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Article

Integrated Supply Chain Risk Assessment Methodology Based on Modified FMEA

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Abstract: Supply chains have rapidly developed and become more complex to increase productivity, reduce costs and meet demand. Moreover, globalization affected complexity and uncertainty, so many risks have arisen in surviving among rivals. Today, supply chain management became more difficult for recognizing the details and controlling the process. So, recognition and assessment of the risks in advance became vital to provide the continuity of the working processes of the company and not cause big losses. This study aims to minimize the damage that may occur by providing the risk assessment. For this purpose, a risk assessment methodology in which risks are determined via literature review and expert views is proposed. Afterwards, a new technique based on Failure Mode and Effects Analysis (FMEA) is utilized. Intuitionistic Fuzzy Analytic Hierarchy Process and Weighted Product are synergistically used within FMEA. Moreover, an application in a widely known fast-moving consumer goods company is performed to validate the proposed methodology.

Keywords: Risk Assessment; Supply Chain Management; Failure Mode and Effects Analysis; Intuitionistic Fuzzy Analytic Hierarchy Process; Weighted Product

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1. Introduction

Nowadays, businesses must be more competitive more than ever to survive in today's global business circumstances in which underestimated risks gained more importance since they can affect success of business steps and cause major loss. In this regard, assessment of risks is vital not only estimate the potential failures and take precautions before occurrence but also eliminate the loss [1].

In today's business environment, one of the main functions in every business which operates successfully is the supply chain management (SCM). In literature, supply chain (SC) basically defined as a system that consists of the integration of all parts of the chain such as suppliers, manufacturers, distributors, retailers, and customers. Having a multi-stakeholder structure brings with it the potential of many risk sources [2]. It is possible that these risks have many different root causes, such as constraints, quality, miscommunication or uncontrollable or unpredictable reasons [3]. However, whatever the root causes, the most important thing is to understand these risks and thus manage them. For a basic risk management, these potential risks should be identified, measured, and then prioritized and appropriate methods should be determined [4].

Regarding the importance of risk management in SCs, the objective of this study is to define the possible risk factors in SCs and assess these risk factors via proposing a methodology. Moreover, a case study is performed in a fast-moving consumer goods company to implement the proposed methodology which includes Failure Mode and Effects Analysis (FMEA), Intuitionistic Fuzzy Analytical Hierarchy Process (IF-AHP) and Weighted Product (WP).

2. Literature Review

In the literature, while defining risk, many different terminologies are used, which basically represent undesirable results such as danger, destruction, and loss etc. In other words, risk is described as the probability of a particular adverse event occurring during a stated period. Some sources [2] define risk as the result of a particular challenge, while others [5] define it as an unclear accident that will affect the accomplishment of objectives in compliance.

2.1. Risk Identification

One of the critical steps that have a direct impact on the success of SCM is the identification of risks. Risk identification, which consists of searching, determining, and defining potential risks, is also the initial step in every risk assessment model. The performance of SCs can affect by those potential risks whether positive or negative ways [4]. Moreover, risk identification helps managers to better understand the future uncertainties in the processes hence these uncertainties could be managed properly with taking into consideration of potential risks [5].

Risk identification can proceed in many ways. Some of the related methods are listed as follows [2]:

- Geo mapping/SC mapping: Visual maps of SC structures, dependencies and handoffs. Using a powerful search tool, organizations can quickly interrogate captured data to reveal information about the profile of their SC, and gain valuable insight into potential risks. Some geo mapping/SC mapping methodologies are Icam Definition for Function Modeling (IDEF0), Supply Chain Operation Reference (SCOR) and Value Stream Mapping [6].
- Looking at historical problems: The possibility of reappearing historical problems might be high. These problems may have appeared in the system itself or to others.
- Researching industry trends: Other organizations might have already investigated relevant risks.
- Group of experts brainstorming: People who have knowledge of risk and experiences in SC come together and share their ideas. Knowledge is generally embedded in people's minds, and access to knowledge includes brainstorming meetings with the experts.
- Assessment surveys: Surveys are fast and effective ways to collect information and data about risks in the SC.
- Site visit: Site visits to SC associates enable to collect “specific” information and data on risk.
- Literature review: Literature review is one of the efficient ways for determining risks. A systematic literature review provides guidance on how the risks are identified in previous studies and the appropriateness of the identification method [7].
- Qualitative methods: It is commonly used for risk identification and risk examination steps. Some qualitative methods are FMEA, Empirical Analysis and Process-Performance modelling [4].

Furthermore, Palaniappan [2] states that, there are also several tools used in risk identification such as checklists, cause and effect diagrams, Gantt charts etc. The main purpose of using risk checklists is to provide a quick reference list for risk experts to ensure that all appropriate activities related to risk assessment have been addressed. It can be used to assure that steps have completed the activities associated with conducting an effective risk assessment. However, cause-and-effect diagrams which are also called as fishbone diagrams, identify many possible causes for an effect or problem. It can be used to structure a brainstorming session and immediately sorts ideas into useful categories. Gantt chart can also be used in risk identification to provide and create a critical path to take notice of before risks occur.

2.2. Risk Classification

Determining and utilizing the most effective techniques for clarifying the risks of the organization and classifying the identified risks are required for the risk assessment process. It is possible to use different information gathering and assessment techniques. However, the important point is the applicability by the organization and getting useful results. After selecting the risk identification techniques, the classification of risks with their sources should be performed. Based on the literature review as summarized in Table 1, it is seen that there is not only one right way to do this. Decisions are made with organizational competencies and techniques that are appropriate to the requirements of risk assessment. In this framework, risk classification should be done in a specific hierarchical structure. In the literature, there are several risk categories. Some of them are listed as follows:

- Demand risk: Variance of demand for a product depends on several factors such as, economic downturn, changes in customer behavior, communication failing, customer becoming more powerful in the bargaining or demand getting changeable. Diabat et al. [3] define sub-risks as labor strikes, absence of qualified worker, unexpected loss of demand because of economic downturn, changeable demand. Demand risk includes new product introductions, insufficient manufacturing and handling capability, high levels of process variations, changeable technology [8]. According to Li et al. [9] it also consists of sudden engineering changes, order cancellations, late orders, skewed order cycles, air traffic, issues at customs, weather conditions, receivables, demand uncertainty. There are many components of demand risk studied by the researchers. However, main categories can be defined as “unexpected or very volatile customer demand”, “deferment in delivery”, and “brand image risk” [1].
- Supply risk: Nowadays, there is an increased dependence on suppliers and it constrains the company to deal with supply risk. This situation leads to the distribution of negative events that affect the ability of domestic firms to meet customer demands (both quantitatively and qualitatively) at expected costs and time or threats to customer life and safety. Primarily supply risk occurs by the cause of variability connected with product and supplier. According to Li et al. [9], supply risk includes supply suspension, material scarcity, limit of capacity, quality issues, and layer risk. However, Manuj and Mentzer [8] claim that it should be examined as a disturbance of supply, inventory, timetable, technology connection, price increase, quality issues, technology changeableness, product complication and frequency of material design changes. Main categories can be defined as “product quality issues”, “complication of important materials”, “unexpected failure of suppliers”, and “unstable behavior in supplier” [1].

