risk reduction activities. With this study, the effects of risks on the supply chain risk management system are investigated. Gaudenzi and Borghesi [8] provided a method to assess supply chain risks affecting the supply chain. Supply chain risk factors were identified by the AHP method. Besides, a case study was applied in this study to raise awareness of supply chain risk factors. Wu et al. [9], identified supply chain risk factors with a comprehensive literature review and several industry interviews and classified them hierarchically, using the AHP method to sort these risk factors. Finally, a prototype computer application was developed and tested in the industry. Manuj and Mentzer [10], aimed to explore the concept of risk management and risk management strategies in global supply chains. The study included a comprehensive literature review and a qualitative study with interviews.

The study explained determining risk management strategies regarding environmental conditions. Schoenherr et al. [11] aimed to review the process used by a U.S. manufacturing company to evaluate supply chain risks and to combine the supply chain risks with the AHP approach. Also, this study contributed to making decisions in uncertain conditions. In the study of Tsai [12], the risks of cash flow related to the supply chain for a business with deviations in cash inflows, outflows, and net flows were measured. The purpose of this study was to identify the risks that affected the cash conversion cycle to get discounts with early payment. Tuncel and Alpan [13], aimed to present how a timed Petri networks framework could be used to model and analyze a supply chain (SC) network that was exposed to various risks.

The study showed that the system performance could be improved through risk management activities and overall system costs could be reduced through mitigation strategies. Wagner and Neshat [14] tried to measure and reduce the supply chain vulnerability in their research with a method based on Fuzzy graphic theory. The research contributed to the literature on reducing supply chain vulnerability and risk mitigation strategies. Tummala and Schoenherr [15] proposed a comprehensive approach in their research to assess and manage risks in supply chains. They also guided how to make the most appropriate decision in the supply chain risk management process. Samvedi et al. [16] measured the risks in the supply chain and collected these risks in a generalized risk study.

For this study, the fuzzy analytical hierarchy process (F-AHP), a fuzzy technique, and the technique for order preference by similarity to an ideal solution (TOPSIS) methods and techniques were used. Mangla et al. [17], attempted to determine supply chain risks with the fuzzy AHP method to take precautions against risk categories and specific risks known in the green supply chain before risks can occur. In recent years, studies on supply chain risks have increased and analytical approaches on identified risks have contributed to both the literature and the businesses [18]-[30]. The supply chain risks in the studies specified in the literature were handled collectively and collected under the main headings and used in this study and presented in Table 1.

The main aim of this study is to define, decide, and prioritize the supply chain risk factors. Based on the purpose, firstly supply chain risks from the literature were gathered and then the obtained risks were grouped and combined and a summary risk table to be considered in the study was created.

Table 1. Classification of supply chain risks used in the study.

Summary of Risks	
Supply Risks	Manufacturing Risks
T1. Procurement cost risks	**P1.** Inadequate manufacturing or processing capability and flexibility
T2. Frequency of material design changes	**P2.** Changes in technology machine and design
T3. Global outsourcing	**P3.** Equipment or facility failure
T4. Transit time variability	**P4.** Risks arising from the employee
T5. Monopoly	**P5.** Cost of capacity, product, and inventory
T6. Risks arising from the supplier	**P6.** Linked phases in manufacturing
T7. Technology uncertainty and changes	**P7.** Technical/knowledge resources
	P8. Risks arising from the product
	P9. Working conditions
	P10. Risks arising from inventories and warehouses
Demand Risks	Financial Risks
TL1. Inaccurate demand forecasts	**F1.** Financial and insurance restrictions
TL2. Risks arising from the customer	**F2.** Inflation and currency exchange rate
TL3. Short lead times and product's life cycle	**F3.** Financial risks arising from the customer
TL4. Inadequate customer relation management	**F4.** Low-profit margin
TL5. Risks arising from competition and competitor	**F5.** Market growth and size
TL6. Low in-house production	**F6.** Wage rate shifts
	F7. Product costs
	F8. Inaccurate finance, accounting, and payment plan management
Macro Risks	Transportation Risks
M1. Nature disasters, infectious outbreaks	**L1.** Risks arising from transportation mode
M2. War, terrorism, and fire accidents	**L2.** Accidents and damages in transportation
M3. External legal issues	**L3.** Working condition
M4. Political/economical and regional instability	**L4.** Lack of training
M5. Government regulations	**L5.** Old technology
M6. Social and cultural complaints and dissatisfaction	**L6.** Risks arising from transportation management
	L7. Port strikes, attacks, and theft
Information Risks	
B1. System integration or extensive systems networking	
B2. Internet security	
B3. Lack of compatibility and communication in IT platforms among supply chain partners	

In the next step, a questionnaire was created to evaluate the risks in the created risk table, and evaluations were received from a certain number of users. According to the collected results, the main risks were evaluated statistically with the help of the Structural Equation Model (SEM), and then sub-risks were prioritized by multi-criteria decision-making methods according to the model results. With the help of obtained results, action plan suggestions have been developed for individuals and/or businesses in the supply chain over prioritized risks. This study proposes an action plan according to the order of importance of the risks faced by businesses by considering the main and sub risks of the supply chain in the literature. The question "What are the main and sub-supply chain risks that businesses should pay attention to and what should they do to prevent them?" was determined as the main research question of the study. The fact that the studies related to supply chain risks do not follow a holistic approach and ignore many risks in the literature makes this study important and effective. The implementation of the analyzes with a general-to-specific approach has based the foundation of the study on solid evaluations.

