SUPPLY CHAIN RISK ASSESSMENT IN THE REFRIGERATOR INDUSTRY OF BANGLADESH: A CASE STUDY

Mohammad Mohasin Sarder

A thesis submitted in partial fulfillment of the requirement for the degree of

MASTER OF ENGINEERING IN ADVANCED ENGINEERING MANAGEMENT

Department of Industrial and Production Engineering

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Certificate of Approval

The thesis Titled "Supply chain risk assessment in the refrigerator industry of Bangladesh: A case study" submitted by Mohammad Mohasin Sarder, Student No.: 1015082117, Session – October 2015 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Master of Engineering in Advanced Engineering Management on 26th September 2021

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It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

Date: 02/09/2022

Mohammad Mohasin Sarder

This Work is dedicated to My Family

For their endless love, support and encouragement

Contents

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List of Abbreviation

AHP : Analytic Hierarchy Process

ASEAN: Association of Southeast Asian Nations

BRMEA : Bangladesh Refrigerator Manufacturers and Exporters Association

MCDM : Multi-criteria Decision Making

SCM : Supply Chain Management

SCRM : Supply Chain Risk Management

SCD: Supply chain disruptions

TOPSIS : Technique for Order of Preference by Similarity to Ideal Solution

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Abstract

Risk exists in various fields of research like finance, manufacturing, healthcare, supply chain management, etc. However, insufficient understanding of uncertain regional differences and various industry trends, have increased firm exposure to supply chain risks. In today's scenario, organizations are becoming more vulnerable in their supply chain due to irregularities of material supply, product demand, skills, and equipment requirements. Supply chain risks consist of complex, uncertain, and vague information, but risk assessment techniques have been unable to handle complexity, and vagueness. Therefore, managing of risk has become important to tackle such kinds of disturbances from a supply chain context.

As refrigerator manufacturing industry is emerging sector in Bangladesh so supply chain in this sector is yet to be stabilized, so there are lots of unseen risks come up which is pretty difficult to predict. Even in regulatory level several functions are yet to be defined. Supply Chain Risk Management (SCRM) have enormous effects on the firm's performance. Therefore, it is necessary to develop strategies appropriate for coping with risks and maintaining the firm's performance level

In this thesis the risks were identified through a combination of literature review and expert opinions from manufacturing field as well as academic field. Research methodology is developed using Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and then Analytical Hierarchy Process (AHP), popular method for multiple criteria decision making (MCDM). Then the proposed methodology is practically implemented through a case study on refrigerator manufacturing industry. Severity and probability is selected as a decision making criteria for TOPSIS. Moreover 6 major risk and 24 sub risk under major risks were ranked using TOPSIS and AHP and rank differences were identified. Results suggests supply related problems are major risk factor in refrigerator industry.

This research work can assist practitioners and industrial managers in the refrigerator manufacturing industry in taking proactive action to minimize its supply chain risks. To the end, a sensitivity analysis test, which gives an understanding of the stability of ranking of risks.

Chapter1: Introduction

1.1 Introduction

A supply chain is the interconnection of series of organizations with amenities, functions, processes, and logistics activities that are involved in producing and delivering a product or service [1] The more complex the supply chain is, the less predictable the likelihood and the impact of disruption is. This relationship indicates higher exposure to supply chain risks [2,3,4] Risk management has emerged as an important issue in managing supply chain effectively in the presence of uncertainties that result from unexpected variations along the supply chain [5]

In today's globalized and highly competitive environment, supply chains became larger and more complex with globally dispersed components [5,6]. Recently, companies have given more consideration to disruption or contingency plans by incorporating Supply Chain Risk Management (SCRM) to avoid the identified supply chain risks, or if not possible, to mitigate or monitor them. Supply chain risk management (SCRM) is a most popular methodology that captures both the operations as well as the financial aspects of decision-making [6.7]. To understand the supply chain interdependencies and to identify potential risk factors, it is necessary to measure risks by their likelihood and consequences. [8,9]

Risk is represented in terms of uncertain event, which possesses the probability of occurrence of unfavorable outcomes like late delivery, financial burdens, business loss, etc. [3,4]. Risk exists in various fields of research like insurance, finance, manufacturing, healthcare, supply chain management, etc. [5,6]. Risk is inherent in almost all the phases of life, but when it comes to business, they are more vulnerable due to changing trends, globalization, complexity, and competitiveness of the firms [10-15]. Changes in demand, uncertain supply, cost savings, and implementing agile or lean structures increase the probability of risks [16,17]. Whatever the reason it would be, the firm's supply chain (SC) is exposed to numerous risks, which create disruptions. If these disruptions are not treated in a timely manner, they a ect the firm's performance [18]. Supply chain disruptions (SCDs) can occur upstream and downstream of the supply chain or can be internal and external: supplier delivery delays, supplier insolvency, fluctuations in demand or estimation errors, natural disasters like hurricanes, floods, earthquakes, fires, etc. [19]. Supply chain risk management (SCRM) have enormous effect on the firm's performance. Therefore, it is necessary to develop strategies appropriate for coping with risks and maintaining the firm's performance level. Adequate risk-mitigation strategies help firms in identifying, assessing, measuring, monitoring, and controlling risks [18].

Life styles in Bangladesh are rapidly being changed over last decades, and time for family is being seriously crunched. Number of working family members is increased to earn their livings, so food habit is also being changed. There has been increase in use of electronics equipment to make our life easy. Equipment like Refrigerator, Oven, Washing machine, and other Kitchen appliances have turned into integral part of our life style, they are no more a luxury. As the market sized has grown over last decade, Bangladesh have shifted from an import based country to a manufacturing based country for electronics equipment. It started with multinational

company like SINGER, but local companies has come up from scratch. Local manufacturing company like WALTON has grown 1000 folds over last decade to make electronics goods into FMCG mode. Refrigerators are no more considered to be a luxury rather a basic need in every household. These has been only been possible due to our strength in local manufacturing, apart from WALTON, JAMUNA, MINISTER, VISION, and ECO + are prominent local brands. In recent times world renowned brands like SAMSUNG, LG, HAIER, and KONKA have started own operation in Bangladesh. But electronics industry is new in our arena, and its supply chain challenges are of different kind form our regular industry like RMG. There are high risks involved in maintaining a supply chain for an electronics industry, especially for product like refrigerator which has highly seasonal impact. Moreover basic raw materials are still total import based so supply chain managers have to be always on their toes to ensure smooth supply considering international scenarios. Situation just got worse with invasion of COVID and cold war between china and USA.

This thesis aims to identify the major risk associated as well as the micro risk under the broad category with supply chain of a refrigerator industry. Risk will be ranked and sensitivity analysis will be performed to identify the major risk which needs to be mitigated. As this thesis is designed with industry experts so rough risk mitigation plan can also be sketched

1.2 Motivation

Refrigerator market in Bangladesh has grown significantly over the last decade and currently it's a market of 3.0 Million pcs per annum with an industry growth over 8% per year. Refrigerator industry is worth more than 50 billion BDT locally. Export market is just in emerging phase still worth 20 Million USD (Last Financial Year Value). Therefore, it is important for companies to agree on a common risk management approach in supply chain networks. Previously some sales or marketing-based analytical work has been done in refrigerator sector of Bangladesh. A lack of empirical studies on Supply Chain Risk Management (SCRM) is observed, especially in the field of manufacturing.

As this emerging sector in Bangladesh so supply chain in this sector is yet to be stabilized, so there are lots of unseen risks come up which is pretty difficult to predict. Even in regulatory level several functions are yet to be defined. Supply Chain Risk Management (SCRM) have enormous effects on the firm's performance. Therefore, it is necessary to develop strategies appropriate for coping with risks and maintaining the firm's performance level [19,20]. Adequate risk-mitigation strategies help firms in identifying, assessing, measuring, monitoring, and controlling Risks [21].

Risk management is generally described as the identification and analysis of risks as well as their Monitoring and mitigation [22] . A main particularity of SCRM, contrary to traditional risk management, is that it is characterized by a cross-company orientation aimed at the identification and reduction of risks not purely at the company level but instead focuses on supply chains [3]. To survive in a risky business environment, it is imperative for companies to have a proper SCRM. If poorly handled, disruptions in supply chains can result in a deficient service level and igh costs [21]. The focus of SCRM is to understand and attempt to avoid the devastating effects that disasters or even minor business disruptions can have in a supply chain [3]

Nowadays global supply chains enable companies to enhance competitive advantages, increase manufacturing flexibility and reduce costs through a broader selection of suppliers.[7] Despite these benefits, however, insufficient understanding of uncertain regional differences and various industrial trends, including outsourcing, supply base reduction, just-in-time, and shorter product life cycles have increased firm exposure to supply chain risks (SCRs) [8] . In today's scenario, organizations are becoming more vulnerable in their supply chain due to irregularities of material supply, product demand, skills and equipment requirements [9,10]. Supply chain (SC) risks consist of complex, uncertain, and vague information, but risk assessment techniques have been unable to handle complexity, uncertainty, and vagueness [11]. Therefore, managing of risk has become important to tackle such kinds of disturbances from a supply chain context.

The following research questions are the basis for the objectives of this study:

1. What is the current supply chain structure in refrigerator industry?
2. What are major and micro risk involved in Refrigerator Industry?
3. Which are the most vulnerable risk in Refrigerator industry?

No notable research has been done on risk assessment in Refrigerator industry in Bangladesh. In this work, an empirical survey will be done to find the most relevant risk and probability index matrix will be used to assess the risks and prioritize them. Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) will be used and then Analytical Hierarchy Process (AHP), a popular method for Multiple criteria decision making (MCDM) process will be applied here to make comparison of rank of risk identified. AHP works on comparison matrix which provides a comprehensive and rational framework for structuring a decision problem, for representing and quantifying its elements, for relating those elements to overall goals, and for evaluating alternative solutions. This research work will focus on identifying the most critical risks and prioritizing them so that most acute risk can be identified and acted upon. Sensitivity analysis will be done in the end to find out the consequence of criteria weights on decision making.