- Operation and process risks: Processes are series of value-adding and administrative actions or steps taken in order to accomplish an appropriate end set in motion by the company. Operation and process risks totally connected to interruption to those processes. This affects company's domestic capability to manufacture and supply goods/services that arise from the result of a disruption in a central performing or processing capacity [2]. Operation and process risks cause a focused organization and show up logistics and manufacturing progress in addition to administrative activities [10]. Risks factors mainly include planning, scheduling, and forecasting errors [4].
- Production risk: The production companies might be led to incompetence in the SC from unsatisfactory performance. Although companies implement massively in programs, such as total quality management, lean production and six sigma, to develop domestic quality and competence; their domestic actions are affected to problems which may cause variation in capability and quality. The important risk sources consist of "manufacturing unpredictability", "changes in production process", "insufficient production capacity" [1]. It includes processes, innovation capability, and technical capability [11].
- Environmental Risk: Risk may occur as a result of cooperation between the SC network and its environment. In 2007, Khan and Burnes [12] stated that economic, political and social developments and events are raising the risk of SC disturbance that is more complex due to the fact that SCs become longer. Punniyamoorthy et al. [1] defined some keywords for the environmental risk such as "policy", "macroeconomic", "social", "natural and manmade disasters". It is also defined as uncontrollable incident that is related with external and contains changeable actions that show up from the SC and environmental interactions. It contains natural disaster, terrorism and war, political unrest in the region, changeable regulatory, strikes and absence of qualified person [1, 3].
- Financial risk: SC finance maintains financial services to all accompanying businesses which include upstream and downstream industries. It consists of a lack of understanding of risk importance, complicated credit environment and the process and acceptance of possessions rights which are complex and confused [10]. Cost risk can be examined under financial risk and it contains supplier's selling price, value-added cost, logistics cost [11]. According to Kara and Fırat [13], financial risk also includes economic environment, cost/price risks, cash flow risks, and changes in currency, economic recession, stability of GDP, tax risk.
- Regulatory risk: Regulatory changes, both foreign and domestic, create challenges to global SCs. Industry-specific changes within countries, such as traceability rules for perishables; changes in a country's stance toward imports and exports, or participation in existing international institutions are also examined in regulation risk [10]. Penalty which stems from breaking the law, the state that does not foresee any movements such as import bans or export restrictions can be studied under this title [13].
- Customer and market risks: Market risk is the likelihood of an encounter loss due to causes which have effects works of the financial markets in which the financier participated. It is affected by salability, marketability, and growth [11]. Besides, market and customer risks are high level of risk categories that can occur in SC. Environmental, economic, political factors and global competition have effects in this risk [4]. According to Kara and Fırat [13], these risks

include quality issues in goods and services, financial power of customers, customer relations, reputation, brand and image risk of the company, and disruption of order system.

- Logistics risk: Logistics risk might be classified as the possible disruptions to the process of products, knowledge, and fund. In SC literature, factors and results of unpredictability in transport operations have been mentioned less. The important logistics factors are determined by several researchers as follows: "storage problems", "transporter financial power", "transport network management" and "deferments in distribution" [1]. According to Wang et al. [11], logistics risk can be studied in three steps as internal, packaging and external. It contains transport failures, adaptability of transportation, delivery failures, weather conditions, inadequate packaging, and failures of labor who work in transportation [13].

Risk classification is one of the vital steps of risk management in SCs. The underlying reason is that key risk factors should be identified for every risk that is going to be classified and taken precaution to ensure that the risks do not overlap with each other as much as possible. After categorizing the risks which are identified in the first step, risk assessment process begins as the third step.

2.3. Risk Assessment

The determined risks are assessed via a suitable technique and their impacts are obtained. Afterwards, companies try to minimize SC risk factors to maximize productivity [14]. Also, risk assessment methods balance demand frequency, the likelihood of supply, allocation of effective resources, determination of decision analysis paths [1].

Different approaches and methodologies are implemented for risk assessment in the literature. Bow-tie analysis is one of the mostly used methods to reduce uncertainty and to position different types of risk in SC by using fault and event tree. Event tree analysis is applied to determine starting event and if event is sufficient, procedures are implemented in system plan. The analysis also provides to calculate risk impacts. Alternatively, the expert's knowledge provides rating to calculate probability of risks [8]. Liu et al. [9] applied influence diagram as an assessment tool. Topology and function layer are considered and processes are defined as controllable and uncontrollable. Thus, risk elements are determined and the relationship of risk elements is described to each other. Chaudhuri et al. [14] claimed that there was no readily proper procedure in the literature for risk assessment. Step by step approach was applied in the study then numerical and linguistic data were provided in determining vulnerable scores for various subsystems. They used FMEA to prioritize and reduce risk factors so vulnerable factors were identified and subsystems which were the degree of supplier involvement, the complexity of the process, complexity of logistics and manufacturing capabilities were defined. These subsystems help companies to reveal the coordination between suppliers and mechanisms.

In 2013, Li et al. [9] developed Extended Risk Matrix Approach to create new risk assessment method by adding the "detectability and recoverability" dimensions to traditional Risk Matrix Approach which only consist of two dimensions: severity and probability. Researchers selected the probability, severity and detectability dimensions to analyze and to evaluate for each risk factor to the multinational IT/Electronics Company. The scores of these dimensions were derived from survey data and in conclusion "disruption risk" was determined more dangerous than the others. Punniyamoorthy et al. [1] applied Cronbach's α-value to evaluate accuracy of risk factors.

Confirmative factor analysis was used to formalize risk assessment tools. The aim of study was to create a 45-component tool with six main risk structures and to provide the development of tools for assessing the SC risks.

Aqlan and Lam [4] applied modelling approaches for SC risk assessment. Modelling approaches were constitutive, qualitative and hybrid models. These models were developed in manufacturing environment. Researchers focused on high-end manufacturing which was part of a manufacturing environment and discovered many uncertainty factors in this area. Uncertainty is a well-known issue which affects the analysis of real-life cases and to overcome the vagueness problems researchers used several approaches. In 2016, Bocquillon and Ekallam [10] used fuzzy inference system to calculate the risk scores with the aim of revealing important risks that have a strong effect. After the application of the risk assessment method, the products having the highest risks were determined.

The methods which are used in literature for risk identification, classification and assessment are summarized in Table 1.

Table 1. Literature review for the used methodologies.

Authors	Risk Identification Methods	Risk Classification Methods	Risk Assessment Methods
Shenoi et al. [15]	• Literature review	• Demand side risk • Supply side risk • Logistic risk • Regulatory, legal and bureaucratic risk • Infrastructure risk • Stock/data management risk • Environment risk • Financial risk	• IPA (Important performance analysis)
Rostamzadeh et al. [16]	• Literature review • Interview with experts • Interview with expert panel consist of managers-research experts-practitioners	• Environmental risks • Organizational risks • Sustainable supply risks • Sustainable production/manufacturer risks • Sustainable distribution risks • Sustainable recycling risks • Information technology related risks	• Integrated MCDM approach based on the TOPSIS and CRITIC method
Qazi et al. [17]	• FMEA	• Inbound-outbound logistics • The operators at the manufacturer • The operations at the suppliers • The final customers	• Bayesian Belief Network (BBN) with RNELPM (Risk Network Expected Loss Propagation Measure for Risk) • UTC (Upper Tail Contribution) • Risk Network Expected Loss (RNEL)
Kırılmaz and Erol [18]	• Literature review • Examined with the managers	• Quality Problems • Inability t to adapt changes in customer demand	• Impact probability matrix