Creating an integrated risk table compiled from literature and analyzing them in an integrated way with SEM and fuzzy MCDM (multi-criteria decision-making) adds a unique and holistic value to supply chain risk management studies in the literature. Hereby, it is intended to make contributions to the literature on goals, motivation, and variety.

2 Materials and methods

Information on the basic materials of the study and the methods used in the study are given in this section.

2.1 Materials and data set

The main material of this study consists of employees of enterprises with a supply chain structure in Turkey. It was decided to collect data based on the employees working in any of the supply chain steps for the study.

For this study where the determination and prioritization of the risks included in the supply chain were examined, 412 business employees were surveyed. A total of 47 questions compiled from the literature were asked to these employees. For the questions, the 5-point Likert scale (1: Absolutely Disagree to 5: Totally Agree) was taken as a basis and the answers were compiled according to this scale. When the questionnaires were evaluated, it was decided to continue with 391 out of 412 surveys in total. The sample size can be determined through some calculations. If the taken sample cannot represent its universe, then errors occur in the results and analysis [31]. An adequate sample is a sample that includes enough elements to provide reliable results [32]. The sample size is calculated with the standard error formula via the central limit theorem [33]. The sample size was determined as 380 according to the calculations in the literature [33]. Hence sample size is determined to adequate for this study to continue for further analysis. The collected data were recorded with MS Excel and some pretreatments were performed for statistical analysis. The 391 data, which contained the main body of the study, were categorized and the answers given by the users of these categories were saved in an MS Excel file separately. All respondents are part of the supply chain as white-collar personnel. Descriptive statistics of the samples are as follows; 45.52% of the respondents were Women while 54.48% were Men; 65.22% of the respondents were under 35 years old while the rest of them are over 35 years of age; 29.67% of the respondents have an Associate degree and Less while the rest of them have a Bachelor's Degree and More and 43.48% of the respondents have more than five years of supply chain experience while the rest of them have less than 5 years of experience.

Before the analysis, to assess the admissibility of the questionnaire Cronbach's Alpha coefficient was calculated as 0.950. The collected data is categorized to correctly process the data of the study, to use it, and to interpret the results. 391 data, which constitutes the main sample of the study, is categorized and the answers given by users of these categories are kept in MS Excel file separately. IBM SPSS Statistics 21 and IBM SPSS AMOS 22 were used for statistical analysis. Fuzzy AHP was carried out using MS Excel 2010. Descriptive statistics of the sample of the study are presented in Table 2.

Table 2. Sample characteristics.

Categories		Percentage of Sample	Sample Size
Gender	Women	45.52%	178
	Men	54.48%	213
Age	Under 35 Age	65.22%	255
	Over 35 Age	34.78%	136
Education	Associate's Degree and Less	29.67%	116
	Bachelor's Degree and More	70.33%	275
Experience	Less than 5 Years	56.52%	221
	Equal and More than 5 Years	43.48%	170

2.2 Methods

Within the scope of this study, SEM and Fuzzy AHP techniques have been used to compile, prioritize, and create action plans within the supply chain. Explanations about these methods used for data collection, statistical analysis, and prioritization are included in this section under the sub-headings.

2.2.1 Fuzzy analytical hierarchy process (F-AHP)

The AHP method is based on the conversion of qualitative expressions into quantitative results as a result of many steps and is a method that is frequently used in the literature. The related method was developed by Saaty in 1980 [34]. However, in the application of AHP, since the binary comparisons are performed by decision-makers and values to be selected are the exact values for comparisons, results become uncertain and non-objective [35]. Besides, classical AHP does not involve uncertainty of the decision maker's judgment. Therefore Fuzzy AHP approach is developed to reduce the negative effects of classic AHP by using fuzzy sets theory by Zadeh [36]. The reason for choosing Fuzzy AHP in this study is to better express verbal uncertainty in binary comparison judgments and increase the level of objectivity of decision-makers. Fuzzy AHP integrates the main AHP steps into the fuzzy domain by using fuzzy numbers in binary comparisons. Binary comparisons are made with linguistic variables by a triangular form [37]-[39],[35],[40]. The steps of the Fuzzy-AHP method is presented below [41];

i. Hierarchy construction: Hierarchy is formed similar to classic AHP,

ii. Binary comparisons: Comparisons between criteria are somehow similar to classic AHP but are performed with a triangular fuzzy scale according to their linguistic terms. Triangular fuzzy scale equivalents and linguistic explanations of classical AHP values are presented in Table 3,

iii. Calculation of normalized weights of the criteria: Geometric means of fuzzy comparison values are calculated in this step by using the equation of $r_i = \left(\prod_{j=i}^{n} d_{ij}\right)^{1/n}$ for each criterion.

iv. The relative fuzzy weight of each criterion calculation according to the values of the third step is performed in this step. Then, the normalized weights of each criterion are calculated by dividing each value of the relative fuzzy weight with the total of all criteria' values.

