Risk Management for Cold Supply Chain: Case of a Developing Country

Amin Ullah Khan[1], Yousaf Ali[2], Dragan Pamucar[3], László Vasa[4]

[1] Ph.D. Scholar at Department of Economics and Law, University of Macerata, Via Crescimbeni 14, Macerata City, Italy, Email: a.ullah1@unimc.it

[2]Associate Professor, School of Management Sciences, Ghulam Ishaq Khan Institute of Engineering Sciences & Technology,23640, Topi, Swabi, KPK, Pakistan, Email: yousafkhan@giki.edu.pk

[3]Professor, Department of Logistics, University of Defense, Belgrade 11000, Serbia

[4]Professor, Széchenyi István University, H-9026 Győr, Hungary, Email: laszlo.vasa@ifat.hu

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Abstract: Cold Supply Chain (CSC) involves temperature-controlled activities in the overall process, ranging from the raw material storage to the final supply of the products to the consumers. The activities involved are easily exposed to risks such as temperature and humidity, equipment failure and quality risk to name a few. Such sensitive processes need proper risk mitigation strategies, to ensure the effective functioning of the overall CSC. For this purpose, the current research conducted a vigorous literature review and identified 40 relevant risks related to CSC in a developing country. The risks were analyzed using Failure Mode and Effect Analysis (FMEA)-Risk Priority Number (RPN) technique to shortlist the significant risks. The significant risks were then subjected to the Full Consistency Method (FUCOM) for prioritization. The results concluded, contamination of food, temperature and humidity and quality as the top-three risks that can be dangerous for the overall cold supply chain. To overcome these risks, the study recommends the proper implementation of traceability systems and Radio Frequency Identification (RFID) systems. Furthermore, employing the latest technologies and efficient personnel training can also help overcome these risks. Such an application of the study in the case of a developing country, Pakistan's CSC forms to be the first of its kind. Furthermore, the application of FMEA-RPN along with the FUCOM technique in the scenario of CSC risk management forms the novelty of this research study.

Keywords: Risk; Cold Chain; FMEA; FUCOM; RFID

1 Introduction

A supply chain can be defined as the set of chains that includes the flow of goods and services from their raw material stage to the end consumers [1]. A supply chain network consists of various sectors that include Fast Moving Consumer Goods (FMCG), automotive, electronic, pharmaceutical and services [2]. One such area of the supply chain, which is being considered currently, is the Cold Supply Chain (CSC). A cold supply chain can be defined as the network that must keep the products stored and transported in a high standard, temperature-controlled environment [3]. The cold supply chain preserves products such as medicines, vaccinations, vegetables, fruits, fast food, seafood, meat, and dairy products to mention a few [4].

Industries having different supply chains are associated with various types of risks during their operations. For example, globally, industries like that in Taiwan have been under the effect of rapid changes in the supply chain and those uncertainties have led to the rise in the supply chain risks. Some of the risks identified were operational, inefficiency in the systems and ineffective employees' risks [5]. Furthermore, quality risks, order constraints, product-related operations and transportation, and logistics accounts to be the typical risks related to the overall supply chains across various industries [6]. These risks can also be associated with the cold supply chain risks globally in the various industries ranging from lack of uniform infrastructure, increased regulations and environmental emissions from cold chain technology [7]. Furthermore, the Cold supply chain consists of very sensitive conditions and requires a temperature-controlled environment [8]. The availability of technologically advanced facilities is imminent for the proper functioning of the cold supply chain. The condition of the frozen products is solely dependent upon the facilities that must be available in a cold supply chain, starting from the initial point and to the end customers [9].

In Pakistan, the role of the cold supply chain is not properly established and that is why the rate of product losses is one of the associated major risks. In 2011, it was estimated that 32% of the food produced gets wasted in Pakistan [10]. According to [11] the general population of Pakistan spent $1.3 billion on frozen or readymade food and such a huge demand accounts for a big-sized market with proper regulations in place. The market demand and supply, if not kept in a balance, can incur many risks to the overall cold supply chain and thus rendering a huge number of losses [12]. Pakistan being an agricultural country, it needs to have developed cold or food supply chains. The application of such an extent could prove to be beneficial for the stakeholders and resulting in developed value-added activities, as recommended by a study carried out in the case of African agriculture [13]. Since the cold supply chain is not established on a much larger scale in Pakistan, the overall operations are very much exposed to various risks. Some of the risks involve the losses incurred in the investments, low standard of kitchen run companies, price wars, fluctuating electricity supply and expensive electrical equipment to mention a few [14]. These risks are connected with various indicators such as transportation, pollution of the environment, warehousing, microbial contamination, and logistics to mention a few. Furthermore, the risks are harder to be analyzed as the overall process consists of complexities that render the analysis of the risks rather difficult if it’s being done under the traditional methods.

The objective of the research is to consult such complexities and perform the risk assessment of the cold supply chain by two different methods i.e., Failure Modes and Effect Analysis (FMEA) and Full Consistency Method (FUCOM). In the first stage of the study, the FMEA method evaluates the risk of failure based on Risk Priority Number (RPN) by taking the Severity, Occurrence and Detection level of the risk into account [15]. It will help categorize or short-list the risks that are associated with the cold supply chain in the context of Pakistan. This will be done through the evaluation of forty risk factors to identify the most prominent ones that are bound to be associated with the cold supply chain of Pakistan. Furthermore, the second stage of this study takes a new subjective Full Consistency Method (FUCOM) into account. The significant risks shortlisted from the first stage are then fed to the FUCOM technique, to prioritize the most hazardous risk that a CSC in the case of a developing country might face during its entire process. Lastly, relevant mitigation strategies are then recommended to overcome the risk factors that might render the cold supply chain ineffective.