		• Increasing raw material prices • Bankruptcy of supplier • Supplier capacity risk • Machine breakdowns • Delivery chain disruptions • Malfunction of IT systems • Accident risk (e.g., fire) • Industrial action risk (Strike etc.) • Transportation failure • Import restrictions • Terrorist attack • Extreme weather conditions • Increasing customs duty	
Luthra et al. [19]	• FMEA • Empirical Analysis • Process-Performance modeling	--	• AHP
Bocquillon and Ekallam [10]	--	• Process Control Risk • Environment Risk	--
Özveri and Kabak [20]	--	--	• FMEA, AHP • AHP-PROMETHEE
Jaberidoost et al. [7]	• Literature Review	--	• AHP • SAW
Aqlan and Lam [4]	• Survey	• Supplier Risk • Customer Risk • Process and Control Risk • Technology Risks • Product Risks • Occupational Risk • Transportation Risk • Commodity Risk	• Fuzzy Set Theory Method • Top-Down and Bottom-Up Analysis
Palaniappan [2]	• Looking at Historical Problems • Researching Industry Trends • Group of Experts Brainstorming • Assessment Surveys • Site Visit • Risk Checklist • Cause-and-Effect Diagrams: • Gantt Charts • Geo Mapping/Supply Chain Mapping	• Supply Risk • Demand Risks • Process and control Risks • Environmental Risks	--
Aslania et al. [21]	--	--	• A hybrid of fuzzy FMEA-AHP
Punniyamoorthy et al. [1]	• Survey	• Supply Risks • Environmental Risks • Demand Risks • Manufacturing Risks • Logistics Risks • Information Risks	• Confirmative factor analysis (CFA) and LISREL 8.8.

Soni and Kodali [22]	--	• Labor Risks • Market Risks • Transfer Risks • Financial Risks • Living conditions • Natural condition	• PROMETHEE • AHP
Chan and Wang [23]	--	--	• Fuzzy TOPSIS • AHP
Li et al. [9]	• Survey Data • 3D Graph representation	• Supply Risks • Demand Risks • Process Risks • Disruption Risks	• Extended Risk Matrix Approach
Maheswaran and Loganathan [24]	--	--	• AHP • PROMETHEE • FMEA
Huang and Paradi [25]	• Modified multistage sequential DEA technique	• Endogenous risk • Exogenous risk	--
Chuang [26]	• Service blueprint	• Service facility o Sales floor facility o Sales floor security o Sales floor surroundings • Prior-service o Incoming goods/merchandise activity o Warehousing and inventory activity • In-service o Customer choice /purchase flow o Cashier flow • Post-service o Post-sale activity o Warranty	• FMEA
Chang and Hsiao [27]	--	• Financial • Functional • Physical • Psychological • Social • Temporal	• Multiplication model and Questionnaire

3. Materials and Method

According to the literature review, it is seen that there are several approaches to analyze risks in SCM. However, uncertainty remains one of the biggest problems that researchers face in real life. In this paper, three approaches are synergistically utilized for risk assessment process to overcome the main problems. These approaches provide the risk rankings according to their importance via calculating Revised Risk Priority Number (R-RPN) with using FMEA, IFs-AHP and WP methods. Proposed methodology of this study is demonstrated in Figure 1.

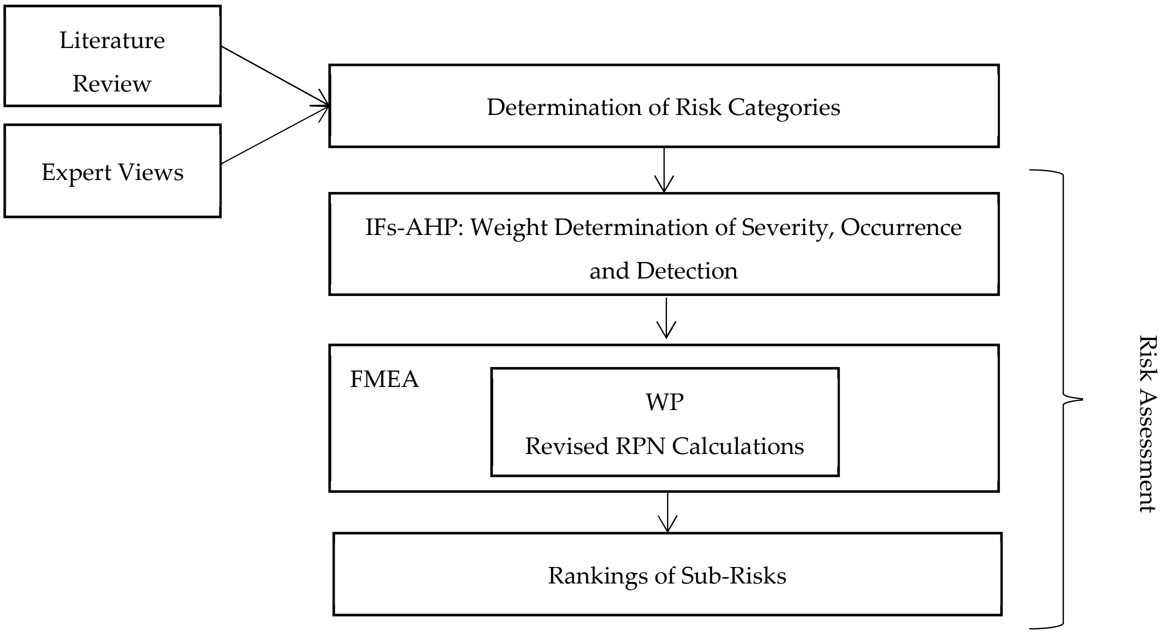

Figure 1. Framework of the proposed model.

Different from the existing literature, a new integrated approach including FMEA, IFs-AHP and WP is generated. To eliminate the deficiency of integrated use of AHP and FMEA in the existing literature, a new approach with WP is used by also considering vagueness via fuzzy approach. Regarding the current integrated use of AHP and FMEA, it is observed that the sum of weighted factors is used. However, multiplication of factors is necessary to fit the original form of FMEA. To make this multiplication is valid; the importance weight should be exponentially indicated. At this point WP is a suitable technique.

The rest of this study is organized as follows. Initially, each method including FMEA, IFs-AHP and WP are explained in details in sub-sections. The new approach using the mentioned methods to substitute the conventional RPN method is elaborated in detail. Afterwards, the proposed methodology is applied in a food company. Finally, results are presented.

3.1. Failure Mode Effect Analysis (FMEA)

FMEA is a reliable method for failure analysis [28]. It is used as a tool of risk assessment [24] and prioritizes the risks [2]. FMEA, which was designed in 1960s, is one of the main systematic techniques focuses on failure analysis [21]. After the methodology is developed it was improved by Ford Motor in 1977 [24]. In today's business environment, it is considered as a very beneficial risk assessment tool and implemented in various fields [28]. FMEA is very successful in detecting the potential failures in processes [20], therefore it enables to decrease the potential risks and to improve the quality, safety and reliability of a system [28]. In processes, root causes of failures can vary, have different impacts and raise from several reasons. In that case, each failure mode with high risk should be considered for evaluation regarding their risk and then they should be prioritized. A significant point of FMEA is that it is a proactive approach [20] which aims to detect the potential failures for each subsystem [28] before they happen in order to prevent them.

In prioritization of the risks, Risk Priority Number (RPN) is used in FMEA [2]. In order to calculate RPN score, three dimensions for each failure mode should be considered such as severity

(S) which indicates the effect of failure, occurrence (O) which is the frequency of failure, and detection (D) which is the probability of detecting the failure [20]. RPN can only be calculated after these values of the risk criteria determined with Eq. 1 [24].

$$RPN = S * O * D \tag{1}$$

The values of S, O and D for each failure mode are obtained from the experts, according to their importance level rating scale which can be between 1 and 10 [24]. These rating scales are given in the Table 2 and Table 3.