Table 3. Triangular fuzzy scale of AHP values.

The scale of Classic AHP	Linguistic Terms	Fuzzy Triangular Scale
1	"Equally Important"	(1, 1.,1)
3	"Weakly Important"	(2, 3, 4)
5	"Fairly Important"	(4, 5, 6)
7	"Strongly Important"	(6, 7, 8)
9	"Absolutely Important"	(9, 9, 9)
2		(1, 2, 3)
4	"Intermittent Values"	(3, 4, 5)
6		(5, 6, 7)
8		(7, 8, 9)

2.2.2 Structural equation model

Structural equation modeling, as a second-generation data analysis technique, is a complex structure model that allows systematic and comprehensive handling of a complex research problem in a single process by modeling the relationships between many dependent and independent variables [42],[43].

Structural equation modeling is a data analysis that is particularly successful in testing complex models, makes many analyzes at once, recommends new arrangements for the network of relationships in the model under study, facilitates to examine of the effects of mediation and moderation; It is a method used in the testing of many theories and the development of new models since it takes into account measurement errors. Structural equation models are a statistical technique used to test models that have causal relationships and correlation relationships between observed variables and latent variables. Also, it is a multivariate method for estimating dependency relationships, which is formed by combining analysis such as variance, covariance analysis, factor analysis, and multiple regression [44]. This method was preferred for this study since it is a holistic and integrated statistical data analysis approach. The most common method used in the structural equation modeling literature to evaluate whether the data supports the model is the two-step method [43]. In the analysis, first, the measurement model is tested [45] and it is checked whether the measurements of the structures in the model measure the related structures correctly. In the second stage, structural models are examined. If there is not a correct measurement in hand, it will not be meaningful to analyze the structural model.

3 Results and discussions

3.1 Findings of the structural equation model of the study

Within the scope of this study, the structural equation model has been established and hypotheses have been formed. Figure 1 represents the research model of the study. It has been investigated whether each major risk group has an impact on supply management risks and the effects of each sub-risk related to the main risk groups to the groups have been examined.

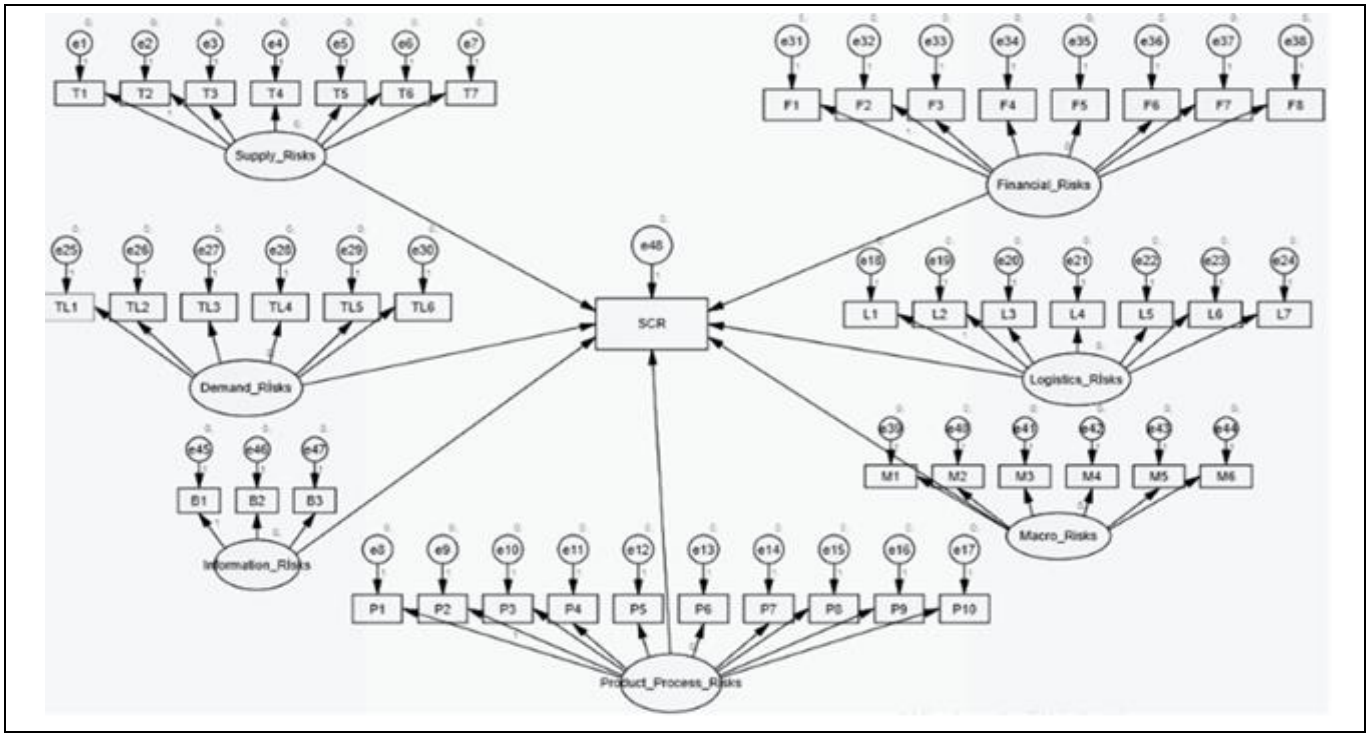

Figure 1. Research model and SEM of the study.