1.3 Contributions and Objectives

The contributions of this study are justified by the specific objectives and findings of this study and uniqueness of the research process as compared to other research conducted in the context of Bangladesh. Case of Refrigerator Manufacturing Industry in Bangladesh is considered in this study. The risks were identified through a combination of literature review and expert opinions from manufacturing field as well as academic field . In Bangladeshi context, no research has been conducted concerning Supply Chain Management Risks Management (SCRM) in Refrigerator manufacturing industry using Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and then Analytical Hierarchy Process (AHP), a popular method for Multiple criteria decision making (MCDM) process will be applied here to make comparison of rank of risk identified approach. This study ranks the identified Risks and their sub-risk in order of severity for removing them and also evaluates and ranks the risks for smooth implementation of SCRM practices in the Refrigerator industry of Bangladesh.

So, the specific objectives of this study are summarized as follows:

- To identify the relevant risks in the supply chain of the refrigerator industry in Bangladesh through empirical study.
- To prioritize the identified risks to determine the most critical risk to be acted up on.
- To perform a comparative analysis between ranks of the identified risks determined through TOPSIS and AHP methods.

1.4 Organization of the Thesis

To fulfill the objectives of this study, this research work is prepared as follows:

Chapter 2: Literature Review

The brief of Supply chain Risk Management of Bangladesh (SCRM), in Refrigerator industry in Bangladesh will be described. Current practices in the industry will be discussed. Reviews of the existing works and the brief of major risk will be presented.

Chapter 3: Methodology

Proposed research methodology with the solution methodology is presented in this chapter. Also overviews the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and Analytical Hierarchy Process (AHP), a popular method for multiple criteria decision making (MCDM).

Chapter 4: Data Collection and Analysis (An Empirical Case Study on Industry Leaders and Academicians)

In this chapter data collection method will discussed and how analysis is being done along with the expert's opinion from industry leaders. An empirical case study is being developed with industry experts and academicians.

Chapter 5: Results and Discussions

Results, discussions on findings and sensitivity analysis are explained in this chapter

Chapter 6: Conclusions, Managerial Implications and Recommendations

Finally, the conclusion along with the managerial implications and future directions of the study is drawn in this chapter.

Chapter 2: Literature Review

This section begins with an introduction to the concept of SCRM. Next, it presents empirical studies regarding risks in the Refrigerator Manufacturing industry and, finally, a brief overview of this industry in Bangladesh.

2.1 Supply Chain Risk Management

The term risk is expressed with a variety of meanings, measurements, and interpretations that may vary according to the research field. A growing body of academic research on risk has emerged from a number of different fields, such as accounting, finance, economics, marketing, regulatory bodies, business, and supply chain [3, 24]. This study focuses on supply chain risks, which consists of 'any risk to the information, material and product flow from original suppliers to the delivery of the final product' . Different risk sources can emerge and affect the supply chain outcome since they are variables that cannot be predicted with certainty [25].

Risk management is generally described as the identification and analysis of risks as well as their monitoring and mitigation [22]. A main particularity of SCRM, contrary to traditional risk management, is that it is characterized by a cross-company orientation aimed at the identification and reduction of risks not purely at the company level but instead focuses on supply chains [3]. To survive in a risky business environment, it is imperative for companies to have a proper SCRM. If poorly handled, disruptions in supply chains can result in a deficient service level and high costs [21]. The focus of SCRM is to understand and attempt to avoid the devastating effects that disasters or even minor business disruptions can have in a supply chain [3].

Supply chain risk identification is considered a fundamental stage of the entire risk management process. This approach involves a comprehensive and structured determination of potential supply chain risks associated with the given problem. The main focus is to recognize supply chain uncertainties to enable efficient risk management [26]. Risk assessment determines the likelihood of occurrence and severity level for each risk identified [23,26].

Risk assessment determines the likelihood of occurrence and severity level for each risk identified. Risk ranking is the expression of probability x severity [11,13], used the risk index to evaluate the risk importance based on surveys, which shows the relative significance among the risks associated. By averaging the scores from all responses, it was possible to find an average significance score for each risk, and this average score (called the risk index score) was used to rank the risks. The model for the calculation of the risk index is offered in Equation 1.

$$R_i = \frac{\sum_{j=1}^{n} r_{ij}}{n} = \frac{1}{n}\sum_{j=1}^{n} \alpha_{ij}\beta_{ij}$$

where Ri = average score for each risk; rij = significance score assessed by respondent j for the risk severity i; i = ordinal number of risk, i [(1, m); m = total number of risks; j = ordinal number of valid feedback to risk i, j [(1, n); n = total number of valid feedbacks to risk i; aij = likelihood occurrence of risk i, assessed by respondent j; and bij = level of consequence of risk i assessed by respondent j [27].

2.2 Overview of Refrigerator industry in Bangladesh

Refrigerator sales has increased many fold to 30 lakh units/Annum in the decade, spurred by increasing domestic manufacturing, higher electricity generation and rising purchasing power. The market expected to grow more than 11 percent annually in this fiscal year 2021-2022, according to a projection by the Bangladesh Refrigerator Manufacturers and Exporters Association (BRMEA).

The market has begun to expand fast in recent years as more firms signed up for making refrigerators using their own brands targeting lower and middle income segments. “Domestic manufacturers are offering refrigerators at comfortable rates and this is one of the main reasons behind the fast growth,” as per BRMEA. Increasing availability of electricity supply in the rural areas, rising buying capacity of the people and the scope to buy a refrigerator through installments are among the factors that are driving the market. Above all, people in the rural areas are getting the appliance at their doorsteps. Proximity is another factor.

The overall annual market size of refrigerators in Bangladesh is about Tk 10,000 crore, according to BRMEA refrigerators have become a lifestyle product among the upper middle and high income families. In the past, people used to buy refrigerators for long-term use whereas they change it more frequently now.

Locally made refrigerators meet about 90 percent of the annual demand and imported ones meet the rest. Walton, Jamuna Electronics, Minister etc. were the frontier leaders to start manufacture of electronic goods in Bangladesh. Among them Walton is the pioneer in manufacturing refrigerators and started their manufacturing facility in 2007. Over the last one decade Walton has grown to be a one of the largest company in Bangladesh. After Walton, many other local companies like Jamuna Electronics, Minister and RFL started manufacturing refrigerator in the country. In 2017, Samsung inaugurated two home appliances manufacturing plant in Bangladesh, in collaboration with Fair Electronics and Transcom Electronics. In 2018, LG in collaboration Butterfly Group opened a Refrigerator manufacturing plant in 2018.

2.3 Current practices of supply chain management in Refrigerator Industry

Refrigerator industry in Bangladesh is still in very early stages, most of the local factories are heavily dependent on imports. Among the global brands Samsung and LG are basically working as assembly plants. All the model developments, designs and research are performed globally, most of the parts are also being manufactured in countries like Korea, and china so for them to

ensure supply of parts on time is really challenging, sometimes required cross docking or accumulation in 3rd country prior to the shipment which makes the life tougher.

As refrigerator business have high seasonal impact so, any sudden change in supply schedule, demand forecast, financial regulations has very high impact. Major local manufacturers are also dependent on the countries like Korea, China, UAE, India, Thailand etc for their raw materials. So their festivities, holidays etc are to be kept in mind and materials has to be stoked accordingly. Most of the local manufacturers have their own model development team stationed locally, but few have locally established full-fledged R&D team. However they have the freedom to select their suppliers on their own and can develop alternative supply chain delivery channels. But again local manufacturers are facing fierce competitions when it is coming to exports, so they had work in lean supply chain to keep the supply chain cost at minimum level and to be cost competitive in international level.

Current COVID situation has made the life tougher for the supply chain professionals; it has become really challenging to meet the regular lead time. Sudden outbreak has caused manufacturer to shift to new suppliers with very short development time, in many cases even the import country has to be changed to meet the demand. This COVID has really make supply chain of local the refrigerator industry vulnerable, leading to higher inventory, higher cash conversion cycles.

2.4 Current Practices of risk assessment in refrigerator industry

Supply chain risks are very persistent in supply, regulatory policy, organizational operation, demand uncertainty, and financial matters. Currently organizations are analyzing the risk in scattered manner and no particular tools are used. However few organizations use a probability and frequency matrix to identify the major risk which might impact the supply chain in very primitive level. Supply chain risks can waste resources as well as deteriorate SCM performance. Therefore, proper identification and analysis of risk are useful in formulating strategies to minimize the risks in the supply chain [28]

The refrigerator facing tremendous uncertainty and fluctuations in demand, which may challenge its business sustainability in both local and international markets. The refrigerator industry are also facing various relevant supply chain issues, like shortage of raw materials, quality problem of the products, sustainable supplier failure and seasonal demand of products This empirical work is designed to identify, analyze and rank the risks in refrigerator industry in the context of Bangladesh. In Bangladesh, the refrigerator industry has a major role in its socio economic growth. Bangladesh has started exports to Several countries like India, Srilanka, Nigeria, Tanzania, Saudi Arabia, Yemen Etc Besides, refrigerator companies are experiencing huge competition in Bangladesh.

Above all, refrigerator companies are facing supply chain disruptions due to continuous technological development, regulatory policy change, and uncertain market environment.

Although, there is significant advancement in infrastructure, information and communication technology in refrigerator industry; yet, the industry is confronting different risks in supply chain [28]. Analyzing risks is becoming a highly focused and increasingly adopted activity among organizations targeting to ensure a smooth and trouble free business [29].