Table 2. Occurrence & Severity Rating Scale [20].

Rating	Description	Potential Risk Rate for Occurrence	Definition for Severity	IF Set		
				μ	ν	π
10	Extremely high	More than one per day	Risk causes a loss of a customer or an employee	1	0	0
9	Very high	Once every 3-4 days	Risk causes a huge lateness on system	0.8	0.1	0.1
8	Repeated failures	Once every week	Risk could cause a major dissatisfaction on customer side	0.62	0.18	0.2
7	High					
6	Moderately high	Once every three months	Risk can cause a minor effect on product/service performance	0.47	0.23	0.3
5	Moderate			0.33	0.27	0.4
4	Relatively low	Once per year	Risk causes a minor dissatisfaction or just annoys customer	0.22	0.28	0.5
3	Low			0.13	0.27	0.6
2	Remote	Once every 3-6 years	A Customer cannot distinguish that	0.06	0.23	0.7
1	Nearly impossible	No one remembers last risk occurrence	Risk has no impact on system	0.02	0.18	0.8

Table 3. Detection Rating Scale [20].

Rating	Description	Definition for Detection	IF Set		
			μ	ν	π
10	Absolute uncertainty	No design control or no chance of detection	1	0	0
9	Very Remote	The risk can be detected with unfeasible inspection	0.8	0.1	0.1
8	Remote				
7	Very Low	The risk can be detected only with manual inspection	0.62	0.18	0.2
6	Low		0.47	0.23	0.3
5	Moderate	The risk can be detected by an un-automated process	0.33	0.27	0.4
4	Moderately High	There is 100% inspection or review of the process, but still un-automated	0.22	0.28	0.5
3	High		0.13	0.27	0.6
2	Very High	There is 100% automated inspection or review of the process	0.06	0.23	0.7
1	Almost certain	There is automated shut-offs to prevent risk	0.02	0.18	0.8

The traditional FMEA is based on prioritizing the risks. The underlying reason of method's extensive use is the simple structure of the method which makes it preferable. However, this structure is again the main reason why the method has some shortcomings. Chang et al. [29] stated that significant criticisms about using the FMEA in a traditional way. Some of these criticisms are duplication of RPN elements, measurement scale violations, problems in determining each dimensions' weights and drawback of determining the subjective structure with current RPN scale. These issues are stated in many researches and Wu et al. [30] proposed a structure in which each dimension calculated differently since each of the three dimensions have different characteristics. In

2017, Liu et al. [31] also emphasized the shortcomings of calculation of RPN and especially pointed out the problems about the weight of risk factors. Huang et al. [25] searched the literature so that they summarized the major flaws. Their analysis showed that major problems are about using crisp numbers in evaluation of risks, sensitive formulation of RPN to the variation and weighting of each dimension. They proposed a new form of FMEA that uses linguistic distribution assessments on the failure modes.

Traditional calculation of FMEA has been criticized for several reasons and becomes one of the mostly studied issues in literature. However, FMEA has been proven to be one of the most important early preventative initiatives for companies and its popularity still increases. Mostly, hybrid methods are generated to overcome the mentioned flaws. Especially, to overcome problems in appropriate weight determination for each dimension, Multi-Criteria Decision Making (MCDM) techniques are used under the fuzzy environment. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje) methods under the fuzzy environment and Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) method are the examples of hybrid models which are proposed in order to evaluate the dimensions in a more meaningful way [24]. In this study, relative importance among severity, occurrence and detection is calculated via using IFs-AHP method with the consideration of the consolidated opinions of four different managers and their teams as four different decision makers' (DM) views of points. Thus, not only the weighting determination problem is considered but also more suitable scale is used to analyze the uncertainty of DM's opinions.

3.2. IFs-AHP

In real-life decision-making process of a problem, DMs are face to face with several circumstances such as time pressure, inefficient information etc. which are directly affect their evaluations. Additionally in some cases DMs ability or attention can be limited during the assessment procedure. These points make the information provided by DMs insufficient and most of the time uncertain in many complex decision-making problems. In this regard, to overcome these uncertainties, fuzzy logic-based tools to describe uncertain decision-making information. In literature, traditional fuzzy logic theorems are developed by many researchers to better reflect and solve the uncertainty in the problem. In this sense, IFs theorems are generally used in approximate induction, sample definition and decision making in literature. Xu and Yager [32] point out that the IFs theory is useful in studies with uncertainty, and they have mentioned that there is a lot of work in the literature for further development of the theory. IFs are generally defined as

$$\mathrm{A} = \langle (\mathrm{x}, \mu_{\mathrm{A}}(\mathrm{x}), v_{\mathrm{A}}(\mathrm{x})) : \mathrm{x} \in \mathrm{X} \rangle \tag{2}$$

Here, $\mu_{\mathrm{A}}(\mathrm{x}): \mathrm{X} \rightarrow [0,1]$ is defined membership and $v_{\mathrm{A}}(\mathrm{x}): \mathrm{X} \rightarrow [0,1]$ is defined non-membership function. These functions have a property of $0 \leq \mu_{\mathrm{A}}(\mathrm{x}) + v_{\mathrm{A}}(\mathrm{x}) \leq 1$. In this case hesitation is defined with

$$\pi_{\mathrm{A}}(\mathrm{x}) = 1 - \mu_{\mathrm{A}}(\mathrm{x}) - v_{\mathrm{A}}(\mathrm{x}) \tag{3}$$

The operations of addition $\oplus$ and multiplication $\otimes$ on IFs were defined by Atanassov [33] as in Eq. (4) and Eq. (5). Let A= $\langle \mu_{\mathrm{A}}, v_{\mathrm{A}} \rangle$ and B = $\langle \mu_{\mathrm{B}}, v_{\mathrm{B}} \rangle$ be IFs. Then,

$$A \oplus B = \langle \mu_{\mathrm{A}} + \mu_{\mathrm{B}} - \mu_{\mathrm{A}}.\mu_{\mathrm{B}}, v_{\mathrm{A}}.v_{\mathrm{B}} \rangle \tag{4}$$

$$A \otimes B = \langle \mu_{\mathrm{A}}.\mu_{\mathrm{B}}, v_{\mathrm{A}} + v_{\mathrm{B}} - v_{\mathrm{A}}.v_{\mathrm{B}} \rangle \tag{5}$$

Let λ is a real value $(\lambda > 0)$ and $\oslash$ represents the division operations, then other operational functions can be defined by Dymova and Sevastjanov [34] as

$$\lambda A = \left(1 - \left(1 - \mu_A\right)^{\lambda}, v_A\right) \tag{6}$$

$$A^{\lambda} = \left(\mu_A{}^{\lambda}, 1 - (1 - v_A)^{\lambda}\right) \tag{7}$$

$$A \oslash B = \left\{\langle x, \frac{\mu_A}{\mu_B}, \frac{v_A - v_B}{1 - v_B}\rangle \middle| x \in X\right\} \tag{8}$$

with conditions A≤B, $\mu_B(x) \neq 0$; $v_B(x) \neq 1$ and $\mu_A . v_B - \mu_B . v_A \geq \mu_A - \mu_B$.