2 Literature Review

Risks can have long-lasting and undesirable effects on the investments carried out by the companies and the overall economy of the countries [16]. A study conducted in Vietnam concluded that government-assisted industries proved to be safer and less risky as compared to industries such as oil, gas, and securities that proved to be more vulnerable to risks. Those industries resulted in fluctuating economy and financial risks for the country because they lacked support from the government [17]. Similarly, financial risks can also arise for the carbon-intensive industries when they shift to a low-carbon economy, resulting in the industries failing to achieve their financial requirements [18]. Such risks in different industries account for proper assessment and management to be analyzed for the danger they can pose towards a certain organization or an economy. The risk assessment and management concept was introduced about thirty to forty years ago. The main motivation behind this concept was to hypothesize, evaluate and manage the risks [19]. One such application of risk assessment and management was carried out in relation to B2B market. The study explored the investment process and evaluated the perceived risk factors in the case of an investment project in relation to a B2B market [20]. Since its inception, it has been employed in various sectors such as the supply chain of various companies to ensure proper evaluation and mitigation of the risks. The assessment and management of the risks in a supply chain are thus, defined as supply chain risk management [21]. Based on the previous discussion, the focus of this study is to assess one of the most critical areas of the supply chain i.e., the cold supply chain for the assessment and management of possible risks that can harm the overall process of CSC.

The cold supply chain consists of practices that are temperature-controlled and needs proper observation and critical care to avoid any issues and damages. The whole network is based on a temperature-controlled environment that ranges from +2 to 8°C to ensure smooth operations of the cold chain network [22]. It includes operations such as keeping the temperature under controlled conditions during transportation. These control conditions show that the cold chain is a quite sensitive network and these conditions render it to be exposed to various risks and failures. Various studies have tried to analyze the cold chain network for various purposes but very few have tried to explore the possibilities of risk towards the overall process. A study conducted for the modeling of optimized design for the cold supply chain concluded that the whole process possesses the risk of greenhouse emissions due to the intensive energy consumption along with the release of refrigerant gases [23]. Furthermore, a study conducted in India explored the possible factors that can affect the overall cold supply chain from a business perspective. Based on the Indian market, some of the imminent risks highlighted were operational, technological, financial, strategic and environmental risks to mention a few. Risk management was concluded to be one of the most critical steps that needed to be considered to resolve these risks while taking the business of the cold chain into account [24]. Furthermore, next-generation cold supply chains are more oriented towards food products. That is because they are more exposed to risks such as shorter shelf-lives, perishable products, damaged quality, and larger supply distances from the manufacturer to the consumer [25]. Similarly, the pharmaceuticals are also exposed to various risks such as the freezing risk involved in the transportation of the tetanus vaccines, etc., where the heat exposure risk is quite lesser as compared to the freezing risk [26]. Furthermore, another study highlights the importance of Time-Temperature Indicators (TTIs) in the detection of pathogens in a serving (of food). TTIs when being irresponsive can pose regulatory or consumer risk, that is the time it takes to detect the pathogen which can result in quite serious health issues [27]. Similarly, another study conducted for the vaccination supply chain in the context of a cold chain concluded the risks of potential hardware failure and incurring the additional cost to cover the losses [28].

Additionally, some of the studies tried to explore the risk factors from the technological point of view. A study considered the Internet of Things (IoT) to monitor the cold supply chain for potential risks. It was concluded that the workers employed in the temperature-controlled environment as low as -15°C can suffer occupational safety risks, illness related to cold temperature, health issues, cold injuries like trench foot and frostbite to mention a few [29]. Similarly, one study introduced the concept of neural networks for risk prediction in terms of the cold supply chain. The model predicted that the indicators such as humidity, temperature, the real-time accessibility of electric vehicles, and the environmental conditions of the overall chain can pose risks with major negative impacts [30]. The aforementioned studies depict some of the risks that have been highlighted across the cold supply chain process in the previous literature. No study, in a developing country, such as, Pakistan covers the risks that can be associated with the cold supply chain of the country. This research study aims to cover that gap by prioritizing the risks that are connected with the cold supply chain of Pakistan and recommending necessary mitigation strategies to manage the risks.

There are various techniques available that have helped the researchers to assess the risks according to their requirements in the previous literature. Some of the widely used techniques being utilized in the previous research include Multi-Criteria Decision-Making techniques (MCDM) [31], Interpretive Structural Modeling (ISM) [32] to mention a few. Furthermore, recently the Failure Mode and Effects Analysis (FMEA) has been incorporated into various studies by the researchers to analyze the risks in the various sectors. FMEA was first introduced by the United States Army in the 1950s to classify the failures based on their effects on the overall success of the process along with the machine or human safety [33]. Since, its inception, various studies have explored this technique for various applications. One study incorporated FMEA and Fault Tree Analysis (FTA) for the analysis of failures in the additive industrialized system for metal printing. The methods were utilized to evaluate the most critical risk factors in the overall process for metal printing [34]. FMEA also holds its applications in industries such as wind turbines where [35] used hybrid cost-FMEA analysis to evaluate the criticality of the wind turbines. The techniques were also used to identify weaknesses and incorporate reliability analysis of the wind turbine systems. Furthermore, FMEA analysis was also incorporated for the reduction of the most prominent risk priority failures in the sterilization of a big hospital. The technique identified the most prominent hazards that the unit might face during its operations [36]. Similarly, FMEA also holds its applications in the medical industry where one study utilized this approach to analyze risks associated with the Gamma knife radiosurgery. FMEA highlighted 40 high-profile risks out of the 86 failure modes. This approach helped to counter them easily once they were being reduced to the most critical risk failures that could have a damaging impact on the overall process [37]. Furthermore, FMEA also holds its applications with the fuzzy set theory where it can be utilized for situations such as the risk assessment for the supercritical water gasification system. The analysis concluded incompatible material selection, reactor design, and corrosion to be the most high-profile risks that the system can face [38]. The previous literature involves justified applications of the FMEA technique and for this purpose, the current research study will incorporate the FMEA-Risk Priority Number (RPN) technique to highlight the significant risks initially identified from the literature review.