With a combination of literature reviews and opinions from relevant industrial experts, the most critical, major risks in supply chain of refrigerator industries of Bangladesh were identified. Six relevant industrial experts including product Manager with 10 years working experience, Two Supply chain manager with around 10 years working experience, Operations manager with 9 years working experience and project and development manager with 5 years working experience from four different Refrigerator manufacturing industries in Bangladesh as well an academician who is working with supply chain research for more than 5 years were involved in the evaluation and refinement of the Risk. A brief of the characteristics of the managers is presented in Table A1 in Appendix. On the basis of the expert opinions and analysis, the major risk and sub-risk were selected for the final evaluation. These risk include six major Risk and forty six sub risk was identified. The main barriers include “Supply Risk (S)”; “Operational Risk (O)”; “Financial Risk (F)”; and “Customer/Demand Risk (C)”, "Inventory & Logistics (L)", and "Legal/Regulatory Risk (R)" and after series of rigorous interviews and merging of several sub risk experts agreed upon 24 (twenty four) sub risk for further analysis. We will overview the major risk in next section literature review.

2.5 Risk in supply chain of a refrigerator Industry

The SCRM process begins with identifying several risks. Risks identification is the key part of the risk assessment phase of the SCRM process. Various authors identified various risks affecting the supply chain. Unfortunately, there is no agreed consensus on classifying supply chain risks in the literature. Using Literature and experts opinion, major and sub major supply chain risk in refrigerator industry in the context of Bangladesh are as below:

2.5.1 Supply Risk (S)

Supply risk comprises any risk involving raw materials or semi-finished goods or finished goods that are supplied to the next level in the supply chain. Supply risk is related to the probable uncertainties to the product flow or information flow within the supply chain network of the company. This risk is associated with a firm’s suppliers, or supplier’s suppliers being inept to deliver the required materials the company needed to effectively meet its production requirement [30].

Through extensive interview session with the professional and academicians major sub risk identified in this category are as below:

Table 2.1: list of Sub Risk under Supply risk

Major Risk	Sub Risk
Supply Risk (S)	
S1	Raw Materials Unavailability
S2	Quality issue at Supplier end/Major Failure at supplier end
S3	Vessel unavailability
S4	Communication Gap between Supplier & Forwarder/Lack of proper information
S5	Delay in Shipment in Supplier End/Missing Delivery times/Improper shipment timing
S6	Shipment Problem – Delay in port, Freight
S7	Incoterms issues with foreign suppliers
S8	Lack of willingness/long term relation ships
S9	Unavailability of alternative supplier/Single Source

2.5.2 Operational Risk (O)

Operational risk is defined as the risk associated with the execution of a company's business functions [31] . Operational risk is initiated with operational events disrupting material or information flow within the supply chain. Operational risks cover malfunction in process, operations complexity, equipment/ machinery breakdown, operational accidents etc.

Following operational risk were identified from the experts.

Table 2.2: list of Sub Risk under Operational Risk (O)

Major Risk	Sub Risk
Operations Risk (O)	
O1	Failure to Conform the Quality Standard/Quality Assurance/Qulaity Failure
O2	Lack of Skilled Manpower
O3	Breakdown of Machine
O4	Incoming Goods & Outgoing goods Space Management
O5	Labor cost Rise/High Cost of skilled labor
O6	Productivity
O7	Sudden Disaster like fire
O8	Specification Mismatch

2.5.3 Financial Risk (F)

Financial risk incurs loss to supply chains due to changes in economic factors like exchange rate changes, collapse of stock markets or increase in the inflation rate. Financial risk also uncovers a firm to possible loss through changes in financial markets. [32]

Sub risk Financial Risk that came up through interview as below.

Table 2.3: list of Sub Risk under Financial Risk (F)

Major Risk	Sub Risk
Financial Risk (F)	
F1	Change in Exchange Rate
F2	Credit Risk in the Market
F3	High Bank Interest/ Change in interest rate
F4	Cash management
F5	Credit Recovery

2.5.4 Customer/Demand Risk (C)

Demand risks are referred as the factors that influence the change in demand. Demand risk relates to potential or actual disturbances in the flow of product and cash between local company and the market. The demand risk may involve inaccurate demand forecasting or other man made natural factors. [33]. Market risks are linked with losses of customers and market position. Various factors related to market features and the company's position may trigger the market risk.[32] Market risks comprise mainly with threats from competitors and alternative products availability in market.[34] We will be referring this as customer related risk.

Sub risks identified are listed below.

Table 2.4: list of Sub Risk under Customer/Demand Risk (C)

Major Risk	Sub Risk
Customer/Demand Risk (C)	
C1	Change in Sales Trend due to Environmental issue/No defined sales trend
C2	Competitor's aggressive campaign/New Product line/Flashy Sales Promotion
C3	Wrong Info related to Market/Lack of market information/Wrong sales information from market
C4	Demand Change due to natural Disaster
C5	High Forecasting Error/High Forecasting Deviation
C6	Introduction of new product from competitors

2.5.5 Inventory & Logistics (L)

Inventory risk is a risk arising from buffer or stock out inventories leading to unnecessary handling cost or lost opportunity cost [26]. Inventory risk results from damage of inventory as well as from too high or too low inventory level.

Logistics risk has a multi-dimensional influence on the supply chain .Logistics risks results from the uncertainty of the supply chain and the logistics network [32,33]. Logistics risk could rapidly affect the

overall supply chain. Logistics risk occurs because of delay or unavailability of either inbound or outbound transportation due to carrier breakdown or weather problems.

Sub risk that came up is listed below

Table 2.5: list of Sub Risk under Inventory & Logistics (L)

Major Risk	Sub Risk
Inventory & Logistics (L)	
L1	Dent & Scratch during handling
L2	Damage of goods due to Warehousing issue/Space Management
L3	Stock accumulation due to Unsuccessful new line up
L4	Bullwhip effect/High Inventory due to uncertainty in market
L5	Political Unrest
L6	Accumulation of Nonmoving material due to design change/Accumulation of non-moving material
L7	High no. of handling
L8	Goods damaged due to wrong storage
L9	Sudden Natural calamity
L10	Missing the deadlines of buyer

2.5.6 Legal/Regulatory Risk (R)

Regulatory risk is the risk of a change in regulations and law that might affect an industry or a business. Such changes in regulations can make significant changes in the framework of an industry, changes in cost-structure, etc. Regulations can increase costs of operations, introduce legal and administrative hurdles, and sometimes even restrict a company from doing business.

Sub Risk came up under this major category are as below

Table 2.6: list of Sub Risk under Legal/Regulatory Risk (R)

Major Risk	Sub Risk
Legal/Regulatory Risk (R)	
R1	Change in Duty/Change in Import Duty
R2	Change in Regulatory/Change In regulations like BSTI certification/Sudden Change in regulation against manufacturers
R3	Tax Structure change
R4	Slow processing in certification
R5	Sudden change in Regulation
R6	Change in incentive Structure
R7	Policies in financial dealing like TT, Swift, LC

2.3 Application of multi-criteria decision making technique in supply chain

Several authors applied multi-critera decision making techniques in supply chains. MCDM refers to screen, prioritize, rank or select a set of alternatives under usually independent, incommensurate or differing attributes.

Evaluating potential risks in supply chain of refrigerator manufacuring industry is a multicriteria decision making (MDCM) problem . In this thesis applied TOPSIS and AHP methods to evaluate the SCR associated with refrigerator manufacturing. By using TOPSIS method, from the decision matrix we can find out the best alternative. But one problem encountered in TOPSIS or other MCDM method is computation of the weightage of the criteria. This problem is tackled AHP as the weightage of the criteria can be computed by forming a comparison matrix for the criteria and following the steps of AHP.

Chapter -3: Methodology

3.1 Research Methodology

To fulfill the objectives of this study, at first the existing literature on Supply Chain Risk Management (SCRM) was examined and a number of consultation sessions were arranged with experts from relevant industries. From the outcomes of reviewing the current literature and opinions from the experts of the relevant industries, the most influential barriers to SCRM were selected in the field of refrigerator manufacturing industry of Bangladesh. In this research work, six evaluators were taken from four leading refrigerator manufacturing or assembling industries and an academician was also included. This study consists of six major barriers and forty-five sub-barriers. The systematic graphical research framework is illustrated in Fig 3.1.

Step 1: Identification of existing risk factors

The objective of this step is to generate a comprehensive list of risks based on the events that might have an adverse impact. In this step, most relevant supply chain risks are identified through a literature survey and from experts‟ input. On the basis of the expert opinions and analysis, the major risk and sub-risk were selected for the final evaluation. These risks include six major risk and forty six sub risk was identified.

Step 2: Selection of the evaluating criteria

Criteria selection is the beginning initiative for supply chain risk management (SCRM) evaluation. Supply chain risks can be evaluated on the basis of their priority and nature of actions required [31] . Risk is considered as a function of expected loss and determined how often the risk will occur and by the severity of the risk. Thereby, in this research, two evaluation criteria are used to evaluate the identified risks.

Probability (C1) – the likelihood of occurrence of each risk,

Severity (C2) – potential effect of each risk type of the organization

In this step, the weight of each criterion has also been identified. After evaluating the risk in “probability-Severity” Index, for all the sub risk identified. We also developed a response index for all the subrisk identified under the major risk. Up on another round of interviews and discussion on the result identified with the experts, sub risks are finalized for further evaluation.

Step 3: Evaluation of identified risks using Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and then Analytical Hierarchy Process (AHP)

In this stage, supply chain risks are evaluated using TOPSIS and AHP technique. For evaluation of ratings and weights of risk factors and criteria, linguistic terms are used.

Step 4: Sensitivity analysis

Sensitivity analysis is a convenient tool to depict how the change in the importance or weight of the criteria influences alternatives. Sensitivity analysis is imposed here to find out the consequence of criteria weights on decision making.