Risks, Financial risks, logistics risks, Macro risks, and Product/Process risks are selected as independent variables to measure and explain supply chain management risks (SCMR). According to the model, the main hypotheses are explained as follows;

H1 : There is a significant relationship between Supply risks and SCMR,
H2 : There is a significant relationship between Demand risks and SCMR,
H3 : There is a significant relationship between Information risks and SCMR,
H4 : There is a significant relationship between Financial risks and SCMR,
H5 : There is a significant relationship between Logistics risks and SCMR.
H6 : There is a significant relationship between Macro risks and SCMR,
H7 : There is a significant relationship between Product/Process risks and SCMR.

Along with testing all hypotheses, predictors of SCMR; correlation of independent variables are calculated in the research model with the help of SEM. Fit indices of the model are presented in Table 4 to reveal how the correct theoretical model fits the observed data.

Table 4. Fit Indices of research model.

Fit Index	Research Model	Recommended Value	Source
CMIN/df	2.753	<5.00	[46]
RMSEA	0.054	<0.06	[47]
NFI	0.956	>0.90	[48]
CFI	0.928	>0.90	[48]
IFI	0.929	>0.90	[48]

Table 4 presents that, all model fit indices satisfy recommended values according to literature values. Hence, the research model is considered that it has a good fit with the data collected. Hypotheses results are presented in Table 5. Results indicate that all hypotheses are supported and are significant.

Table 5. Hypotheses results

Hypotheses	Supported	Explanation
H1: (Supply risks and SCM Risks)	Yes*	Significant positive relationship
H2: (Demand risks and SCM Risks)	Yes*	Significant positive relationship
H3: (Information risks and SCM Risks)	Yes**	Significant positive relationship
H4: (Financial risks and SCM Risks)	Yes*	Significant positive relationship
H5: (Logistics risks and SCM Risks)	Yes*	Significant positive relationship
H6: (Macro risks and SCM Risks)	Yes**	Significant positive relationship
H7: (Product/Process risks and SCM Risks)	Yes**	Significant positive relationship
	*p<0.001; **p<0.05	

Covariances between independent variables are examined to reveal that the significance level of the relationships among independent variables. As can be seen in Table 6, defined covariance's are significant at 0.001 level. In Table 6, Supply Risks, Information Risks, Logistics Risks, Financial Risks, Product and Process_Risks, Demand Risks, Macro Risks are presented as #1, #2, #3, #4, #5, #6 and #7 respectively.

Table 6. Covariance significances.

Covariance Status	#1	#2	#3	#4	#5	#6	#7
#1	-	Yes*	Yes*	Yes*	Yes*	Yes*	Yes*
#2		-	Yes*	Yes*	Yes*	Yes*	Yes*
#3			-	Yes*	Yes*	Yes*	Yes*
#4				-	Yes*	Yes*	Yes*
#5					-	Yes*	Yes*
#6						-	Yes*
#7							-
*p<0.001; **p<0.05							

In Table 7, correlations among independent variables of the model are provided. The highest correlations are formed between supply and product/process risks; supply risks and demand risks; product/process risks and logistics risks; information risks and logistics risks; logistics risks and demand risks; product/process risks and demand risks; information risks and demand risks.

Table 7. Correlation results.

Correlations				Correlation Status
Supply_Risks	<-->	Financial_Risks	0.505	Moderate
Supply_Risks	<-->	Logistics_Risks	0.698	Moderate
Supply_Risks	<-->	Macro_Risks	0.416	Low
Supply_Risks	<-->	Product_Process_Risks	0.842	High
Information_Risks	<-->	Supply_Risks	0.582	Moderate
Supply_Risks	<-->	Demand_Risks	0.760	High
Logistics_Risks	<-->	Financial_Risks	0.564	Moderate
Financial_Risks	<-->	Macro_Risks	0.431	Low
Product_Process_Risks	<-->	Financial_Risks	0.614	Moderate
Information_Risks	<-->	Financial_Risks	0.384	Low
Demand_Risks	<-->	Financial_Risks	0.460	Low
Logistics_Risks	<-->	Macro_Risks	0.501	Moderate
Product_Process_Risks	<-->	Logistics_Risks	0.757	High
Information_Risks	<-->	Logistics_Risks	0.736	High
Logistics_Risks	<-->	Demand_Risks	0.700	High
Product_Process_Risks	<-->	Macro_Risks	0.496	Low
Information_Risks	<-->	Macro_Risks	0.420	Low
Demand_Risks	<-->	Macro_Risks	0.526	Moderate
Information_Risks	<-->	Product_Process_Risks	0.583	Moderate
Product_Process_Risks	<-->	Demand_Risks	0.755	High
Information_Risks	<-->	Demand_Risks	0.772	High

In the research model, the predictors of Supply Chain Risks explain 80,6% of its variance while the strongest predictors have resulted in Demand risks, Supply risks, Logistics risks, Product/process risks, Financial risks, Information risks, and Macro risks respectively. When the percentages of disclosure of main risks are calculated, Demand and Supply risks present the highest proportions as the total of fifty percent. To reduce the number of main risks to be examined for further analysis, Demand and Supply risks are selected since those risks are highly correlated items.