Preliminaries of IFs sets are vital to better understand the IFs-AHP methodology steps which are given in detail in the following part. In this study, AHP is only used for the weight determination thus the explanations of the methodology consist of weight determination steps.

- Step 1. Developing a hierarchical structure: Objective of the problems is identified and criteria for each level are determined. Then criteria are evaluated for all alternatives which are also defined in the hierarchical structure of the problem.
- Step 2. Developing pairwise comparisons: Evaluations of DMs for each criteria and alternative are collected and pairwise comparison matrices are created based on the linguistic scale given in Table 4.

Table 4. Linguistic evaluation scale for IFs-AHP [35].

Preference on Pair-wise Comparison	IFNs			Reciprocal IFNs		
	μ	ν	π	μ	ν	π
Equally important (EI)	0.02	0.18	0.8	0.02	0.18	0.8
Intermediate value (IV)	0.06	0.23	0.7	0.23	0.06	0.7
Moderately more important (MMI)	0.13	0.27	0.6	0.27	0.13	0.6
Intermediate value (IV)	0.22	0.28	0.5	0.28	0.22	0.5
Strongly more important (SMI)	0.33	0.27	0.4	0.27	0.33	0.4
Intermediate value (IV)	0.47	0.23	0.3	0.23	0.47	0.3
Very strong more important (VSMI)	0.62	0.18	0.2	0.18	0.62	0.2
Intermediate value (IV)	0.8	0.1	0.1	0.1	0.8	0.1
Extremely more important (EMI)	1	0	0	0	1	0

- Step 3. Calculation of DMs' weights: In MCDM methodologies, there can be several DMs and importance of them can be different. In such cases, a linguistic term is assigned to the DM to rate then the weight of the DM is calculated by Eq. (9). In Table 5, the linguistic terms for DMs' ratings are presented.

Table 5. Linguistic terms for decision makers [36].

Linguistic Terms	DMs' Ratings	IFNs		
		μ	ν	π
Very Important	VI	0.8	0.1	0.1
Important	I	0.5	0.2	0.3
Medium	M	0.5	0.5	0
Bad	B	0.3	0.5	0.2
Very Bad	VB	0.2	0.7	0.1

Let's assume that there are several DMs in the problem and Dl= $\langle \mu_l, v_l, \pi_l \rangle$ is an IFs for DM k. If there are m DMs, to find the kth DM's weight, Eq. (9) is applied.

$$\lambda_k = \frac{\mu_k + \pi_k\left(\frac{\mu_k}{\mu_k + \upsilon_k}\right)}{\sum_{l=1}^{m}\left[\mu_l + \pi_l\left(\frac{\mu_l}{\mu_l + \upsilon_l}\right)\right]} \; where\ \lambda_l \in [0,1]\ and\ \sum_{l=1}^{m}\lambda_l = 1 \quad (9)$$

- Step 4. Determining IF decision matrix: Xu [36] defined an intuitionistic fuzzy weighted averaging (IFWA) operator to aggregate the DMs' opinions. In group-decision making problems, individual opinions must sum up to construct a decision matrix. Let $R^{(l)} = (r_{ij}^{l})_{mxn}$ is a pairwise comparison matrix developed in step 2 for each DM and $\lambda = \{\lambda_1, \lambda_2, \dots \lambda_k\}$ is the weight of DM found in step 3. Then IFWA operator is calculated with

$$R = \left(r_{ij}\right)_{mxn} = IFWA_{\lambda}\left(r_{ij}^{1}, r_{ij}^{2}, \dots r_{ij}^{l}\right) = \lambda_1 r_{ij}^{1} \oplus \lambda_2 r_{ij}^{2} \oplus \dots \oplus \lambda_k r_{ij}^{k} = \left[1 - \prod_{l=1}^{k}\left(1 - \mu_{ij}^{(l)}\right)^{\lambda_l}, \prod_{l=1}^{k}\left(v_{ij}^{(l)}\right)^{\lambda_l}, \prod_{l=1}^{k}\left(1 - \mu_{ij}^{(l)}\right)^{\lambda_l} - \prod_{l=1}^{k}\left(v_{ij}^{(l)}\right)^{\lambda_l}\right] \quad (10)$$

- Step 5. Calculation of IFs weights: In literature, there are several methods such as eigenvector calculations, arithmetic mean and geometric mean etc. to calculate weights. According to Sadiq and Tesfamariam [38] there is no significant difference among these methodologies. In their study, firstly they used geometric mean and then normalized it to find final weights with Eq. (11) and Eq. (12). Let's assume that J_i represents the geometric mean operation and w_i represents the weights (i=1 to n) as

$$J_i = (J_{i1} \otimes J_{i2} \otimes \dots \otimes J_{in})^{1/n} \quad (11)$$

$$w_i = J_i \otimes (J_1 \oplus \dots \oplus J_n)^{-1} \quad (12)$$

3.3. Weighted Product

In problems where multiple criteria have different importance weights, Weighted Product (WP) is one of the easiest scoring methods preferred by many studies. Within the method, the importance weight of each attribute (w_j) becomes exponents and the score of an alternative (V_i) is calculated as in Eq. (13) [39]:

$$V_i = \prod_j (X_{ij})^{w_j} \quad (13)$$

where i represent alternative, j represent attribute, V_i is the total score of alternative "i", X_{ij} is the score of alternative "i" with respect to attribute "j" and w_j is the importance weight of attribute "j".

The shortcomings of RPN calculations is mentioned several times in literature. A simple example generally to best way to better present the limitation of traditional calculation of FMEA. Assume that, in the first failure mode for a risk type, Occurrence (O) is equal to 2, Severity (S) is equal to 5 and Detection (D) is equal to 7 and in the second mode "O" is equal to 7, "S" is equal to 5 and "D" is equal to 2. In such case, even though different scores are determined for different failure modes, overall RPN values for both failure modes are the same as equal to 70. This deficiency stems from assuming the severity, occurrence and detection's importance as the same [20]. On the other hand, in real-world cases, the relative importance of each criterion is very important in real life cases. However, the given example clearly indicated that traditional calculation of RPN values make risk assessments deficient.

In this paper, WP which is a single MCDM method is used for calculating RPN. In the text, RPN will be mentioned as Revised Risk Priority Number (R-RPN) to show the difference. WP model provides to obtain a consistent result by using the specified importance weight for the interested factor [40]. Therefore, the new R-RPN is calculated via WP to eliminate the deficiency of the traditional approach of FMEA with the formula:

$$\text{Revised} - \text{RPN} = S(O)W(O) \times S(D)W(D) \times S(S)W(S) \quad (14)$$

where, W and S are the importance weight and score of each criterion for all sub-risks, respectively. Relative weights for each criterion are calculated using IFs-AHP methodology and scores are determined based on the opinions of DMs. These mentioned score values are also in a scale of IFs to overcome the hesitation of the DMs.

For each approach, the R-RPN is calculated for each failure mode. After calculating the R-RPN, it is possible to obtain ranking among the sub-risks based on the rules of IFs. In this study, traditional ranking methodology which will be mentioned in the application section is used for the final R-RPN values.

4. Application in a Food Company

The application of the proposed methodology is performed in a food company. Firstly, a set of meetings were organized with the managers of demand, raw material planning, finance-operations and SC managers to specify main and sub-risk factors. Sub-risks are explained in the following section according to the company's operations. After specifying them, the integrated methodology is implemented and finally the rankings are obtained.