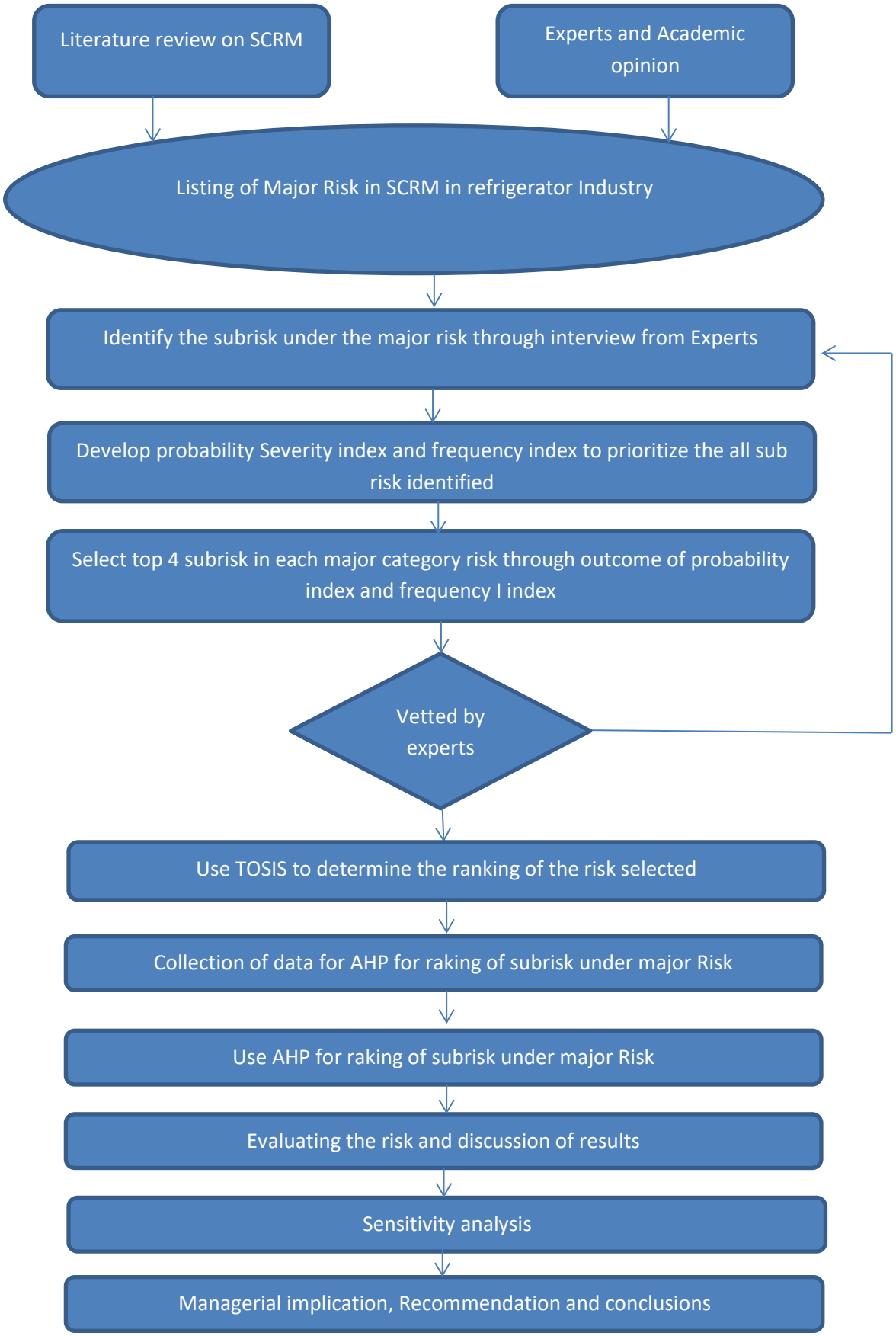


Figure 3.1 :The flow Chart of present Research

3.2 Solution Methodology

Mathematical method used in this thesis is described sequentially

1. Probability Severity Index
2. TOPSIS
3. AHP
4. Sensitivity Analysis

3.2.1 Probability Severity Index

Risk assessment determines the likelihood of occurrence and severity level for each risk identified [11,16,35]. Risk evaluation includes two sub-steps, which are risk ranking and risk acceptance [11]. Risk ranking is the expression of probability x severity [11,27]. The risk index to evaluate the risk importance based on surveys, which shows the relative significance among the risks associated. By averaging the scores from all responses, it was possible to find an average significance score for each risk, and this average score (called the risk index score) was used to rank the risks. The model for the calculation of the risk index is offered in Equation 3.1.

$$R_i = \frac{\sum_{j=1}^{n} r_{ij}}{n} = \frac{1}{n}\sum_{j=1}^{n} \alpha_{ij}\beta_{ij} \qquad \text{.....(3.1)}$$

where Ri = average score for each risk; rij = significance score assessed by respondent j for the risk severity i; i = ordinal number of risk, i [(1, m); m = total number of risks; j = ordinal number of valid feedback to risk i, j [(1, n); n = total number of valid feedbacks to risk i; aij = likelihood occurrence of risk i, assessed by respondent j; and bij = level of consequence of risk i assessed by respondent j.

3.2.2 Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)

Hwang and Yoon in 1981 proposed the Technique for Order Preference by Similarity to Ideal Situation (TOPSIS). TOPSIS is one of the useful Multi Criteria Decision Making (MCDM). According to this technique, the best alternative would be the one that should have the shortest Euclidian distance from the positive ideal solution and farthest from the negative ideal solution.

A MCDM problem with m alternatives (A1, A2,…., Am) that are evaluated by n attributes (C1, C2 ,…., Cn), decision matrix will be obtained with m rows and n columns as the following matrix. An element xij of the matrix indicates the performance rating of the ith alternative, Ai, with respect to the jth attribute, Cj, as shown in Eq. (3.2):

$$D = \begin{array}{c|cccccccc} & C_1 & C_2 & C_3 & . & . & . & C_n \\ A_1 & X_{11} & X_{12} & X_{13} & . & . & . & X_{1n} \\ A_2 & X_{21} & X_{22} & X_{23} & . & . & . & X_{2n} \\ A_3 & X_{31} & X_{32} & X_{33} & . & . & . & X_{3n} \\ . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . \\ A_m & X_{m1} & X_{m2} & X_{m3} & . & . & . & X_{mn} \end{array} \quad \text{……..…….(3.2)}$$

Step 1: Construction of normalized decision matrix. This step transforms various attribute dimensions into non-dimensional attributes, which allows comparisons across criteria. The normalized value of xij is defined in Eq. (3.3).

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{j} x_{ij}^2}} \quad \text{……..(3.3)}$$

i = 1, 2,….,m ; j = 1, 2,….,n

Step 2: Construction of the weighted normalized decision matrix. Assume a set of weights for each criteria wj such that W = {wj | j = 1, 2, …, n}. Multiply each column of the normalized decision matrix by its associated weight gives the weighted normalized decision matrix. An element of the new matrix is:

vij = wj x rij , for i = 1, 2,…, m; j = 1, 2,…, n ……..(3.4)

Step 3: Determination of the positive ideal (A+) and negative ideal (A–) solutions. The A* and A– are defined as positive ideal solution (PIS) and negative ideal solution (NIS) respectively, in terms of the weighted normalized values, as shown in Eqs. (3.5) and (3.6).

Positive Ideal solution:

$$A^* = \{v_1^*, \ldots\ldots, v_n^*\}, where\ v_j^* = \max\left(v_{ij}\right) if\ j \in J; \min\left(v_{ij}\right) if\ j \in J'\} \quad \text{…….(3.5)}$$

Negative ideal solution:

$$A^- = \{v_1^-, \ldots\ldots, v_n^-\}, where\ v' = \min\left(v_{ij}\right) if\ j \in J; \max\left(v_{ij}\right) if\ j \in J'\} \quad \text{…….(3.6)}$$

Where J is a set of benefit attributes (larger the better type) and J' is a set of cost attributes (smaller the better type).

Step 4: Calculation of the separation measures for each alternative. The separation of each alternative from the positive ideal alternative is:

$$S_i^* = \sqrt{\sum(v_{ij} - v_j^*)^2} \text{ for i} = 1, 2, 3, \ldots, \text{m.} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.7)$$

Similarly, the separation of each alternative from the negative ideal alternative is:

$$S_i^- = \sqrt{\sum(v_{ij} - v_j^-)^2} \text{ for i} = 1, 2, 3, \ldots, \text{m}$$

… ……(3.8)

Step 5: Calculation of the relative closeness to the ideal solution or similarities. Next, the relative closeness of alternative Ai with respect to the ideal solution A* is defined as follows:

$$C_i^* = \frac{S_i^-}{S_i^* - S_i^-} \; ; 0 \leq C_i^* \leq 1, \text{ for i} = 1, 2, 3, \ldots, \text{m} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.9)$$

Evidently , $C^*_i = 1$ if and only if $A_i = A^*$ and $C_i^- = 0$ if and only if $A_i = A^-$.

Step 6: Ranking the preference order. The best satisfied alternative can now be decided according to preference rank order of C*i . Choose an alternative C*i with maximum or rank the alternatives according to in C*i decreasing order

3.2.3 Analytical Hierarchy Process (AHP)

AHP is a decision analysis tool proposed by Prof. Thomas L. Saaty (1980). With the help of AHP, difficult problems are evaluated very easily [38]. The complex decision problems are converted into a hierarchical structure consisting of multiple levels, like goal, criteria, sub-criteria [39,40]. AHP allows policy makers to have optimal decisions in an organizational context. The input for the AHP can be picked from subjective assessment like review, interview and preference. AHP is used as a better decision making tools compared to ANP, TOPSIS, VIKOR, ELECTRE due to its wide acceptability and applicability, less pair wise comparisons, and simplicity in use [38,40]. However, AHP may involve some small inconsistency in human judgment [41]. Hence, AHP has been criticized because it sometimes results in an unbalanced scale of judgment and ranking. In this research, we used AHP to evaluate SCRM in refrigerator industry to know their priority.