3.2 Risk assessment

According to the results of the hypotheses tested through the SEM established in section 4.2, since Demand and Supply Risks explained fifty percent of SCMR, it was decided to examine these two main risks for further analysis. In the literature section, sub-risks under the main risks were mentioned. To examine, prioritize, and further analyze the selected supply and demand risks, the explanations of related sub-risks and the problems they cause are defined in Table 8 to lay the groundwork for risk analysis.

Table 8. Definition and effects of the selected sub-risks.

	Risk Code	Selected Sub-Risks from SEM	Explanation of The Risks Created by The Sub-Risks
Supply Risks	T1	Procurement Cost	High purchasing costs can be associated with high raw material and shipping costs. In this case, the high cost of raw materials and auxiliary materials loaded as a direct cost to the produced goods increases the cost of the material and increases the cost of the produced goods. Thus, while the chance of competition for product sales decreases, profit margin decreases.
	T2	Frequency of Material Design Changes	The frequency of the material design change corresponds to the change in the design of the manufactured product. This leads to the constant change of the line of the machine where the goods are produced. This extra cost also brings an operational burden.
	T3	Global outsourcing	Global outsourcing causes the business to remain external. The arrival time of the goods is prolonged when there is an increase in the price of foreign sources or global crises. This extends product production time and causes customer dissatisfaction.
	T4	Transit time variability	The variability of the time in the supply of the material causes the material's adequacy to be calculated completely, which can lead to overstock or understock problems. From another point of view, the late departure of the product that goes to the customer may lead to customer dissatisfaction and this may lead to loss of sales.
	T5	Monopoly	Buying the monopoly-supplied goods in one place requires submission to the given price. In such a case, bargaining power is very low. Production costs increase with increasing material costs. Also, material supply may be delayed if the supplier experiences any problems.
	T6	Risks arising from supplier	Risks from the supplier can be defined as the risks such as wrongly choosing the supplier, late shipment of the supplier, wrong shipment, or incomplete shipment of the supplier. These risks create a direct or indirect cost to the business. Time, labor, production, and customer losses can occur.
	T7	Technology Uncertainty and changes	Continuous progress and development of technology lead businesses to unlimited competition. Trying to purchase new machines and equipment without paying for a newly developed technological product is an operational risk that causes businesses to exceed the costs they can bear.
Demand Risks	TL1	Inaccurate demand forecasts;	Incorrect demand estimation can lead to over or under-stock. It leads to loss of sales caused by inventory costs or inventory. From another point of view, due to incorrect or incomplete demand estimation, the quantity discount cannot be used or an appropriate shipping plan cannot be made.
	TL2	Risks arising from costumer	If the customer places an incorrect order and the company ignores the relevant order, it causes the stock to remain inactive. The delayed debt payment situations arising from the financial difficulties of the customers may hurt the business. Customers' requesting their orders before the delivery date may also cause other displacements in the production plan.
	TL3	Short lead times and product's life cycle	Short delivery times cause the product not to be given within the promised time in case of any setback. In this case, customer dissatisfaction may arise. Also, the short life cycle of the product requires the product to be produced in a short time. This can cause bottlenecks.
	TL4	Inadequate customer relation management	Inadequate customer relationship management can lead to wrong orders being received from the customer and the wrong product being produced. From another point of view, when the customer is not satisfied in terms of quality, the lack of an appropriate quality control procedure will lead to a loss of customers. The lack of customer management can negatively affect all supply chain processes from material demand forecasting to sales.
	TL5	Risks arising from competition and competitor	As competitors supply the goods cheaper as a result of supplying materials at low prices, the chance of competition may decrease. Or it reduces the chance of competing, who cannot analyze the market well. From another point of view, competitors can offer product flexibility to adapt to the market. If the company cannot produce such products, the market will remain on a limited product scale and remain weak in competition.
	TL6	Low in-house production	The fact that the product within the enterprise is limited, that is, the fact that the product produces many sub-materials from the outside brings foreign commitment. It cannot make a profit in terms of cost. Disruptions in the procurement process also bring about time, labor, raw material, and operational problems.

In order to prioritize among sub-risks, to eliminate which risk, or to minimize its impact, a risk analysis was carried out with the Fuzzy Analytical Hierarchy Process. The fuzzy AHP method was selected as an MCDM method to increase the objectivity levels of decision-makers. The binary comparisons among 13 sub-risks were scored by 5 different managers in the sample group and the scores averaged. Fuzzy AHP results are presented in the following tables. In Table 9, binary comparisons with triangular fuzzy scale are presented for all criteria.