4.1. Sub-risks Identification

The risk categories which are evaluated in surveys are demand risks, supply risks, operational risks, financial risks, and logistics risks. Each of these risks and their sub-risks are explained in detail as follows:

- Demand risks: The sub-risks are defined via interview with the demand manager (Manager 1) and literature review. These sub-risks are as follows:
    - Unanticipated or volatile customer demand is a real problem for companies, from discrete manufacturing to process industries. Many factors cause demand volatility including customer demand increase, product customization, technological developments, global competition, and upward supply variation. Unanticipated or volatile customer demand is a challenge encountered by companies at all levels. Dealing with volatile demand in an adequate method can bring about important advantage for a company, including minimum SC costs and enhanced customer service status. In addition, dealing with volatile demand efficiently might be a big advantage in competition.
    - Equivalent products are the products that have the similar features with the existing product. These products can create risks since they can be easily preferred instead of the existing product. This risk directly affects the management of demand strategies.
    - Change in market trend can result with huge variance between forecasted demand and actual demand. Customers' purchase habits or priorities can be affected by many factors in the market.
    - Pricing strategy accounts for segments, payment capabilities, market conditions, competitor actions, trade margins and input costs, among others. Price strategy is a very important element of demand risks, because if the company chooses wrong price strategy, it causes loss or less profit.

- Supply risks: The sub-risks are defined via interview with the raw material planning manager (Manager 2) and literature review. These sub-risks are as follows:
    - Supplier's inventory can cause the disruption on the customer's production due to the insufficiency of alternative suppliers. However, this situation may have several reasons to occur. If the supplier becomes aware of the customer's possible needs, they may take action to prevent this.
    - Company's inventory is related with the level of company's selected goods. Most of the raw materials are purchased before start to production. If their expiration dates are not too short, they should be stocked within the company. If these supplied stocks level is not managed properly, it can affect the production process negatively.
    - Incapable supplier is one of the important sub-risks of supply risks. The supplier selection process has high importance on company's strategies. The supplier's capacity should be capable of satisfying the company's demand. Otherwise, this issue causes to lose revenue on both sides. The other point is that, the supplier must direct the own investment plans according to customers' annual targets. The supplier's facility conditions, number of employees etc. must meet the customer's criteria, as well.
    - Inconsistent forecast mostly occurs internally. Most of the mentioned supply risks source from inconsistency between planned and actual. There are always uncontrollable factors such as disruption on market, changing climate etc. However, if there is a huge variance between the actual and forecasted values if there is no uncontrollable event, it can be surely said that there is a mistake on forecasting process. The forecast inconsistency may occur on supplier side or customer side.
- Operational risks: The sub-risks are defined via interview with finance-operations manager (Manager 3) and literature review. These sub-risks are as follows:
    - Inconsistent production rate can occur internally or externally. Any situation of inconsistent production rate, which is on supplier or firm side, may affect all the business processes. There can be different kind of reasons, which are caused to inconsistency, but in studied case these are mostly machine malfunctions, maintenance on equipment.
    - Database issues within the company happen internally. Every company has a database or reporting system for each stage. These systems can be interrelated. For a SC process, the managers should be aware of the actual produced amount or sales trend of firm's products by following from database system.
    - Mismanaging the employees, which can occur at all level of employees, may affect all the business process. If it occurs on blue-collar employees, it may cause to disruption on production or logistics process. Then, it causes to arise other types of risks, such as inconsistency on production rate.
    - Inadequate or unqualified employees is related with human resources stage of business. It is impossible to carry out the business operation successfully with untrained employees or lack of human-power.
- Financial risks: The sub-risks are defined via interview with finance-operations manager (Manager 3) and literature review. These sub-risks are as follows:

    - The threat of economic crisis is an external and uncontrollable sub-risk factor. In unsteady markets, there is always a threat of economic crisis. This threat may affect the market's consumption habits. Also, the foreign-financed companies may be affected on internal side.
    - Uncertainty in foreign exchange rate risk occurs if supplier uses a foreign currency, thus any fluctuation in a market may have a high impact. In some cases, the company must review on pricing regulations. Or, the company must reorganize payment plan according to the value of local currency against to foreign currency.
    - Cyber risks mean that any risk of financial disruption or loss happen from some sort of failure of its information technology system. Any financial loss affects the whole stage of business, mostly SC system.
    - Disagreement on financial aspects with supplier can change from company to company. The underlying reason is that each company may have a different type of internal management regulations. This difference may cause a conflict between firm and its suppliers. To explain, the payment schedule or billing process can be different and as a result, a disagreement may arise between the firms who are working together.
- Logistics risks: The sub-risks are defined via interview with the SC manager (Manager 4) and literature review. These sub-risks are as follows:
    - Inefficiency in transport infrastructure is one of the most important factors for a country's progress and companies' logistics. Transportation infrastructure improves the quality and safety of ability to move in the economy and upgrades economic growth. However, in some cases such as road construction etc., the logistics cost would be higher than estimated.
    - Vehicle procurement problem occurs when the cooperated company's vehicles are inadequate or when there are not enough vehicles in hand. The transfer activity of the company is interrupted by the emergence of this risk.
    - Track and trace of vehicles include the operation of deciding the current and previous locations (and other information) of different item or property. The company needs technological infrastructure to perform the process. If there is problem and risk in track and trace of vehicles, it causes delays in logistics process.
    - Seasonal logistics risk depends on the demand changes among the seasons. As an example in summer, demand can be much more than winter, as a result, logistics activities become frequent with the increasing demand in the related time.

4.2. Implementation of the Proposed Methodology on Case Study

Initially, managers in the case company were asked to meet with their teams and to present a consolidated evaluation data as a result of these interviews. In the following sections, where the application is explained step-by-step, the terminology "DM" reflects the aggregated opinion of the relevant manager and their team. This term was used to facilitate the follow-up of the application steps throughout the study.

The aggregated data obtained as a result of interviews with each manager's team were used as an input and the weighted values of S, O and D are calculated via IF-AHP. The weighted values are shown as WS, WO, and WD respectively. Thereafter, as the second step, the R-RPN of each risk sub-criterion is calculated via modified FMEA. WS, WO and WD are used as the inputs for modified FMEA.

4.2.1. Determination of Criteria Weights with IFs-AHP

In determining the weights of S, O and D, IFs-AHP structure is used. The data is provided by managers which have different importance weights. The hierarchy of the evaluation process is presented in Figure 2.

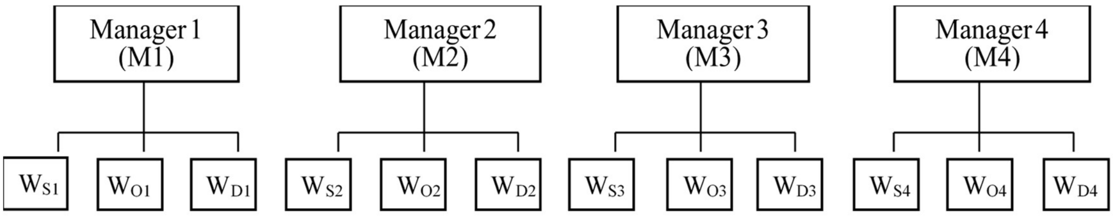

Figure 2. Analytical hierarchy process structure of the case study.

Each managers' evaluations for criterion using linguistic scale given in Table 4 and their intuitionistic scores are presented in Table 6.

Table 6. Criteria evaluations provided by the decision makers.