The basic steps of AHP [38,40] are explained in below:

(1) Fix the aim of present study: evaluating the risks to examine their priority ranking in the SCRM of refrigerator industry is fixed as the goal of this study.

(2) Construct pairwise comparisons matrix: pairwise comparison matrix is constructed with the help of expert's feedback from assigned pharmaceutical companies. The pair wise comparisons matrix (A) among the risk is constructed with the help of a nine-point Saaty's scale [42]. The element aij of the matrix A is the relative importance of ith risk factor with respect to jth risk factor. The representation is done like the following: A ¼ [aij], each entry in matrix A is positive (aij W 0)[28].

(3) Calculation of the eigen values and eigen vectors and priority weights: the formulated pair wise comparison matrices are then used to calculate the eigen values and eigen vector. Next, the priority weights of the listed risks are calculated.

(4) Computation of the consistency ratio (CR): the CR checks the consistency of formulated pair wise comparisons matrices. CR is calculated with the help of following mathematical equation, CR ¼ CI/RI, where, consistency index (CI) can be calculated by CI ¼ Maximum Eigenvalue−n/n−1. The random consistency index (RI) value depends upon value of (n) as shown in Table 3.1. The value of CR should be less than 0.10 to have better level of consistency [40].

Random Index (RI)

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.58

Source: [10]

Table 3.1: Random Index table

3.2.4 Sensitivity Analysis

Sensitivity analysis is applied to see if the importance of the criteria is changed, how the risk factors will be changed. Often data in multiple criteria decision making (MCDM) problems are not exact and changeable. Therefore, an important step in many applications of MCDM is to perform sensitivity analysis according to the input data.

The significance of quantitative criteria is usually determined with some errors. If measurements are not accurate, the result obtained is not accurate either, but sensitivity of the result may be checked by varying the parameters Sensitivity analysis has a goal to identify which criteria have the greatest substantial influence in the decision making procedure. A possible definition of sensitivity analysis (SA) is the following: The study of how uncertainty in the output of a model (numerical or otherwise) can be apportioned to different sources of uncertainty in the model input [50]

Chapter 4 :

Data Collection and Analysis (A Case Study with Industry Leaders)

4.1 Data Collection

The developed methodology and framework has been applied to an empirical case study and used to rank the major risks along with the sub-Risks in Supply Chain Risk Management (SCRM) refrigerator manufacturing industry in Bangladesh.

In this work, case companies were selected based on purposive sampling method rather than statistical sampling [43]. In the purposive sampling method, the case companies are not selected randomly [44, 45]. The four refrigerator manufacturing/Assembly companies operating in Bangladesh were selected due to their immense interest to examine and manage the risks in their supply chain context. Next, ten industrial and field experts were selected from the listed four companies and an academician was selected. The selected experts are highly competent on supply chain risk management in refrigerator industry. We collected expert's feedback through several rounds of personal interviews, e-mail communication and telephonic discussion through questionnaire as provided in Appendix 1. An interview protocol was prepared based on a set of questionnaire with focusing several themes. The profile of experts along with the company details contacted for data collection in this work is shown in Table 4.1.

Name of organization	Designation	Years of experience	Brief Company Information
XYZ1	Head of Supply Chain, Executive Director	10 years	Factory Area: 1200 Acres+ Total Employees: 25000+ Annual Turnover(2019) : 4500 Crores from refrigerator
	Head of Sourcing (Refrigerator), Sr. Additional Director	9 Years	
XYZ2	Supply chain Manager, (product head)	10 Years	Factory Area : 75 Acres+ Total Employees: 5000+ Annual Turnover(2019): 300 Crore from Refrigerator products
XYZ3	Operations Manager	9 Years	Factory Area : 100 Acres+ Total Employees: 6000+ Annual Turnover(2019): 500 Crore from Refrigerator products
XYZ4	Project and development manager	5 Years	Factory Area : 100 Acres+ Total Employees: 5000+ Annual Turnover(2019): 180 Crore from Refrigerator products
XYZ5	Associate Professor	8 Years+	Academician

Table 4.1: Profile of Experts

In this research, On the basis of the expert opinions and analysis, the major risk and sub-risk were selected for the final evaluation through Delphi method. These include six major risks and forty six sub risk was identified. The main risks include “Supply Risk (S)”; “Operational Risk (O)”; “Financial Risk (F)”; and “Customer/Demand Risk (C)”, "Inventory & Logistics (L)", and "Legal/Regulatory Risk (R)". After finalizing the major risks, open ended questionnaire for identification of sub risks were provided to the experts, they reverted back with 46 sub risks under six categories. After series of rigorous interviews and merging of several sub risk experts agreed upon 24 (Twenty four) sub risks for further analysis.

4.2 Evaluating the risk factor with Probability Severity Index

As mentioned in methodology, we have used several methods to analyze the data; primarily analysis was done through “Probability-Severity” Index. As the questionnaire was open ended so some linguistic corrections were adopted.

Among the major risk, rank through probability –Severity matrixes is as below:

Risk	Weightage of Risk	Severity	Probability	Index Value	Rank
Supply Risk (S)	5.00	0.90	0.45	0.405	1
Operational Risk (O)	4.00	0.70	0.50	0.350	3
Financial Risk (F)	4.25	0.55	0.55	0.303	4
Customer/Demand Risk (C)	3.75	0.45	0.65	0.293	5
Inventory & Logistics (L)	2.75	0.60	0.40	0.240	6
Legal/Regulatory Risk (R)	4.50	0.80	0.44	0.352	2

Table 4.2: Rank of Major Risk Through Probability-Severity Index

Similarly all the sub risk identified through interview was also rank under the major risk listed.

Risk	Sub Risk	Weightage of Risk	Severity	Probability	Index Value	Rank (Local)	Rank (Global)
Supply Risk (S)							
S1	Raw Materials Unavailability	5.00	0.90	0.50	0.45	1	5
S2	Quality issue at Supplier end/Major Failure at supplier end	5.00	0.77	0.10	0.08	8	44
S3	Vessel unavailability	4.00	0.50	0.10	0.05	9	45
S4	Communication Gap between Supplier & Forwarder/Lack of proper information	3.00	0.50	0.70	0.35	5	16
S5	Delay in Shipment in Supplier End/Missing Delivery times/Improper shipment timing	5.00	0.77	0.50	0.38	4	14
S6	Shipment Problem – Delay in port, Freight	4.00	0.50	0.90	0.45	1	5
S7	Incoterms issues with foreign suppliers	4.00	0.50	0.50	0.25	6	25
S8	Lack of willingness/long term relation ships	4.00	0.50	0.50	0.25	6	25
S9	Unavailability of alternative supplier/Single Source	3.00	0.70	0.60	0.42	3	13
Operational Risk (O)							
O1	Failure to Conform the Quality Standard/Quality Assurance/Qulaity Failure	4.33	0.77	0.23	0.18	5	37
O2	Lack of Skilled Manpower	4.00	0.50	0.60	0.30	7	23
O3	Breakdown of Machine	5.00	0.70	0.50	0.35	8	16
O4	Incoming Goods & Outgoing goods Space Management	4.00	0.90	0.50	0.45	9	5
O5	Labor cost Rise/High Cost of skilled labor	3.00	0.50	0.50	0.25	6	25
O6	Productivity	3.00	0.10	0.50	0.05	1	45
O7	Sudden Disaster like fire	5.00	0.90	0.10	0.09	3	38
O8	Speciafication Mismatch	3.00	0.90	0.10	0.09	3	38
O9	Introduction of new technology	3.00	0.50	0.10	0.05	1	45
O8	Maintenance Time/Machine Maintenance	5.00	0.90	0.50	0.45	9	5

Financial Risk (F)							
F1	Change in Exchange Rate	3.67	0.77	0.50	0.38	5	14
F2	Credit Risk in the Market	4.00	0.50	0.50	0.25	1	25
F3	High Bank Interest/ Change in interest rate	4.00	0.50	0.70	0.35	4	16
F4	Cash management	5.00	0.90	0.37	0.33	3	22
F5	Credit Recovery	4.00	0.90	0.50	0.45	6	5
F6	Lack of timely funding	4.00	0.50	0.50	0.25	1	25
Customer/Demand Risk (C)							
C1	Change in Sales Trend due to Environmental issue/No defined sales trend	4.50	0.50	0.70	0.35	3	16
C2	Competitor's aggressive campaign/New Product line/Flashy Sales Promotion	3.00	0.50	0.50	0.25	1	25
C3	Wrong Info related to Market/Lack of market information/Wrong sales information from market	3.75	0.50	0.70	0.35	3	16
C4	Demand Change due to natural Disaster	5.00	0.90	0.90	0.81	6	1
C5	High Forecasting Error/High Forecasting Devaition	4.67	0.63	0.90	0.57	5	2
C6	Introduction of new product from competitors	4.00	0.50	0.50	0.25	1	25
Inventory & Logistics (L)							
L1	Dent & Scratch during handling	5.00	0.90	0.50	0.45	8	5
L2	Damage of goods due to Warehousing issue/Sapce Management	4.00	0.70	0.50	0.35	7	16
L3	Stock accumulation due to Unsuccessful new line up	3.00	0.90	0.10	0.09	1	38
L4	Bullwhip effect/High Ineventory due to uncertainity in market	4.00	0.70	0.70	0.49	10	3
L5	Political Unrest	3.00	0.90	0.10	0.09	1	38

L6	Accumulation of Non moving material due to design change/Accumulation of non moving material	3.50	0.50	0.50	0.25	4	25
L7	High no. of handling	5.00	0.50	0.50	0.25	4	25
L8	Goods damaged due to wrong storage	5.00	0.90	0.50	0.45	8	5
L9	Sudden Natural calamity	5.00	0.90	0.10	0.09	1	38
L10	Missing the deadlines of buyer	4.00	0.50	0.50	0.25	4	25
Legal/Regulatory Risk (R)							
R1	Change in Duty/Change in Import Duty	5.00	0.90	0.50	0.45	6	5
R2	Change in Regulatory/Change In regulations like BSTI certification/Sudden Change in regulation against manufacturers	4.67	0.77	0.37	0.28	5	24
R3	Tax Structure change	5.00	0.70	0.70	0.49	7	3
R4	Slow processing in certification	3.00	0.10	0.90	0.09	2	38
R5	Sudden change in Regulation	3.00	0.50	0.50	0.25	3	25
R6	Change in incentive Structure	3.00	0.50	0.10	0.05	1	45
R7	Policies in financial dealing like TT, Swift, LC	5.00	0.50	0.50	0.25	3	25

Table 4.3: Global ranking through Probability-Severity Index

To precise the data and for further calculations, No. of response in each sub risk was identified and Response index was also calculated to identify the top four sub risk in each major category. And after series of interview with the experts finally 4 risks under each major risk was finalized. In total 24 sub risk were listed. To perform the TOPSIS analysis severity and probability for the listed sub risk was collected through questionnaire as presented in Annexure –B. Weightage of severity and probability was collected as well.