The second stage involves the prioritization of the risks that were being highlighted by the FMEA-RPN analysis in the previous step. For prioritization, the current study incorporates the Full Consistency Method (FUCOM). FUCOM possesses various applications by identifying the weight coefficients of the factors or the criteria along with the concluding values of deviation from the full consistency (DFC). The application of the FUCOM technique can be depicted from a comparative study between various techniques such as FUCOM, Best Worst Method (BWM) and Analytical Hierarchal Process (AHP). The study concluded FUCOM to be the best technique for the analysis of weight coefficients of the concerned criteria [39]. Furthermore, a hybrid technique was formed between FUCOM and Interval Rough Combined Compromise Solution (CoCoSo). The reason for establishing this combination was to evaluate the stock management system in storage to find the significance of various parameters and to find the optimal suppliers for each product group [40]. Similarly, FUCOM also possesses its applications in the contractor selection by using the same concept of weighting, in combination with Grey-Stepwise Weight Analysis Ratio Assessment (SWARA) method [41]. Furthermore, Delphi-FUCOM-Service Quality (SERVQUAL) model was employed to improve the service quality of logistics services [42]. FUCOM also holds its applications with the fuzzy set theory in a hybrid combination with TOPSIS to select the best location for the Radio Frequency Identification (RFID) monitoring device. The aim was to identify the macro and micro-location of the RFID device on the railway line of Serbian Railways [43]. Assessing a rural settlement for tourism development is another application of FUCOM technique. A study carried out in the Brcko district of Bosnia and Herzegovina assessed the rural tourism potential of the settlements and provided evaluation of the sustainability of the rural tourism in the region [44]. Furthermore, a hybrid combination of FUCOM and AHP techniques were applied to assess the performance and evaluation of four different airlines via a comparative study. The study proved reliability as the most important performance factor [45]. The selection of a sustainable supplier in the case of supply chain is one of the key applications of the FUCOM technique in combination with Rough SAW model [46]. A comparative analysis study carried out for the selection of forklift in a warehouse involved the hybrid application of FUCOM technique with WASPAS model. The study also implemented the possibility of applying the model in the case of a group-decision making scenario [47]. Similarly, for more accurate results, one study proposed the idea of Fuzzy-FUCOM method under the scenario of a green supplier selection [48]. Another interesting application involves selection of a brigade command post's critical location to provide better results in the case of combat operations. The study involved a hybrid combination of FUCOM with Z-number and MABAC model [49]. FUCOM also holds its application in the form of a hybrid combination with a multi-criteria decision-making technique for car selection in the case of Pakistan [50]. Lastly, evaluation of the barriers involved in the circular supply chain management of the pharmaceutical industry in the case of a developing country combined fuzzy-FUCOM with fuzzy-QFD technique [51].

2.1 Research Gap

Based on the above literature review, it can be justified that the previous literature lacks the risk assessment and its mitigation in the area of the cold supply chain, in the context of a developing country like Pakistan. Furthermore, previous literature possesses no application of the novel hybrid technique i.e. FMEA-RPN along with the FUCOM method for risk identification and prioritization, both in the context of developed and developing countries. The assessment of risks and their mitigation in the area of the cold supply chain forms a research gap and the main purpose of this study. Similarly, the application of the novel hybrid technique FMEA(RPN)-FUCOM tends to formulate a new approach thus forming a methodological novelty for the current research.

3 Methodology

3.1 Data Collection for FMEA-RPN

The data collection for this study is based on various stages starting from the risk collection based on a vigorous literature review. The risks that were collected from the literature review, relevant to this study are depicted in Table 3. Analysis of these risks is based on two different stages and for this purpose, two different questionnaires were drafted for the FMEA-RPN and FUCOM methods respectively.

The first step of the study is to minimize the listed risks to identify the most significant risks using the FMEA-RPN method. For this purpose, a questionnaire was drafted for the 40 risk factors, which were evaluated by the experts based on a scale from 1 to 10. The questionnaire comprised of three different sections i.e., evaluation of risks based on Occurrence, Severity and Detection respectively. Data were collected through the questionnaire from 18 decision-makers. The breakdown of the experts' profiles is depicted in Table 1. The number of experts can be justified from the fact that only the relevant experts related to the cold supply chain area were contacted to serve the purpose of avoiding unauthentic responses.

Table 1

Experts' Profile respondents for FMEA-RPN analysis

Expert Profile	Number of respondents
Supply chain managers	6
Academic experts/researchers	5
Industrial experts	3
Supply chain researchers	4

The data collected from the experts is subjected to the FMEA-RPN method to evaluate the most significant and relevant risk factors.

Steps involved in the FMEA-RPN method are as follows.

3.2 FMEA-RPN Method

The Risk Priority Number (RPN) method in FMEA methodology considers three risk factors and analyzes the risk modes by ranking them on a scale of 1 to 10. The three factors include Occurrence, Severity and Detection and are calculated as a mathematical product as shown in Equation 1.

$$RPN = S \times O \times D \in [1, 1000] \qquad (1)$$

Three different evaluation criteria were adopted for the occurrence, severity and detection based on the 1 to 10 scale. The rating of the expert for a risk's occurrence ranges from 1 to 10 i.e., from nearly impossible to the extremely high chances of happening. Furthermore, the expert rates a risk based on its severity ranging from 1 (risk does not affect) to 10 (risk being extremely hazardous). Lastly, a risk-rated by an expert based on its probability of being detected, ranging from 1 (certain chance of risk detection) to 10 (almost uncertain risk detection). The expert ratings for all three factors are utilized in equation 1 to identify the risk priority number for each of the risks and to identify the significant risk factors that are to be further evaluated in the second phase.

3.3 Data Collection for FUCOM

The risks identified after evaluation through the FMEA based RPN method are now subjected to risk prioritization through the FUCOM method. For this purpose, data were collected from the experts to rank the risks based on their danger to the CSC. A Likert scale of 1 to 5 was adopted with 1 showing the risk being very less risky while 5 depicts the risks to be very risky. 24 experts responded to the questionnaire according to their expertise for FUCOM analysis to prioritize the risks involved. The experts' profile is depicted in Table 2. The steps involved in the FUCOM technique are as followed.