Manager 1 (M1)								
--	S	O	D	→	--	S	O	D
S	EI	MMI	EMI		S	(0.02; 0.18)	(0.13; 0.27)	(1; 0)
O	1/MMI	EI	IV		O	(0.27; 0.13)	(0.02; 0.18)	(0.06; 0.23)
D	1/EMI	1/IV	EI		D	(0; 1)	(0.23; 0.06)	(0.02; 0.18)
Manager 2 (M2)								
--	S	O	D	→	--	S	O	D
S	EI	1/MMI	1/EMI		S	(0.02; 0.18)	(0.27; 0.13)	(0; 1)
O	MMI	EI	1/VSMI		O	(0.13; 0.27)	(0.02; 0.18)	(0.18; 0.62)
D	EMI	VSMI	EI		D	(1; 0)	(0.62; 0.18)	(0.02; 0.18)
Manager 3 (M3)								
--	S	O	D	→	--	S	O	D
S	EI	1/IV	SMI		S	(0.02; 0.18)	(0.28; 0.22)	(0.33; 0.27)
O	IV	EI	EMI		O	(0.22; 0.28)	(0.02; 0.18)	(1; 0)
D	1/SMI	1/EMI	EI		D	(0.27; 0.33)	(0; 1)	(0.02; 0.18)
Manager 4 (M4)								
--	S	O	D	→	--	S	O	D
S	EI	1/MMI	1/VSMI		S	(0.02; 0.18)	(0.27; 0.13)	(0.18; 0.62)
O	MMI	EI	1/SMI		O	(0.13; 0.27)	(0.02; 0.18)	(0.27; 0.33)
D	VSMI	SMI	EI		D	(0.62; 0.18)	(0.33; 0.27)	(0.02; 0.18)

DMs are rated based on the linguistic term scale which is presented in Table 5. The evaluation of DMs and their calculated weights, in which Eq. (9) is used, are presented in Table 7.

After the determination of DMs' weights, fuzzy decision matrix is calculated by applying the IFWA operator. Provided information is aggregated and final scores are presented as aggregated matrix in Table 8.

Table 7. Decision makers' weights.

Manager	Linguistic Terms	μ	ν	π	Weights
M1	Very Important	0.8	0.1	0.1	0.277
M2	Very Important	0.8	0.1	0.1	0.277
M3	Important	0.5	0.2	0.3	0.223
M4	Important	0.5	0.2	0.3	0.223

Table 8. Aggregated Matrix.

Dimensions	S			O			D		
	μ	ν	π	μ	ν	π	μ	ν	π
S	0.020	0.180	0.020	0.236	0.179	0.241	1.000	0.000	0.849
O	0.191	0.222	0.198	0.020	0.180	0.020	1.000	0.000	0.601
D	1.000	0.000	0.849	0.349	0.213	0.388	0.020	0.180	0.020

To compute the final IF weights of each criterion, step 5 of the proposed IFs-AHP model is applied. Based on the related calculations (Eq. (11) and Eq. (12)), final weight scores are found and these scores are presented in Table 9.

Table 9. Weight values of Severity, Occurrence and Detectability.

Weights of Dimensions	μ	ν	π
Weight of Severity (WS)	0.388167	0.523021	0.088812
Weight of Occurrence (WO)	0.361892	0.559930	0.078178
Weight of Detectability (WD)	0.442442	0.552132	0.005426

The scores of WS, WO and WD, determined IF weights, are used to calculate R-RPN values. However, IF scores should be converted to crisp numbers since WP method is used in calculating R-RPN values. Thillaigovindan et al. [41] stated that major problem in dealing with IFs is transforming them into a single numerical value although IFs can represent the DMs' opinions effectively. According to study, score functions can be considered as a tool for turning the intuitionistic sets to a single real number. In 2011, Chen [42] made a comparative analysis for score functions in IFs and compared six different score functions then suggested an appropriate score function which is presented in Eq. (15):

$$S(x_{ij}) = \mu_{ij} - v_{ij}.\pi_{ij} \tag{15}$$

Score function is evaluated as a proper function especially in a complex decision-making problem. In this study, Eq. (15) is used to find single value for each criterion. After the equation is applied to the values given in Table 9, final weights for WS, WO and WD are found as 0.342; 0.318 and 0.440, respectively.

4.2.2. Calculation of R-RPNs for Each Sub-risk

The obtained values of WS, WO and WD are used in finding R-RPNs. Sub-risks are evaluated by experts from the case study company based on the scale given in Table 2 and Table 3. In Table 10, these evaluations and their IF scores are presented.

Table 10. Evaluated sub-risks.

Attributes	Occurrence	Severity	Detection	Occurrence μ	Occurrence ν	Occurrence π	Severity μ	Severity ν	Severity π	Detection μ	Detection ν	Detection π
SUPPLY RISKS												
Supplier's Inventory	4	7	9	0.22	0.28	0.5	0.62	0.18	0.2	0.8	0.1	0.1
Company's Inventory	2	8	1	0.06	0.23	0.7	0.62	0.18	0.2	0.02	0.18	0.8
Incapable Supplier	6	5	7	0.47	0.23	0.3	0.33	0.27	0.4	0.62	0.18	0.2
Inconsistent Forecast	10	5	10	1	0	0	0.33	0.27	0.4	1	0	0
FINANCIAL RISKS												
Uncertainty on Foreign Exchange Rate	10	10	3	1	0	0	1	0	0	0.13	0.27	0.6
The Threat of Economic Crisis	8	9	3	0.62	0.18	0.2	0.8	0.1	0.1	0.13	0.27	0.6
Cyber Risks	4	8	6	0.22	0.28	0.5	0.62	0.18	0.2	0.47	0.23	0.3
Disagreement on Financial Aspects with Supplier	5	5	6	0.33	0.27	0.4	0.33	0.27	0.4	0.47	0.23	0.3
OPERATIONAL RISKS												
Inconsistent Production Rate	6	6	2	0.47	0.23	0.3	0.47	0.23	0.3	0.06	0.23	0.7
Database Issues within the Company	7	7	3	0.62	0.18	0.2	0.62	0.18	0.2	0.13	0.27	0.6
Mismanaging the Employees	3	7	3	0.13	0.27	0.6	0.62	0.18	0.2	0.13	0.27	0.6
Inadequate or Unqualified Employers	3	9	3	0.13	0.27	0.6	0.8	0.1	0.1	0.13	0.27	0.6
DEMAND RISKS												
Unanticipated or Volatile Customer Demand	10	9	10	1	0	0	0.8	0.1	0.1	1	0	0
Equivalent Products	7	3	6	0.62	0.18	0.2	0.13	0.27	0.6	0.47	0.23	0.3
Change in Market Trend	4	5	9	0.22	0.28	0.5	0.33	0.27	0.4	0.8	0.1	0.1
Price Strategy	2	8	1	0.06	0.23	0.7	0.62	0.18	0.2	0.02	0.18	0.8
LOGISTIC RISKS												
Inefficiency in Transport Infrastructure (Technically)	4	5	3	0.22	0.28	0.5	0.33	0.27	0.4	0.13	0.27	0.6
Vehicle Procurement Problem	7	9	2	0.62	0.18	0.2	0.8	0.1	0.1	0.06	0.23	0.7
Track and Trace of Vehicles	6	7	5	0.47	0,23	0.3	0.62	0.18	0.2	0.33	0.27	0.4
Seasonal Logistics	7	6	3	0.62	0.18	0.2	0.47	0.23	0.3	0.13	0.27	0.6

After the evaluations are collected from the experts for each sub-risk, R-RPN values are calculated via considering the weight values that are found with IFs-AHP and presented in Table 11.