Risk	Major Risk	Sub Risk	
Supply Chain Risk	Supply Risk (S)	S1	Quality issue at Supplier end/Major Failure at supplier end
		S2	Communication Gap between Supplier & Forwarder/Lack of proper information
		S3	Delay in Shipment in Supplier End/Missing Delivery times/Improper shipment timing
		S4	Unavailability of alternative supplier/Single Source
	Operational Risk (O)	O1	Failure to Conform the Quality Standard/Quality Assurance/Qulaity Failure
		O2	Lack of Skilled Manpower
		O3	Breakdown of Machine/Maintenance Time/Machine Maintenance
		O4	Labor cost Rise/High Cost of skilled labor
	Financial Risk(F)	F1	Change in Exchange Rate
		F2	Credit Risk in the Market/Credit Recovery
		F3	High Bank Interest/ Change in interest rate
		F4	Cash management
	Customer/Demand Risk (C)	C1	Change in Sales Trend due to Environmental issue/No defined sales trend/Demand Change due to natural Disaster
		C2	Competitor's aggressive campaign/New Product line/Flashy Sales Promotion
		C3	Wrong Info related to Market/Lack of market information/Wrong sales information from market
		C5	High Forecasting Error/High Forecasting Devaition
	Inventory & Logistics (L)	L1	Dent & Scratch during handling/High Handling
		L2	Damage of goods due to Warehousing issue/Sapce Management
		L3	Stock accumulation due to Unsuccessful new line up/Design Change
		L4	Bullwhip effect/High Ineventory due to uncertainity in market
	Legal/Regulatory Risk (R)	R1	Change in Duty/Change in Import Duty
		R2	Change in Regulatory/Change In regulations like BSTI certification/Sudden Change in regulation against manufacturers
		R3	Tax Structure change
		R6	Policies in financial dealing like TT, Swift, LC

Table 4.4 : Sub risk Finalized for further analysis through Delphi Method

4.3 Evaluating the risk factor with TOPSIS

Decision matrix for the TOSIS was constructed from the experts input. For major risk decision matrix is as below:

Risk	Severity	Probability
Supply Risk (S)	0.90	0.45
Operational Risk (O)	0.75	0.50
Financial Risk (F)	0.55	0.55
Customer/Demand Risk (C)	0.45	0.65
Inventory & Logistics (L)	0.60	0.40
Legal/Regulatory Risk (R)	0.80	0.44

Table 4.5: Decision matrix for major risk

Normalized matrix developed from decision matrix is as below:

Risk	Severity	Probability
Supply Risk (S)	0.22	0.15
Operational Risk (O)	0.19	0.17
Financial Risk (F)	0.14	0.18
Customer/Demand Risk (C)	0.11	0.22
Inventory & Logistics (L)	0.15	0.13
Legal/Regulatory Risk (R)	0.20	0.15

Table 4.6: Normalized matrix for Major risk

To calculate the weighted normalized matrix the attribute weight information is required. From the analytical hierarchy process (AHP), the relative weight of each criterion has been estimated. The linguistic definitions for the importance ratios are shown in Table 4.7. The experts were requested to participate in pair wise comparison matrix. There were various arguments in the discussion process. The discussion needed to synchronize to arrive at a harmony for each comparison matrix. The pairwise comparison on the two criteria and associated weights are shown in Table 4.8 and 4.9.

Level of importance (*aij*)	**Linguistic definition for comparison of the *ith* and the *jth* items**
1	The *i*th item is equal important as the *j*th item
3	The *i*th item is slightly more important than the *j*th item
5	The *i*th item is more important than the *j*th item
7	The *i*th item is strongly more important than the *j*th item
9	The *i*th item is extremely more important than the *j*th item
2,4,6,8	The intermediate values between two adjacent judgments
1/aij = aji	The transposed evaluation between the *i*th and the *j*th items

Table 4.7 : The linguistic definitions for the importance ratios of two selected items

	C1	C2
Severity (C1)	1	3
Probability(C2)	0.333333333	1

Table 4.8: pairwise comparison of relative importance

	C1	C2	Weightage
Severity (C1)	0.75	0.75	0.75
Probability(C2)	0.25	0.25	0.25

Table 4.9: pairwise comparison of relative importance with weight

The weighted normalized decision matrix is shown in Table 4.10. The positive ideal solution and the negative ideal solution are shown in Table 4.11

Risk	**Severity**	**Probability**
Supply Risk (S)	0.166667	0.03762542
Operational Risk (O)	0.138889	0.04180602
Financial Risk (F)	0.101852	0.04598662
Customer/Demand Risk (C)	0.083333	0.05434783
Inventory & Logistics (L)	0.111111	0.03344482
Legal/Regulatory Risk (R)	0.148148	0.0367893

Table: 4.10: Weighted normalized decision matrix

	Severity (C1)	Probability(C2)
PIS A*	0.166667	0.05434783
NIS A-	0.083333	0.03344482

Table 4.11: The positive ideal solution and the negative ideal solution

TOPSIS analysis result for major risk is represented in table 4.12

Risk	**S***	**S-**	**Pi**	**Rank**
Supply Risk (S)	0.016722	0.083438	0.833044	1
Operational Risk (O)	0.029009	0.069528	0.705604	2
Financial Risk (F)	0.079472	0.049575	0.384165	5
Customer/Demand Risk (C)	0.099489	0.054348	0.353281	6
Inventory & Logistics (L)	0.064846	0.043476	0.40136	4
Legal/Regulatory Risk (R)	0.041187	0.074528	0.644064	3

Table 4.12: TOPSIS analysis results for major risk

Similarly rank is being analyzed with TOPSIS for sub risk as well. Decision matrix prepared from expert's opinion is presented in table 4.13

Sub risk	Description of Sub risk	Severity	Probability
S1	Quality issue at Supplier end/Major Failure at supplier end	0.80	0.62
S2	Communication Gap between Supplier & Forwarder/Lack of proper information	0.47	0.80
S3	Delay in Shipment in Supplier End/Missing Delivery times/Improper shipment timing	0.56	0.50
S4	Unavailability of alternative supplier/Single Source	0.75	0.40
O1	Failure to Conform the Quality Standard/Quality Assurance/Quality Failure	0.84	0.23
O2	Lack of Skilled Manpower	0.40	0.60
O3	Breakdown of Machine/Maintenance Time/Machine Maintenance	0.57	0.50
O4	Labor cost Rise/High Cost of skilled labor	0.30	0.40
F1	Change in Exchange Rate	0.50	0.50

F2	Credit Risk in the Market/Credit Recovery	0.40	0.50
F3	High Bank Interest/ Change in interest rate	0.40	0.70
F4	Cash management	0.30	0.30
C1	Change in Sales Trend due to Environmental issue/No defined sales trend/Demand Change due to natural Disaster	0.30	0.70
C2	Competitor's aggressive campaign/New Product line/Flashy Sales Promotion	0.20	0.50
C3	Wrong Info related to Market/Lack of market information/Wrong sales information from market	0.45	0.50
C5	High Forecasting Error/High Forecasting Devaition	0.38	0.80
L1	Dent & Scratch during handling/High Handling	0.39	0.40
L2	Damage of goods due to Warehousing issue/Sapce Management	0.30	0.50
L3	Stock accumulation due to Unsuccessful new line up/Design Change	0.45	0.10
L4	Bullwhip effect/High Ineventory due to uncertainity in market	0.50	0.50
R1	Change in Duty/Change in Import Duty	0.58	0.50
R2	Change in Regulatory/Change In regulations like BSTI certification/Sudden Change in regulation against manufacturers	0.38	0.50
R3	Tax Structure change	0.60	0.70
R6	Policies in financial dealing like TT, Swift, LC	0.40	0.10