Table 2

Experts' profile respondents for FUCOM analysis

Expert Profile	No. of respondents
Supply chain managers	12
Academic experts/researchers	2
Industrial experts	8
Supply chain researchers	2

3.4 FUCOM

Full Consistency Method (FUCOM) is based on the pairwise comparison principle and involves the deviation from maximum consistency to validate the results. The method was developed by [39] to ensure that factors or the criteria can be evaluated while encountering lesser deficiencies. The major advantage that FUCOM possesses is involving a lesser number of pairwise comparisons of the factors i.e. n-1, where n shows the number of factors of criteria. Similarly, the FUCOM method helps in removing the redundancy of pairwise comparisons of the factors, which might occur in subjective models for evaluating weights for the factors. Since FUCOM evaluates the weights of the factors or the criteria, this study incorporates the same concept to evaluate the weights of the risks, for risk prioritization. To do so, the data collected from the experts mentioned in Table 2. is analyzed using the FUCOM method by utilizing the following steps.

Step 1: In the first step, the risk factors are ranked according to their significance by the experts. They are ranked from the predefined set of risk factors. The risk factors are arranged according to their weights, in descending order (risk with more weight is arranged at the starting point). The representation is given in Equation 2.

$$R_{j\,(1)} > R_{j\,(2)} > \cdots > R_{j\,(l)} \tag{2}$$

Where R shows risk factors, arranged in descending order, based on weights assigned by the experts. Furthermore, l represents the rank of the risks. If the significance weights of any two risk factors are equal, = is placed instead of > between them.

Step 2: The second step involves the evaluation of comparative priority ($\frac{\alpha_l}{(l+1)}, l = 1,2,\dots,m$) of the risk factors is carried out through a comparison of the ranking factors. The comparative priority of the evaluation criteria is an advantage of the $R_{j\,(l)}$ ranked risk as compared to the risk factor of $R_{j\,(l+1)}$ rank. The comparative priorities of the risk factors are then depicted in the form of a vector and are shown in Equation 3.

$$\varphi = (\alpha_{\frac{1}{2}}, \alpha_{\frac{2}{3}}, \dots, \frac{\alpha_l}{l+1}) \tag{3}$$

Here, $\frac{\alpha_l}{l+1}$ represents the significance priority of the $R_{j\,(l)}$ ranked risk.

To do so, the significance UL of the top-ranked risk factor is determined with respect to the rest of the risk factors, by utilizing the absolute ratings (t) obtained from the experts. The significance is represented in Equation 4.

$$U_L = \frac{t_1}{t_L} \tag{4}$$

Here, if R1 > R2 > R3, then the value of R1 will be equal to 1 while R2 = $\frac{w_1}{w_2}$ and R3 = $\frac{w_1}{w_3}$ to calculate the significance values.

These values can then be considered to evaluate comparative priorities as shown in Equation 5.

$$\frac{\alpha_l}{l+1} = \frac{s_{l+1}}{s_l} \tag{5}$$

Step 3: The weights should satisfy two conditions to form a non-linear programming model.

The weight coefficient of the risks is equal to the comparative priority among the evaluated factors $\frac{\alpha_l}{l+1}$. The condition is depicted in Equation 6.

$$\frac{w_l}{w_{l+1}} = \frac{\alpha_l}{l+1} \tag{6}$$

The condition of mathematical transitivity should be satisfied by the final weight coefficient values of the risks as depicted in Equation 7.

$$\frac{w_l}{w_{l+2}} = \frac{\alpha_l}{l+1} \otimes \frac{\alpha_{l+1}}{l+2} \tag{7}$$

Minimum Deviation from Full Consistency (DFC) (χ) condition is only satisfied when the transitivity condition is met i.e. $\chi = 0$. The satisfaction of the mathematical transitivity conditions thus defines the consistency of the model [52]. That is the major reason for utilizing the FUCOM analysis, which is to minimize the DFC for accurate results.

Step 4: The final step consists of formulating a non-linear program model to achieve the final conclusive weights of the risk factors. The steps involved are depicted in Equation 8.

$$\min \chi \tag{8}$$

$$s.t.$$

$$\left| \frac{w_l}{w_{l+1}} - \frac{\alpha_l}{l+1} \right| \leq \chi, \forall_j$$

$$\left| \frac{w_l}{w_{l+2}} - \frac{\alpha_l}{l+1} \bigotimes \frac{\alpha_{l+1}}{l+2} \right| \leq \chi, \forall_j$$

$$\sum_{j=1}^{m} w_j = 1, \forall_j$$

$$w_j \geq 0, \forall_j$$

The non-linear model is subjected to LINDO software to calculate the weights of the risk factors and to obtain the degree of DFC (χ) to confirm the consistency of the results.

4 Results and Discussion

The results of this study are divided into two stages. The first stage narrows down the most significant risks and to do so, the traditional FMEA-RPN method is utilized to evaluate the data collected from the experts. FMEA's RPN technique is merely implemented to highlight or shortlist the most significant risks that can be evaluated further for prioritization in the next stage.

4.1 FMEA-RPN

The results from the first stage FMEA-RPN analysis are depicted in Table 3, which evaluates the risks based on their Occurrence, Severity, and Detection.