4.2.3. Ranking Sub-risks and Results

Comparison of the IF values is an important problem and several methodologies are generated and used in literature. However, score and accuracy functions are basically suggested for comparisons [37]. Dymova et al. [34] defined the comparison of IFs based on the order relationships between any pair set and used the formulation given in Eq. (16). Let a and b be two IFs sets. Suppose that S(x) =μ(x) +ν(x) represents the score function and that H(x) =μ(x)-ν(x) represents the accuracy function. Comparison of the two IFs sets depend on the following calculations:

$$If\ S(a) > S(b), then\ b\ is\ smaller\ than\ a;$$

$$If\ S(a) = S(b), then$$

$$(1)\ If\ H(a) = H(b), then\ a = b;\ (2)\ If\ H(a) < H(b), then\ a\ is\ smaller\ than\ b. \quad (16)$$

Table 11. R-RPN values based on proposed methodology.

R-RPN Values	μ	ν	π
SUPPLY RISKS			
Supplier's Inventory	0.9946774	0.0002939	0.0050287
Company's Inventory	0.9284840	0.0004365	0.0710795
Incapable Supplier	0.9871943	0.0006798	0.0121259
Inconsistent Forecast	1	0	0
FINANCIAL RISKS			
Uncertainty on Foreign Exchange Rate	1	0	0
The Threat of Economic Crisis	0.9938859	0.0002791	0.0058349
Cyber Risks	0.9839098	0.0007049	0.0153853
Disagreement on Financial Aspects with Supplier	0.9735362	0.001054	0.0254098
OPERATIONAL RISKS			
Inconsistent Production Rate	0.9655471	0.0007396	0.0337133
Database Issues within the Company	0.9874129	0.0005181	0.0120690
Mismanaging the Employees	0.9580722	0.0008057	0.0411221
Inadequate or Unqualified Employers	0.979634	0.0004341	0.0199320
DEMAND RISKS			
Unanticipated or Volatile Customer Demand	1	0	0
Equivalent Products	0.9796825	0.0006777	0.0196398
Change in Market Trend	0.9887868	0.0004577	0.0107555
Price Strategy	0.9284840	0.0004365	0.0710795
LOGISTIC RISKS			
Inefficiency in Transport Infrastructure (Technically)	0.9289269	0.0013066	0.0697665
Vehicle Procurement Problem	0.9926722	0.0002345	0.0070933
Track and Trace of Vehicles	0.9876278	0.0006751	0.0116971
Seasonal Logistics	0.9809490	0.0006756	0.0183753

Table 12. Score and Accuracy Function values of sub-risks.

Attributes	Score Function Value	Accuracy Function Value
SUPPLY RISKS		
Supplier's Inventory	0.9943835	0.994971319
Company's Inventory	0.9280474	0.928920529
Incapable Supplier	0.9865145	0.987874073
Inconsistent Forecast	1	1
FINANCIAL RISKS		
Uncertainty on Foreign Exchange Rate	1	1
The Threat of Economic Crisis	0.9936068	0.994165060
Cyber Risks	0.9832049	0.984614675
Disagreement on Financial Aspects with Supplier	0.9724822	0.974590173
OPERATIONAL RISKS		
Inconsistent Production Rate	0.9648075	0.966286738
Database Issues within the Company	0.9868948	0.987930972
Mismanaging the Employees	0.9572665	0.958877867
Inadequate or Unqualified Employers	0.9791999	0,980068044
DEMAND RISKS		
Unanticipated or Volatile Customer Demand	1	1
Equivalent Products	0.9790047	0.980360225
Change in Market Trend	0.9883291	0.989244463
Price Strategy	0.9280474	0.928920529
LOGISTIC RISKS		
Inefficiency in Transport Infrastructure (Technically)	0.9276204	0.930233487
Vehicle Procurement Problem	0.9924377	0.992906727
Track and Trace of Vehicles	0.9869527	0.988302948
Seasonal Logistics	0.9802734	0.981624655

Firstly, the score and accuracy function values are calculated for each sub-risk based on the values presented in Table 11. Results are presented in Table 12.

According to the calculated score and accuracy function values, Eq. (15) is implemented to each sub-risk and then final ranking is determined via comparing each sub-risk pair separately. In Table 13, the final rankings of the mentioned sub-risks are presented.

Table 13. Rankings of the sub-risks.

Attributes	Final Rankings
SUPPLY RISKS	
Supplier's Inventory	2
Company's Inventory	16
Incapable Supplier	8
Inconsistent Forecast	1
FINANCIAL RISKS	
Uncertainty on Foreign Exchange Rate	1
The Threat of Economic Crisis	3
Cyber Risks	9
Disagreement on Financial Aspects with Supplier	13
OPERATIONAL RISKS	
Inconsistent Production Rate	14
Database Issues within the Company	7
Mismanaging the Employees	15
Inadequate or Unqualified Employers	11
DEMAND RISKS	
Unanticipated or Volatile Customer Demand	1
Equivalent Products	12
Change in Market Trend	5
Price Strategy	16
LOGISTIC RISKS	
Inefficiency in Transport Infrastructure (Technically)	17
Vehicle Procurement Problem	4
Track and Trace of Vehicles	6
Seasonal Logistics	10

Regarding the final rankings shown in the Table 13, the three most important risks are determined as "Inconsistent Forecast", "Uncertainty on Foreign Exchange Rate" and "Unanticipated or Volatile Customer Demand". Hence, the required regulatory actions can be performed by obeying the obtained rankings.

5. Conclusions

In this paper, the SC risk factors, which have the highest risk rates, are aimed to be determined. Initially, literature is reviewed and surveys are applied to reveal the possible risk factors. As an output of this part, five main risk factor categories including Supply, Demand, Operational, Financial and Logistic Risks are determined. Moreover, to specify the sub-risks, data collection tools are used as meetings with experts and literature review. A couple of meetings are set with experts to observe the sub-risk factors in the case company in detail.

Besides risk identification and classification, risk assessment stage is also one of the most important parts in risk management process. Various techniques are used at this stage and there is no one dominant technique. Based on the importance of this stage, a hybrid model is proposed to assess the sub-risks of the stated SC risk categories. In the generated hybrid model, IFs are used to evaluate the opinions of DMs. It is a well-known fact that FMEA is one of the most used methodologies and it is very popular among risk assessment studies. However, there are several deficiencies in this method. Especially, the methodology causes a very important shortcoming in terms of weight calculations of severity, occurrence and detection. To eliminate this deficiency, WP is embedded to the method to provide a more accurate calculation basis. Thus, an integrated model of FMEA and IF-AHP is proposed. By this way, Revised RPN value is obtained for each sub-risk after the application of the questionnaire method on the managers for determining risk assessment criteria weights.

As a result of the proposed methodology, the most important sub-risks have been decided as "Inconsistent Forecast", "Uncertainty on Foreign Exchange Rate" and "Unanticipated or Volatile Customer Demand". As an output of this paper, a comprehensive SC risk ranking report is provided for the company. The company can use that output, to take precautions or set their own risk priorities. Hence, the main earning is basically to define the possible SC risks before they occur. Also, this project's output can be used by similar companies' SC operations. For the further studies, the specified most important sub-risks can be analyzed deeply to define the source and eliminate the possible effects of these sub-risks in order to prevent any kind of losses. Apart from this, different risk assessment methods can be applied in the same business unit and the results can be compared. Moreover, the output of this study can be adapted to other industries.

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