Table 4.13: Decision matrix for sub risk

Sub risk	Description of Sub risk	Severity	Probability
S1	Quality issue at Supplier end/Major Failure at supplier end	0.071301883	0.052307433
S2	Communication Gap between Supplier & Forwarder/Lack of proper information	0.041889856	0.067493462
S3	Delay in Shipment in Supplier End/Missing Delivery times/Improper shipment timing	0.049911318	0.042183413
S4	Unavailability of alternative supplier/Single Source	0.066845516	0.033746731
O1	Failure to Conform the Quality Standard/Quality Assurance/Quality Failure	0.074866977	0.019657471
O2	Lack of Skilled Manpower	0.035650942	0.050620096
O3	Breakdown of Machine/Maintenance Time/Machine Maintenance	0.050802592	0.042183413
O4	Labor cost Rise/High Cost of skilled labor	0.026738206	0.033746731
F1	Change in Exchange Rate	0.044554764	0.042183413
F2	Credit Risk in the Market/Credit Recovery	0.035650942	0.042183413
F3	High Bank Interest/ Change in interest rate	0.035650942	0.059056779
F4	Cash management	0.026738206	0.025310048
C1	Change in Sales Trend due to Environmental issue/No defined sales trend/Demand Change due to natural Disaster	0.026738206	0.059056779
C2	Competitor's aggressive campaign/New Product line/Flashy Sales Promotion	0.017825471	0.042183413
C3	Wrong Info related to Market/Lack of market information/Wrong sales information from market	0.040107309	0.042183413
C5	High Forecasting Error/High Forecasting Devaition	0.033868395	0.067493462
L1	Dent & Scratch during handling/High Handling	0.034759668	0.033746731
L2	Damage of goods due to Warehousing issue/Space Management	0.026738206	0.042183413
L3	Stock accumulation due to Unsuccessful new line up/Design Change	0.040107309	0.008436683
L4	Bullwhip effect/High Inventory due to uncertainty in market	0.044563677	0.042183413
R1	Change in Duty/Change in Import Duty	0.051693865	0.042183413
R2	Change in Regulatory/Change In regulations like BSTI certification/Sudden Change in regulation against manufacturers	0.033868395	0.042183413
R3	Tax Structure change	0.053476412	0.059056779
R6	Policies in financial dealing like TT, Swift, LC	0.035650942	0.008436683

Table 4.14: Normalized Decision matrix for sub risk

Considering table 4.8, weightage is used to calculate the weighted normalized decision matrix as below.

Sub risk	Description of Sub risk	Severity	Probability
S1	Quality issue at Supplier end/Major Failure at supplier end	0.053476	0.013077
S2	Communication Gap between Supplier & Forwarder/Lack of proper information	0.031417392	0.016873365
S3	Delay in Shipment in Supplier End/Missing Delivery times/Improper shipment timing	0.037433489	0.010545853
S4	Unavailability of alternative supplier/Single Source	0.050134137	0.008436683
O1	Failure to Conform the Quality Standard/Quality Assurance/Quality Failure	0.056150233	0.004914368
O2	Lack of Skilled Manpower	0.026738206	0.012655024
O3	Breakdown of Machine/Maintenance Time/Machine Maintenance	0.038101944	0.010545853
O4	Labor cost Rise/High Cost of skilled labor	0.020053655	0.008436683
F1	Change in Exchange Rate	0.033416073	0.010545853
F2	Credit Risk in the Market/Credit Recovery	0.026738206	0.010545853
F3	High Bank Interest/ Change in interest rate	0.026738206	0.014764195
F4	Cash management	0.020053655	0.006327512
C1	Change in Sales Trend due to Environmental issue/No defined sales trend/Demand Change due to natural Disaster	0.020053655	0.014764195
C2	Competitor's aggressive campaign/New Product line/Flashy Sales Promotion	0.013369103	0.010545853
C3	Wrong Info related to Market/Lack of market information/Wrong sales information from market	0.030080482	0.010545853
C5	High Forecasting Error/High Forecasting Devaition	0.025401296	0.016873365
L1	Dent & Scratch during handling/High Handling	0.026069751	0.008436683
L2	Damage of goods due to Warehousing issue/Space Management	0.020053655	0.010545853
L3	Stock accumulation due to Unsuccessful new line up/Design Change	0.030080482	0.002109171
L4	Bullwhip effect/High Inventory due to uncertainty in market	0.033422758	0.010545853
R1	Change in Duty/Change in Import Duty	0.038770399	0.010545853
R2	Change in Regulatory/Change In regulations like BSTI certification/Sudden Change in regulation against manufacturers	0.025401296	0.010545853
R3	Tax Structure change	0.040107309	0.014764195
R6	Policies in financial dealing like TT, Swift, LC	0.026738206	0.002109171

Table 4.15: Weighted normalized matrix for sub risk

Positive ideal solution and negative ideal solution is calculated as below:

	Severity (C1)	Probability(C2)
PIS A*	0.06	0.02
NIS A-	0.01	0.00

Table 4.16: Positive ideal solution and negative ideal solution for subrisk

And TOPSIS analysis results for sub risk is as below:

Sub risk	Description of Sub risk	**S***	**S-**	**Pi**	**Rank**
S1	Quality issue at Supplier end/Major Failure at supplier end	0.0046	0.04157988	0.899540731	1
S2	Communication Gap between Supplier & Forwarder/Lack of proper information	0.0247	0.023317851	0.485276076	8
S3	Delay in Shipment in Supplier End/Missing Delivery times/Improper shipment timing	0.0198	0.025500437	0.563448272	7
S4	Unavailability of alternative supplier/Single Source	0.0104	0.037305564	0.782619487	2
O1	Failure to Conform the Quality Standard/Quality Assurance/Quality Failure	0.0120	0.042873001	0.781897468	3
O2	Lack of Skilled Manpower	0.0297	0.017027858	0.364303578	14
O3	Breakdown of Machine/Maintenance Time/Machine Maintenance	0.0191	0.026132184	0.577410976	6
O4	Labor cost Rise/High Cost of skilled labor	0.0371	0.009204381	0.198911364	22
F1	Change in Exchange Rate	0.0236	0.021749911	0.479620118	10
F2	Credit Risk in the Market/Credit Recovery	0.0301	0.015808559	0.344461696	16
F3	High Bank Interest/ Change in interest rate	0.0295	0.018408763	0.384346095	12
F4	Cash management	0.0376	0.007904279	0.173682875	23
C1	Change in Sales Trend due to Environmental issue/No defined sales trend/Demand Change due to natural Disaster	0.0362	0.014311983	0.283573338	20
C2	Competitor's aggressive campaign/New Product line/Flashy Sales Promotion	0.0432	0.008436683	0.163238352	24
C3	Wrong Info related to Market/Lack of market information/Wrong sales information from market	0.0268	0.018720251	0.411010393	11
C5	High Forecasting Error/High Forecasting Devaition	0.0307	0.019046131	0.38249031	13
L1	Dent & Scratch during handling/High Handling	0.0312	0.014189569	0.312333846	18

L2	Damage of goods due to Warehousing issue/Space Management	0.0366	0.010763868	0.227033906	21
L3	Stock accumulation due to Unsuccessful new line up/Design Change	0.0300	0.016711379	0.358063314	15
L4	Bullwhip effect/High Inventory due to uncertainty in market	0.0236	0.021756072	0.479758931	9
R1	Change in Duty/Change in Import Duty	0.0185	0.026765714	0.591356517	5
R2	Change in Regulatory/Change In regulations like BSTI certification/Sudden Change in regulation against manufacturers	0.0314	0.014695281	0.318849152	17
R3	Tax Structure change	0.0162	0.029581773	0.64641599	4
R6	Policies in financial dealing like TT, Swift, LC	0.0329	0.013369103	0.288881743	19

Table 4.17: TOPSIS analysis results for sub risk with global ranking

As seen from the results in major risk supply risk is the most vital risk and customer/demand risk obtained the lowest rank. Similarly for sub risk Quality issue at Supplier end/Major Failure at supplier end (S1) is ranked highest and Competitor's aggressive campaign/New Product line/Flashy Sales Promotion (C2) is ranked lowest.

4.4 Evaluating the Risk identified and prioritizing using AHP

In this step, the finalized risks were prioritized using AHP with the help of expert's inputs. A hierarchical structural is constructed using expert inputs (table 4.4).

This hierarchical structural figure comprises of three different levels: evaluating the supply chain risks management in refrigerator industry (Level-1), 4 main risks (Level-2) and 16 sub risks (Level-3).The pair wise comparisons relation matrices are formed for both the major risks and the sub risks using experts' inputs through provided Saaty scale. With the help of experts feedback, at first pair wise comparison relation matrix for the main risks is formulated and then we calculated the priority weights and ranking for each risk .

Likewise, the pair wise comparison relation matrices for sub risks under each main risks are formulated and their corresponding priority weights are calculated. The pair wise comparison matrices are used to determine the relative importance of weights and global importance of weights and their rank are evaluated. Global weights are computed by multiplying relative weights of main risks with relative weights of sub risks and then global ranking is determined accordingly.

From the experts opinion, pairwise comparison for the major risk is developed

Main Risks						
Risk	S	O	F	C	L	R
Supply Risk (S)	1.00	2.50	4.00	2.33	2.30	1.83
Operational Risk (O)	0.40	1.00	3.00	1.83	2.33	1.00
Financial Risk (F)	0.25	0.33	1.00	1.80	2.30	0.47
Customer/Demand Risk (C)	0.43	0.55	0.56	1.00	1.33	0.33
Inventory & Logistics (L)	0.43	0.43	0.43	0.75	1.00	1.17
Legal/Regulatory Risk (R)	0.55	1.00	2.14	3.00	0.86	1.00

Table 4.18: Pair wise comparison relation matrix for major risk in SCRM of refrigerator industry

And from the pairwise matrix normalized matrix, relative weight and rank is being developed.