Table 3
FMEA-RPN analysis for the signification of Cold Supply Chain risks

Risk	Occurrence	Severity	Detection	Total	Rank
Contamination of food risk [53]	6.389	6.056	4.889	189.143	1
Quality risk [54]	5.556	6.167	5.000	171.296	2
Deficiency of facilities & equipment risk [55]	5.722	5.667	5.278	171.137	3
Environmental pollution of the plant risk [55]	5.889	5.333	5.444	170.996	4
Technological backwardness risk [56]	6.222	5.389	4.944	165.791	5
Poor management risk [54]	5.778	5.444	4.778	150.294	6
Market competition and uncertainty risk [57]	5.444	5.167	5.333	150.025	7
Manufacturing risk [58]	5.222	5.722	5.000	149.414	8
Temperature and humidity risk [59]	5.889	5.722	4.389	147.895	9
Supplier reluctance to shift towards sustainability risk [57]	5.833	5.000	5.056	147.454	10
Delivery planning risk [59]	5.889	5.611	4.444	146.859	11
Equipment failure risk [59]	6.167	5.333	4.444	146.173	12
Improper transport equipment risk [55]	5.722	5.167	4.889	144.539	13
Deliberate acts of theft risk [56]	5.222	5.167	5.333	143.901	14
Planning & control risk [58]	5.222	5.722	4.778	142.773	15
Supplier Reputation risk [54]	5.611	5.500	4.611	142.304	16
Cold chain failure risk [60]	5.167	5.667	4.833	141.509	17
Act of human error risk [56]	6.000	5.111	4.611	141.407	18
Instability of supply & demand risk [60]	5.389	5.500	4.722	139.961	19
Incorrect labelling & purchasing risk [53]	5.389	5.778	4.444	138.381	20

Risk	**Occurrence**	**Severity**	**Detection**	**Total**	**Rank**
Financial risk [54]	5.778	5.444	4.333	136.313	21
Delay rate of distribution risk [60]	5.111	5.444	4.833	134.498	22
Dangerous working methods risks [55]	5.444	5.667	4.333	133.691	23
Storage maintenance risk [59]	5.278	5.611	4.500	133.264	24
Lack of green practices risk [57]	5.944	4.778	4.611	130.961	25
Resistance to advancement risk [57]	5.444	5.056	4.722	129.978	26
Waste rate during distribution risk [60]	5.556	5.000	4.667	129.630	27
Traffic environmental risk [59]	5.722	4.833	4.611	127.531	28
Hardware failure risk [56]	5.000	5.389	4.722	127.238	29
Technical Software failure risk [56]	4.944	5.444	4.722	127.121	30
Customer acceptance risk [59]	5.222	4.944	4.722	121.932	31
Lack of government support risk [57]	5.278	5.056	4.444	118.587	32
Road traffic conditions risk	5.333	4.667	4.722	117.531	33
Physical plant risk [58]	4.944	5.722	4.000	113.173	34
Employee abuse risk [56]	4.833	4.833	4.722	110.316	35
Political instability risk [58]	4.000	5.000	5.333	106.667	36
Cold storage capacity risk [60]	5.056	5.056	3.833	97.975	37
Natural disaster risk [61]	4.222	5.444	4.222	97.059	38
Compromise to intellectual property risk [56]	4.722	4.500	4.333	92.083	39
Terrorist attacks risk [61]	3.222	5.111	5.222	86.005	40

Table 3 shows the RPN measure of the risks which were identified after a vigorous literature review. The RPN technique narrowed down the most significant risks that render the cold supply chain fails. The results represent that contamination of the food, quality risk and deficiency of facilities and equipment risks proves to be among the most significant risks that can render the process to fail. These are risks with the highest RPN values and possess a greater possibility of their occurrence, the measure of their severity, and harder to be detected.

Contamination of food comprises of chemical or foreign object contamination and its effects reach out to poor hygiene and health issues for the consumers. The occurrence values for the contamination of food show a higher trend, thus depicting that there is a higher risk for the contamination to occur in the cold chain. The values show that its occurrence cannot be ruled out from the cold supply chain of Pakistan and it must be given proper attention. Similarly, the severity is significant, which means that the cold chain's performance will be degraded once the products get contaminated. Furthermore, its detection level is moderate, which depicts that there will be a half-chance to detect the contamination of food that might have happened through the immersion of foreign objects or chemicals.

Similarly, the other two significant risks like the quality and deficiency of facilities and equipment risk depict a similar situation in case of occurrence, severity, and detection. The reason for their significance can be justified by the fact that quality is an integral part of the cold chain and it can easily shut down a business and ruin a company's image if the products' quality is not up to the mark. The quality risk is mainly linked to the overall process of the cold chain which proves to be its failure if the overall process gets compromised. Furthermore, poor facilities in the cold chain can contribute towards the deficiency of facilities and equipment risk, rendering the whole process to fail. Lack of facilities can affect the operations, result in quality damage during transportation and even result in drastic health hazards when the damaged frozen products are consumed.

From the FMEA-RPN analysis, only the top 20 significant cold chain risk factors i.e., contamination of food to Incorrect labelling & purchasing risk with the highest RPN values are selected to be prioritized/ranked further by evaluation through FUCOM assessment. The final ranked risks are then subjected to policy formulations and recommendations for risk management.

4.2 FUCOM

The next step involves risk prioritization through FUCOM analysis. FUCOM is employed to prioritize the 20 significant risk factors that were obtained from the FMEA-RPN analysis in the previous step. For this purpose, the data was collected from the relevant experts through a 5-point Likert scale. The data was collected to gather ratings for each of the risk factors on a scale of 1 to 5 and then the responses for each risk factor were averaged to get the absolute rating of each risk factor. The absolute ratings obtained after the responses gathered from the experts are depicted in Table 4.

The next step involves the calculation of significance (UL) of the top risk factor as compared to the other risks by utilizing equation 4. The analysis depicted that the most important risk factors constitute a significance of 1 i.e., contamination of food risk while the other factors possess a higher value greater than 1, depicting that they are less significant as compared to the most important risk factor.

Furthermore, the decision-makers perform a pairwise comparison of the ranked risk factors from the previous step. This step is performed using equation 5 and it evaluates comparative priority values (α) of the risk factors. The results are depicted in the form of comparative priorities of the risk factors evaluated through pair-wise comparison.