In Table 10, normalized weights of the criteria are presented after performing all necessary calculations according to the Fuzzy AHP method that has been given in the relevant section.

Table 9. Binary comparisons with triangular fuzzy scale.

Criteria	T1	T2	T3	T4	T5	T6	T7	TL1	TL2	TL3	TL4	TL5	TL6
	(1	(2	(7	(4	(3	(5	(5	(2	(3	(3	(6	(7	(5
T1	1	3	8	5	4	6	6	3	4	4	7	8	6
	1)	4)	9)	6)	5)	7)	7)	4)	5)	5)	8)	9)	7)
	(1/4	(1	(7	(3	(3	(3	(3	(2	(3	(2	(7	(7	(3
T2	1/3	1	8	4	4	4	4	3	4	3	8	8	4
	1/2)	1)	9)	5)	5)	5)	5)	4)	5)	4)	9)	9)	5)
	(1/9	(1/9	(1	(1/4	(1/3	(1/5	(1/6	(1/5	(1/5	(1/5	(1	(1	(1/4
T3	1/8	1/8	1	1/3	1/2	1/4	1/5	1/4	1/4	1/4	1	1	1/3
	1/7)	1/7)	1)	1/2)	1)	1/3)	1/4)	1/3)	1/3)	1/3)	1)	1)	1/2)
	(1/6	(1/5	(2	(1	(1/3	(1	(2	(2	(1/3	(1/5	(2	(3	(2
T4	1/5	1/4	3	1	1/2	1	3	3	1/2	1/4	3	4	3
	1/4)	1/3)	4)	1)	1)	1)	4)	4)	1)	1/3)	4)	5)	4)
	(1/5	(1/5	(1	(1	(1	(1/5	(1/3	(1/5	(1/3	(1/3	(1	(2	(1/3
T5	1/4	1/4	2	2	1	1/4	1/2	1/4	1/2	1/2	1	3	1/2
	1/3)	1/3)	3)	3)	1)	1/3)	1)	1/3)	1)	1)	1)	4)	1)
	(1/7	(1/5	(3	(1	(3	(1	(5	(1	(1	(1/4	(4	(5	(2
T6	1/6	1/4	4	1	4	1	6	1	1	1/3	5	6	3
	1/5)	1/3)	5)	1)	5)	1)	7)	1)	1)	1/2)	6)	7)	4)
	(1/7	(1/5	(4, 5,	(1/4	(1	(1/7	(1	(1/3	(1/4	(1/3	(2	(2	(2
T7	1/6	1/4	6)	1/3	2	1/6	1	1/2	1/3	1/2	3	3	3
	1/5)	1/3)		1/2)	3)	1/5)	1)	1)	1/2)	1)	4)	4)	4)
	(1/4	(1/4	(3	(1/4	(3	(1	(1	(1	(5	(7	(3	(5	(1/4
TL1	1/3	1/3	4	1/3	4	1	2	1	6	8	4	6	1/3
	1/2)	1/2)	5)	1/2)	5)	1)	3)	1)	7)	9)	5)	7)	1/2)
	(1/5	(1/5	(3	(1	(1	(1	(2	(1/7	(1	(2	(3	(5	(2
TL2	1/4	1/4	4	2	2	1	3	1/6	1	3	4	6	3
	1/3)	1/3)	5)	3)	3)	1)	4)	1/5)	1)	4)	5)	7)	4)
	(1/5	(1/4	(3	(3	(1	(2	(1	(1/9	(1/4	(1	(3	(5	(2
TL3	1/4	1/3	4	4	2	3	2	1/8	1/3	1	4	6	3
	1/3)	1/2)	5)	5)	3)	4)	3)	1/7)	1/2)	1)	5)	7)	4)
	(1/8	(1/9	(1	(1/4	(1	(1/6	(1/4	(1/5	(1/5	(1/5	(1	(2	(1/3
TL4	1/7	1/8	1	1/3	1	1/5	1/3	1/4	1/4	1/4	1	3	1/2
	1/6)	1/7)	1)	1/2)	1)	1/4)	1/2)	1/3)	1/3)	1/3)	1)	4)	1)
	(1/9	(1/9	(1	(1/5	(1/4	(1/7	(1/4	(1/7	(1/7	(1/7	(1/4	(1	(1/4
TL5	1/8	1/8	1	1/4	1/3	1/6	1/3	1/6	1/6	1/6	1/3	1	1/3
	1/7)	1/7)	1)	1/3)	1/2)	1/5)	1/2)	1/5)	1/5)	1/5)	1/2)	1)	1/2)
	(1/7	(1/5	(5	(1/4	(1	(1/4	(1/4	(2	(1/4	(1/4	(1	(2	(1
TL6	1/6	1/4	6	1/3	2	1/3	1/3	3	1/3	1/3	2	3	1
	1/5)	1/3)	7)	1/2)	3)	1/2)	1/2)	4)	1/2)	1/2)	3)	4)	1)

Table 10. Results of normalized weights.