Table 4

Absolute rating of the risk factors assigned by the experts on a scale of 1 to 5

Risk	**Contamination of food risk**	**Temperature and humidity risk**	**Quality risk**	**Environmental pollution of the plant risk**	**Poor management risk**	**Technological backwardness risk**	**Deficiency of facilities & equipment risk**	**Supplier reluctance to shift towards sustainability risk**	**Incorrect labelling & purchasing risk**	**Improper transport equipment risk**	**Instability of supply & demand risk**	**Market competition and uncertainty risk**	**Cold chain failure risk**	**Equipment failure risk**	**Manufacturing risk**	**Planning & control risk**	**Delivery planning risk**	**Act of human error risk**	**Supplier Reputation risk**	**Deliberate acts of theft risk**
Absolute	3.917	3.667	3.625	3.542	3.458	3.333	3.208	3.167	3.167	3.125	3.083	3.042	3.042	3.000	2.958	2.958	2.833	2.708	2.667	2.583

The next step constitutes the two conditions that the final values of weights should comply with. The values are evaluated using condition equation 6 as shown in Table 5. The table shows that the final values of the weight coefficients equal the value of comparative priority, thus fulfilling the first condition. Furthermore, the weight coefficients meet condition 2 i.e., mathematical transitivity which is depicted by equation 7 and the results are represented in Table 6.

Table 5

The first condition is fulfilled with values of weight coefficients equaling comparative priorities

$$\frac{\boldsymbol{w1}}{\boldsymbol{w2}}=\mathbf{1.068},\frac{\boldsymbol{w2}}{\boldsymbol{w3}}=\mathbf{1.011},\frac{\boldsymbol{w3}}{\boldsymbol{w4}}=\mathbf{1.024},\frac{\boldsymbol{w4}}{\boldsymbol{w5}}=\mathbf{1.024},\frac{\boldsymbol{w5}}{\boldsymbol{w6}}=\mathbf{1.038},\frac{\boldsymbol{w6}}{\boldsymbol{w7}}=\mathbf{1.039},$$

$$\frac{\boldsymbol{w7}}{\boldsymbol{w8}}=\mathbf{1.013},\frac{\boldsymbol{w8}}{\boldsymbol{w9}}=\mathbf{1.000},\frac{\boldsymbol{w9}}{\boldsymbol{w10}}=\mathbf{1.013},\frac{\boldsymbol{w10}}{\boldsymbol{w11}}=\mathbf{1.014},\frac{\boldsymbol{w11}}{\boldsymbol{w12}}=\mathbf{1.014},\frac{\boldsymbol{w12}}{\boldsymbol{w13}}=\mathbf{1.000}$$

$$\frac{\boldsymbol{w13}}{\boldsymbol{w14}}=\mathbf{1.014},\frac{\boldsymbol{w14}}{\boldsymbol{w15}}=\mathbf{1.014},\frac{\boldsymbol{w15}}{\boldsymbol{w16}}=\mathbf{1.000},\frac{\boldsymbol{w16}}{\boldsymbol{w17}}=\mathbf{1.044},\frac{\boldsymbol{w17}}{\boldsymbol{w18}}=\mathbf{1.046},$$

$$\frac{\boldsymbol{w18}}{\boldsymbol{w19}}=\mathbf{1.016},\frac{\boldsymbol{w19}}{\boldsymbol{w20}}=\mathbf{1.032}$$

Table 6

The second condition of mathematical transitivity is fulfilled by weight coefficients

$$\frac{w1}{w3}=\frac{\alpha 1}{2}*\frac{\alpha 2}{3}=1.080,\quad \frac{w2}{w4}=\frac{\alpha 2}{3}*\frac{\alpha 3}{4}=1.035,\quad \frac{w3}{w5}=\frac{\alpha 3}{4}*\frac{\alpha 4}{5}=1.048,$$

$$\frac{w4}{w6}=\frac{\alpha 4}{5}*\frac{\alpha 5}{6}=1.063,\quad \frac{w5}{w7}=\frac{\alpha 5}{6}*\frac{\alpha 6}{7}=1.078,\quad \frac{w6}{w8}=\frac{\alpha 6}{7}*\frac{\alpha 7}{8}=1.053,$$

$$\frac{w7}{w9}=\frac{\alpha 7}{8}*\frac{\alpha 8}{9}=1.013,\quad \frac{w8}{w10}=\frac{\alpha 8}{9}*\frac{\alpha 9}{10}=1.013,\quad \frac{w9}{w11}=\frac{\alpha 9}{10}*\frac{\alpha 10}{11}=1.027,$$

$$\frac{w10}{w12}=\frac{\alpha 10}{11}*\frac{\alpha 11}{12}=1.027,\quad \frac{w11}{w13}=\frac{\alpha 11}{12}*\frac{\alpha 12}{13}=1.014,\quad \frac{w12}{w14}=\frac{\alpha 12}{13}*\frac{\alpha 13}{14}=1.014,$$

$$\frac{w13}{w15}=\frac{\alpha 13}{14}*\frac{\alpha 14}{15}=1.028,\quad \frac{w14}{w16}=\frac{\alpha 14}{15}*\frac{\alpha 15}{16}=1.014,\quad \frac{w15}{w17}=\frac{\alpha 15}{16}*\frac{\alpha 16}{17}=1.044,$$

$$\frac{w16}{w18}=\frac{\alpha 16}{17}*\frac{\alpha 17}{18}=1.092,\quad \frac{w17}{w19}=\frac{\alpha 17}{18}*\frac{\alpha 18}{19}=1.063,\quad \frac{w18}{w20}=\frac{\alpha 18}{19}*\frac{\alpha 19}{20}=1.048$$

Lastly, the expression 8 was utilized to formulate the model for determining the conclusive weight coefficients for the risk factors. The non-linear model formulated is mentioned below.

$$Min = \chi$$

Subjected to the following constraints

$$\left|\frac{W_1}{W_2}\text{-}1.068\right|\le\chi,\ \left|\frac{W_2}{W_3}\text{-}1.011\right|\le\chi,\ \left|\frac{W_3}{W_4}\text{-}1.024\right|\le\chi,\ \left|\frac{W_4}{W_5}\text{-}1.024\right|\le\chi,$$

$$\left|\frac{W_5}{W_6}\text{-}1.038\right|\le\chi,\ \left|\frac{W_6}{W_7}\text{-}1.039\right|\le\chi,\ \left|\frac{W_7}{W_8}\text{-}1.013\right|\le\chi,\ \left|\frac{W_8}{W_9}\text{-}1.000\right|\le\chi,$$

$$\left|\frac{W_9}{W_{10}}\text{-}1.013\right|\le\chi,\ \left|\frac{W_{10}}{W_{11}}\text{-}1.014\right|\le\chi,\ \left|\frac{W_{11}}{W_{12}}\text{-}1.014\right|\le\chi,\ \left|\frac{W_{12}}{W_{13}}\text{-}1.000\right|\le\chi,$$

$$\left|\frac{W_{13}}{W_{14}}\text{-}1.014\right|\le\chi,\ \left|\frac{W_{14}}{W_{15}}\text{-}1.014\right|\le\chi,\ \left|\frac{W_{15}}{W_{16}}\text{-}1.000\right|\le\chi,\ \left|\frac{W_{16}}{W_{17}}\text{-}1.044\right|\le\chi,$$

$$\left|\frac{W_{17}}{W_{18}}\text{-}1.046\right|\le\chi,\ \left|\frac{W_{18}}{W_{19}}\text{-}1.016\right|\le\chi,\ \left|\frac{W_{19}}{W_{20}}\text{-}1.032\right|\le\chi,\ \left|\frac{W_1}{W_3}\text{-}1.080\right|\le\chi,$$

$$\left|\frac{W_2}{W_4}\text{-}1.035\right|\le\chi,\ \left|\frac{W_3}{W_5}\text{-}1.048\right|\le\chi,\ \left|\frac{W_4}{W_6}\text{-}1.063\right|\le\chi,\ \left|\frac{W_5}{W_7}\text{-}1.078\right|\le\chi,$$

$$\left|\frac{W_6}{W_8}\text{-}1.053\right|\le\chi,\ \left|\frac{W_7}{W_9}\text{-}1.013\right|\le\chi,\ \left|\frac{W_8}{W_{10}}\text{-}1.013\right|\le\chi,\ \left|\frac{W_9}{W_{11}}\text{-}1.027\right|\le\chi,$$

$$\left|\frac{W_{10}}{W_{12}}\text{-}1.027\right|\le\chi,\ \left|\frac{W_{11}}{W_{13}}\text{-}1.014\right|\le\chi,\ \left|\frac{W_{12}}{W_{14}}\text{-}1.014\right|\le\chi,\ \left|\frac{W_{13}}{W_{15}}\text{-}1.028\right|\le\chi,$$

$$\left|\frac{W_{14}}{W_{16}}-1.014\right| \leq \chi, \left|\frac{W_{15}}{W_{17}}-1.044\right| \leq \chi, \left|\frac{W_{16}}{W_{18}}-1.092\right| \leq \chi, \left|\frac{W_{17}}{W_{19}}-1.063\right| \leq \chi,$$

$$\left|\frac{W_{18}}{W_{20}}-1.048\right| \leq \chi$$

$$W_1 + W_2 + W_3 + W_4 + W_5 + W_6 + W_7 + W_8 + W_9 + W_{10} + W_{11} + W_{12} + W_{13} + W_{14} + W_{15} + W_{16} + W_{17} + W_{18} + W_{19} + W_{20} = 1$$

$$W_L \geq 0$$

The model was subjected to LINGO software and the final values of the risks evaluated are depicted in Table 7.

Table 7

Final weights were evaluated to prioritize the risk factors

Risks	**Weights**
Contamination of food risk	0.06225
Temperature and humidity risk	0.05837
Quality risk	0.05772
Environmental pollution of the plant risk	0.05640
Poor management risk	0.05507
Technological backwardness	0.05299
Deficiency of facilities & equipment risk	0.05100
Supplier reluctance to shift towards sustainability risk	0.05026
Incorrect labelling & purchasing risk	0.05026
Improper transport equipment	0.04954
Instability of supply & demand	0.04885
Market competition and uncertainty risk	0.04815
Cold chain failure risk	0.04815
Equipment failure risk	0.04741
Manufacturing risk	0.04676
Planning & control risk	0.04667
Delivery planning risk	0.04471
Act of human error risk	0.04267
Supplier Reputation risk	0.04200
Deliberate acts of theft risk	0.04076

Table 7. represents the final weights calculated through the code in LINGO software. The authenticity of the results can be justified by the fact that the sum of all the risk factors' weights is equal to 1. The values acknowledge the ranking of the risks identified by absolute rating in the first step by the experts. It can be seen that contamination of the food or a product can prove to be the most dangerous risk towards the functioning of the overall cold supply chain of a developing country. Furthermore, the risk of temperature and humidity and quality occupies the second and third rank respectively. The risk prioritization values show that deliberate acts of theft risks constitute to be the least significant risks that can pose a threat to the cold supply chain of a developing country. The code also evaluated the value of DFC (χ) to be equal to 0.001802837, which represents that the deviation of the final weights of the risks from the optimal value is negligible. The three top-most prominent risks are taken into account and discussed.

The most critical risk factor that can be dangerous to the cold supply chain was concluded to be the contamination of food or cold products either chemically or by any other means. This means that any unwanted foreign object is allowed to seep into the frozen food product, resulting in the product and quality damage. This risk can, in turn, pose serious health risks and can eventually result in the closure of various businesses. Furthermore, undercooking a product and then freezing it for consumption can possess serious contaminants which can also pose threats to human health [53]. Similarly, cold food storage under poor arrangements in the warehouses and transportation can lead to loss of food quality because of insects and fungal contamination and infestation [62]. The most dangerous infestation that needs to be checked at every stage of the cold chain is that of Mycotoxin. A mycotoxin is a fungus that can pose serious threats to the health of both humans and animals. It is commonly found in food products and can easily make its way into the exposed product, resulting in damages and losses. That contaminated food upon consumption poses a danger to the health of the customers, can bring down a company's image and can harm the overall cold chain [63].