	Criteria	Ni	Rank
T1	Procurement Cost	0.245881	1
T2	Frequency of Material Design Changes	0.179857	2
T3	Global outsourcing	0.015967	12
T4	Transit time variability	0.063042	7
T5	Monopoly	0.040926	10
T6	Risks arising from supplier	0.079936	5
T7	Technology Uncertainty and changes	0.045683	8
TL1	Inaccurate demand forecasts	0.090741	3
TL2	Risks arising from costumer	0.080087	4
TL3	Short lead times and product's life cycle	0.076276	6
TL4	Inadequate customer relation management	0.023529	11
TL5	Risks arising from competition and competitor	0.015295	13
TL6	Low in-house production	0.042779	9

According to the Fuzzy AHP results; risks that arise from Procurement Cost; Frequency of Material Design Changes; Inaccurate demand forecasts constitute the three most critical and important sub-risks within the supply chain management, respectively. Hence, action plans are needed to be established according to these rankings from Fuzzy AHP results. Preparing and implementing an action plan according to the rankings in the Fuzzy AHP results can create operational problems for businesses. For this reason, it is revealed with the help of Pareto Analysis for which sub-risks the action plan should be created in the first stage according to the determined rankings. When the 80-20 rule is applied; a prior action plan should be prepared for risks arising from Procurement Cost, Frequency of Material, Design Changes, Inaccurate demand forecasts, Risks arising from supplier, Risks arising from the customer, Transit time variability, and Low in-house production. Pareto Chart according to Fuzzy AHP results is illustrated in Figure 2. Suggestions and recommendations are made in the last section of this study.

With the results obtained from Fuzzy AHP and Pareto analysis, the suggestive action plan created for the sub-risks that should be included in the priority action plan is presented in Table 11.

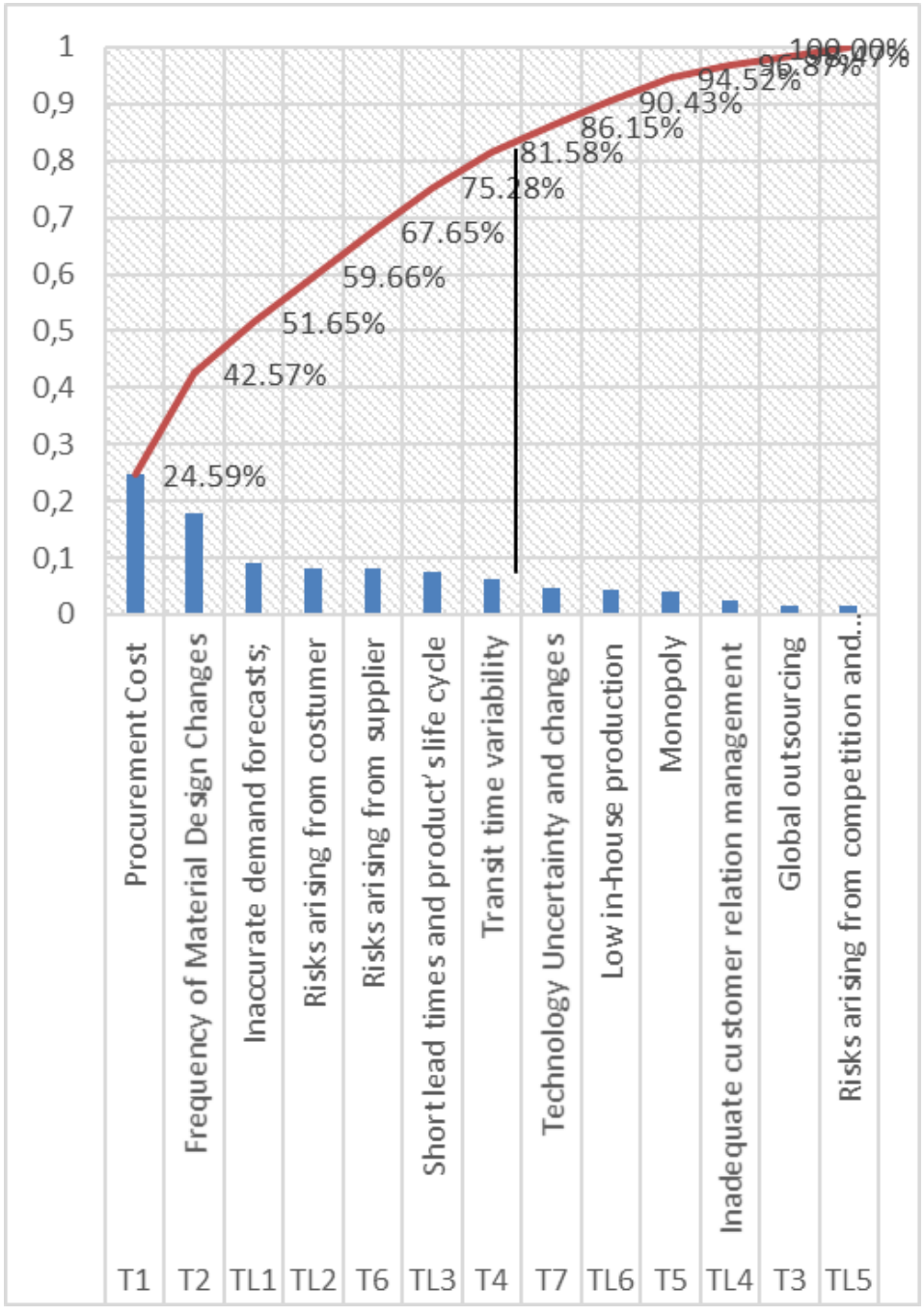

Figure 2. Pareto chart for the sub-risks.