Furthermore, the second-high profile risk that the cold supply chain in a developing country faces is the temperature and humidity risk. In summers, the weather in countries like Pakistan gets extremely hot and humid, thus posing serious threats to frozen goods because they are very temperature-sensitive. The problem of electricity is extremely massive and thus the electric supply being cutoff for the warehouses and cold storage can damage the food items, medicines, vaccinations, etc. Such an energy crisis cripples other industries along with it and the cold chain of frozen products is one of them [64]. Similarly, the use of outdated technology and untrained staff at the processes can also raise the issue of temperature and humidity.

Lastly, the third most critical risk that a developing country like Pakistan faces is the quality of the product risk. The products in the cold chain such as meat, vegetables, medicines, vaccinations, etc. constitute to be the most sensitive and thus are vulnerable to quality issues. One such example comprises the Pakistani food products that are usually susceptible to the contamination of heavy metals and various other adulterants which ruin the quality of the frozen foods along with serious threats to human life [65].

In a developing country such as Pakistan, such risks can arise due to the lack of coordination between the suppliers and the manufacturers as well as improper food preparation methods. Similarly, the risks of cold chain product contamination and waste are higher in the harvest and transportation durations in the country. Furthermore, various forms of product contamination are quite normal in the context of Pakistan in the case of biological, chemical and physical threats. Some are harder to detect due to the unavailability of necessary technology and equipment. To ensure frozen food product security, the government must take necessary actions to implement an advanced traceability system to trace the contaminants at every stage of the chain. Similarly, the system of traceability must be implemented along with other necessary tools such as production planning, proper logistics and Hazard Analysis and Critical Control Point (HACCP) to ensure that the food is contaminant-free. Furthermore, the implementation of new technologies such as Radio Frequency Identification (RFID) must be utilized to ensure the active and passive identification and radio sensing of the products for foreign contaminants. In this way, the country can improve its frozen product quality manifolds and prove to be extremely effective for the consumers. It will enable the consumers to be sure of the companies and corporations to have a secure operational culture and that they are willing to take measures that can help towards the improved consumers' perception of the corporate security [66]. Furthermore, the temperature and humidity risk should be mitigated by introducing advanced technology that can help preserve food and other cold chain products without damaging their quality. It is the responsibility of the concerned company to hire competent and trained personnel to ensure the proper functioning of the installed machinery at various cold storage locations. Also, the suppliers must be selected based on their sustainable practices to ensure proper transportation and storage of frozen food items, sensitive medicines, vaccinations, etc. Similarly, to ensure food quality is maintained, the cold chain suppliers and the government should work together to ensure that the process is standardized. Standardization will ensure that all the requirements for a frozen product are met before launching them into the market. It will help save lives and ensure that the profits generated from this industry are stable [66].

In short, if the cold chain industry of a developing country such as Pakistan is to operate risk-free, the companies and the government needs to ensure that all the steps are required to maintain cold chain products such as protection from foreign contaminants, temperature control, and quality are taken into account. Such measures can enable the policymakers to draft the design and operations of the cold chain by canceling out the hazardous effects of the risks. Similarly, for a proper risk free cold supply chain to develop, the companies and the governmental authorities need to provide well-timed and proactive communication to their consumers, providing them with the updates regarding the measures taken to ensure trust building. In this way, a foundation of a proper developed business model can be laid [67] [68].

4.3 Practical Implications & limitations

The cold supply chain in developing countries like Pakistan is not given proper attention as per the requirement to ensure its proper functioning. Similarly, there has been no study conducted in the context of a developing country that takes risks into account in the context of a cold supply chain. This study highlights prominent risks and prioritizes them based on their danger level. This study recommends necessary steps that are needed to ensure that the risks are mitigated to a maximum level and attain sustainability in the overall operations. Furthermore, the application of the study covers all aspects of the cold supply chain and addresses risks associated with the chain overall. Lastly, it will help the industries and the companies to gain their image in the country and internationally, thus increasing their brand and customer loyalty. Similarly, the customers will be able to get proper products that are health-friendly and deprived of any hazardous contaminants. The scope of the study can also be extended to cater to the issues of the countries that rely on cold chain processes.

As mentioned earlier that there has been almost no study conducted in this regard in the context of a developing country and especially Pakistan, the data collection proved to be quite a hurdle. The lack of experts in this area managed to slow down the overall process of data collection and thus the process of the overall analysis. This constitutes to be the limitation of this study.

Conclusions

Risks are usually the undesired effects that can alter the course of human lives, infrastructure, industries and economies to be precise. The steps that are required to evaluate the risks and propose effective measures to cope with those risks constitute to be risk mitigation strategies. Risk mitigation strategies can be employed in almost every industry and is a requirement of an effective supply chain.

This study explores the risks that are most likely to affect the cold supply chain of a developing country like Pakistan. For this purpose, a vigorous literature review and articles were studied and 40 most relevant risks were identified related to the cold supply chain. Furthermore, the study employs a two-way approach to analyze those risks. Firstly, out of 40 risks, 20 most prominent risks were narrowed down after consultation with the experts who rated them the highest based on Occurrence, Severity, and Detection. Those risks were highlighted using the RPN tool of FMEA analysis. The next step involves the prioritization/ranking of those risks through the FUCOM method which identified contamination of food, temperature and humidity and quality as the top three most hazardous risks that are bound to happen in the cold chain processes. Similarly, deliberate acts of theft in the cold chain processes by some personnel were identified to be the least prominent risk that can render the cold chain process ineffective.

Pakistan, as a developing country, needs to pursue proper traceability measures, to ensure that the contamination of the frozen products, by any foreign contaminants, should be traced at any stage of the cold chain process. This will ensure that both the contamination and quality of the products are protected, at any stage of the process. Similarly, for proper inspection, identification and sensing of the products for any foreign contaminants, the implementation of RFID technology must be taken into account. This practice is already being implemented by multinational companies, like Walmart, to ensure that the products are traceable, quality is maintained and the overall process is effective. Furthermore, necessary measures, like the installation of the latest machinery and properly trained staff, must be taken into account, to ensure that the potential risks, like, temperature, humidity and quality, are considered. Such implementation of the latest technologies will enable proper functioning of cold storage thus, mitigating the majority of these risks.

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