Table 11. Action plan recommendations.

Sub-Risk	Action Plan Recommendations	The Common Studies in Literature
T1. Procurement Cost	* Better planning and coordination of supply and demand	[17]
	* Multiple source strategy	[10]
	* Ability to supply from more than one supplier for a product	[14]
	* By increasing the communication with the supplier, find out if the supplier is producing from the same order to receive the order given in smaller quantities at less cost.	
	* To get substitute material for the material to be purchased	
T2. Frequency of Material Design Changes	* Including customer tastes in product designs	[10]
	* To be able to respond quickly to changes in material design by increasing flexibility in machines and workbenches	[13] [49]
	* Increasing the training for the workforce to ensure that the changes adapt quickly	[16]
TL1. Inaccurate demand forecasts;	* Managing demand through promotions and incentives can be given to customers.	[6] [49]
	* Better planning and coordination of demand	
	* Purchase demand forecasting system program	
TL2. Risks arising from costumer	* Investing in good communication infrastructure, avoiding miscommunication due to lack of communication	[9] [10]
	* Better planning and coordination of supply and demand	[12]
	* Managing demand through promotions and giving incentives to customers	[14]
	* Contracting through banks to guarantee customer payments	
T6. Risks arising from supplier	* Better strategy development in supplier evaluation and selection	[5]
	* Creating supplier development programs.	[6]
	* Better planning and coordination with suppliers	[8]
	* Working with multiple supplier systems	[16]
	* Establish binding contracts with suppliers	
TL3. Short lead times and product's life cycle		[8] [12]
	* To prepare the proactive action plan avoiding bottlenecks.	[14]
	* Increasing flexibility to enable more production on determined time.	
	* Better training of employees to adapt to short lead times.	
T4. Transit time variability	* To set tolerance time and plan accordingly, considering that the shipping times may change in material supply or order delivery to the customer.	[6] [10]
	* To create an optimum transport plan by considering the times and variations in ship, road, and airline transports.	[49]
	* To determine the duration of the contract against the loss that will occur due to time changes and thus to get the return for the loss that may occur	

4 Conclusions

Supply chain risk management is process management that businesses must have and manage efficiently to survive in an ever-developing competitive environment. For this reason, it is strategically important for businesses to take precautions against the risks they face or face while carrying out their activities within the scope of the supply chain. An action plan to be created against the possible effects of risks will increase the life span of the companies within the process life cycle. Based on these important points, this study aimed to identify, prioritize

supply chain risks and create an action plan for prioritized risks. In line with these purposes, a comprehensive literature review was carried out and risks in the supply chain were divided into main titles as Supply Risks, Manufacturing Risks, Financial Risks, Demand Risks, Macro Risks, Transportation Risks, and Information Risks. After determining the sub-risks under each main risk, with the help of the questionnaire prepared, evaluations for the related risks were obtained from 391 supply chain process employees. The study model has been transformed into a Structural Equation Model and it has been determined that the risks arising from supply and demand processes from the main risks determined by multiple hypothesis tests are the main risks that explain the supply chain risks the most. Based on the result of the Pareto analysis carried out, 50% of the supply chain risks consist of supply and demand risks. Hence, it was decided to prioritize the sub-risks under these two main risks. To prioritize the sub-risks, the Fuzzy AHP method was performed to increase the objectivity levels of decision-makers. Results indicated that sub-risks of procurement cost, frequency of material design changes, inaccurate demand forecasts, and risks arising from supplier, risks arising from the costumer, transit time variability, and low in-house production were calculated as the most significant risks for companies. Hence, an action plan was recommended. The study has both theoretical and practical original contributions, as it handles the risks in the literature with an integrated approach and uses integrated analyzes. The study is considered to be of great importance to a business anywhere in the supply chain. Examining and prioritizing the risks compiled from the literature with their main and sub-forms are guiding for businesses; it is a map study on which risks they should take to prevent and even direct their investments. In future studies, it is planned to increase the sample size and compare it with the results in different sectors.

5 Author contribution statements

In the scope of this study, the Murat OTURAKÇI put forward the formation of idea, performed the design and the spelling and checking the article; the Rabia Sultan YILDIRIM obtained the data, performed the analysis and examined the results for the article in terms of content were contributed.

6 Ethics committee approval and conflict of interest statement

There is no need to obtain permission from the ethics committee for the article prepared. There is no conflict of interest with any person / institution in the article prepared.

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