Risk	S	O	F	C	L	R	Weight	Relative Weight	Rank
Supply Risk (S)	0.33	0.43	0.36	0.22	0.23	0.32	31%	0.31	1
Operational Risk (O)	0.13	0.17	0.27	0.17	0.23	0.17	19%	0.19	2
Financial Risk (F)	0.08	0.06	0.09	0.17	0.23	0.08	12%	0.12	4
Customer/Demand Risk (C)	0.14	0.09	0.05	0.09	0.13	0.06	9%	0.09	6
Inventory & Logistics (L)	0.14	0.07	0.04	0.07	0.10	0.20	10%	0.10	5
Legal/Regulatory Risk (R)	0.18	0.17	0.19	0.28	0.08	0.17	18%	0.18	3

Table 4.19: Normalized matrix, relative weight and rank of Major risk

Consistency index and consistency is also being calculated to validate the calculation

Risk	S	O	F	C	L	R	Sum	Consistency
Supply Risk (S)	0.31	0.48	0.47	0.22	0.24	0.33	2.05	6.55
Operational Risk (O)	0.13	0.19	0.35	0.17	0.24	0.18	1.26	6.62
Financial Risk (F)	0.08	0.06	0.12	0.17	0.24	0.08	0.75	6.41
Customer/Demand Risk (C)	0.13	0.10	0.07	0.09	0.14	0.06	0.60	6.32
Inventory & Logistics (L)	0.14	0.08	0.05	0.07	0.10	0.21	0.65	6.28
Legal/Regulatory Risk (R)	0.17	0.19	0.25	0.28	0.09	0.18	1.17	6.48
							Total	38.66
							No. of comparison	6
							Average Consistency	6.44
							CI	0.09
							RI	1.24
							consistency	0.07148281

Table 4.20: Consistency index and Consistency value for major risk

As seen from the results in major risk supply risk is the most vital risk and customer/demand risk obtained the lowest rank through AHP.

Similarly all the sub risk under the major risk is being ranked.

Pairwise matrix for sub risk under supply major risk is as below:

Supply Risk (S)					
Risk	Description	S1	S2	S3	S4
S1	Quality issue at Supplier end/Major Failure at supplier end	1.00	4.00	3.00	1.67
S2	Communication Gap between Supplier & Forwarder/Lack of proper information	0.25	1.00	0.63	0.43
S3	Delay in Shipment in Supplier End/Missing Delivery times/Improper shipment timing	0.33	1.58	1.00	0.47
S4	Unavailability of alternative supplier/Single Source	0.60	2.31	2.14	1.00

Table 4.21: Pair wise comparison relation matrix for sub risk under supply risk

And from the pairwise matrix normalized matrix, relative weight and rank is being developed. Along with it consistency index and consistency is calculated, which the consistency of judgments across all pairwise comparisons [46]

Supply Risk (S)							
Risk	Description	S1	S2	S3	S4	Relative Weight	Rank
S1	Quality issue at Supplier end/Major Failure at supplier end	1.00	4.00	3.00	1.67	0.45	1
S2	Communication Gap between Supplier & Forwarder/Lack of proper information	0.25	1.00	0.63	0.43	0.11	4
S3	Delay in Shipment in Supplier End/Missing Delivery times/Improper shipment timing	0.33	1.58	1.00	0.47	0.15	3
S4	Unavailability of alternative supplier/Single Source	0.60	2.31	2.14	1.00	0.28	2
						CI	0.004324
						RI	0.9
						consistency	0.004804

Table 4.22: Rank, Consistency index and Consistency value for sub risk under supply risk

Pairwise matrix for sub risk under operational major risk is as below:

Operational risk (S)					
Risk	Description	O1	O2	O3	O4
O1	Failure to Conform the Quality Standard/Quality Assurance/Quality Failure	1.00	4.50	3.00	4.00
O2	Lack of Skilled Manpower	0.22	1.00	0.47	1.50
O3	Breakdown of Machine/Maintenance Time/Machine Maintenance	0.33	2.14	1.00	5.00
O4	Labor cost Rise/High Cost of skilled labor	0.25	0.67	0.20	1.00

Table 4.23: Pair wise comparison relation matrix for sub risk under operational risk

And from the pairwise matrix normalized matrix, relative weight and rank is being developed. Along with it consistency index and consistency is calculated.

	Operational Risk (O)	O1	O2	O3	O4	Relative Weight	Rank
O1	Failure to Conform the Quality Standard/Quality Assurance/Qulaity Failure	0.55	0.54	0.64	0.35	0.52	1
O2	Lack of Skilled Manpower	0.12	0.12	0.10	0.13	0.12	3
O3	Breakdown of Machine/Maintenance Time/Machine Maintenance	0.18	0.26	0.21	0.43	0.27	2
O4	Labor cost Rise/High Cost of skilled labor	0.14	0.08	0.04	0.09	0.09	4
						CI	0.05081
						RI	0.9
						consistency	0.05645

Table 4.24: Rank, Consistency index and Consistency value for sub risk under operational risk

For sub risk under financial risk

Financial Risk (F)					
Risk	Description	F1	F2	F3	F4
F1	Change in Exchange Rate	1.00	2.83	0.97	2.80
F2	Credit Risk in the Market/Credit Recovery	0.35	1.00	0.50	1.00
F3	High Bank Interest/ Change in interest rate	1.03	2.00	1.00	2.80
F4	Cash management	0.36	1.00	0.36	1.00

Table 4.25: Pair wise comparison relation matrix for sub risk under financial risk

And from the pairwise matrix normalized matrix, relative weight and rank is being developed. Along with it consistency index and consistency is calculated.

Financial Risk (F)							
Risk	Description	F1	F2	F3	F4	Relative Weight	Rank
F1	Change in Exchange Rate	1.00	2.83	0.97	2.80	0.37	1
F2	Credit Risk in the Market/Credit Recovery	0.35	1.00	0.50	1.00	0.15	3
F3	High Bank Interest/ Change in interest rate	1.03	2.00	1.00	2.80	0.35	2
F4	Cash management	0.36	1.00	0.36	1.00	0.13	4
						CI	0.01
						RI	0.9
						consistency	0.00605

Table 4.26: Rank, Consistency index and Consistency value for sub risk under financial risk

For sub risk under Customer/Demand Risk risk

Customer/Demand Risk (C)					
Risk	Description	C1	C2	C3	C4
C1	Change in Sales Trend due to Environmental issue/No defined sales trend/Demand Change due to natural Disaster	1.00	2.83	1.17	0.63
C2	Competitor's aggressive campaign/New Product line/Flashy Sales Promotion	0.35	1.00	0.43	0.63
C3	Wrong Info related to Market/Lack of market information/Wrong sales information from market	0.86	2.31	1.00	2.30
C4	High Forecasting Error/High Forecasting Deviation	1.58	1.58	0.43	1.00

Table 4.27: Pair wise comparison relation matrix for sub risk under Customer/demand financial risk

And from the pairwise matrix normalized matrix, relative weight and rank is being developed. Along with it consistency index and consistency is calculated for sub risk under customer/demand Risk.

Customer/Demand Risk (C)							
Risk	Description	C1	C2	C3	C4	Relative Rank	Rank
C1	Change in Sales Trend due to Environmental issue/No defined sales trend/Demand Change due to natural Disaster	1.00	2.83	1.17	0.63	0.29	2
C2	Competitor's aggressive campaign/New Product line/Flashy Sales Promotion	0.35	1.00	0.43	0.63	0.13	4
C3	Wrong Info related to Market/Lack of market information/Wrong sales information from market	0.86	2.31	1.00	2.30	0.34	1
C4	High Forecasting Error/High Forecasting Deviation	1.58	1.58	0.43	1.00	0.25	3
						CI	0.07286
						RI	0.9
						consistency	0.08095

Table 4.28: Rank, Consistency index and Consistency value for sub risk under customer/demand risk

For sub risk under Inventory & Logistics risk

Inventory & Logistics (L)					
Risk	Description	L1	L2	L3	L4
L1	Dent & Scratch during handling/High Handling	1.00	1.50	1.47	0.30
L2	Damage of goods due to Warehousing issue/Sapce Management	0.67	1.00	0.50	0.47
L3	Stock accumulation due to Unsuccessful new line up/Design Change	0.68	2.00	1.00	0.67
L4	Bullwhip effect/High Ineventory due to uncertainity in market	3.33	2.14	1.50	1.00

Table 4.29: Pair wise comparison relation matrix for sub risk under Inventory & Logistics risk

And from the pairwise matrix normalized matrix, relative weight and rank is being developed. Along with it consistency index and consistency is calculated for sub risk under Inventory & Logistics risk.

Inventory & Logistics (L)							
Risk	Description	L1	L2	L3	L4	Relative Weight	Rank
L1	Dent & Scratch during handling/High Handling	1.00	1.50	1.47	0.30	0.21	3
L2	Damage of goods due to Warehousing issue/Space Management	0.67	1.00	0.50	0.47	0.14	4
L3	Stock accumulation due to Unsuccessful new line up/Design Change	0.68	2.00	1.00	0.67	0.23	2
L4	Bullwhip effect/High Inventory due to uncertainty in market	3.33	2.14	1.50	1.00	0.41	1
						CI	0.06
						RI	0.9
						consistency	0.06349

Table 4.30: Rank, Consistency index and Consistency value for sub risk under Inventory & Logistics risk

For sub risk under Inventory & Logistics risk

Legal/Regulatory Risk (R)					
Risk	Description	R1	R2	R3	R4
R1	Change in Duty/Change in Import Duty	1.00	4.50	2.50	3.00
R2	Change in Regulatory/Change In regulations like BSTI certification/Sudden Change in regulation against manufacturers	0.22	1.00	0.27	1.50
R3	Tax Structure change	0.40	3.75	1.00	4.00
R4	Policies in financial dealing like TT, Swift, LC	0.33	0.67	0.25	1.00

Table 4.31: Pair wise comparison relation matrix for sub risk under Legal/Regulatory risk

And from the pairwise matrix normalized matrix, relative weight and rank is being developed. Along with it consistency index and consistency is calculated for sub risk under Legal/Regulatory Risk risk.

Legal/Regulatory Risk (R)							
Risk	Description	R1	R2	R3	R4	Relative weight	Rank
R1	Change in Duty/Change in Import Duty	1.00	4.50	2.50	3.00	0.475835	1

R2	Change in Regulatory/Change In regulations like BSTI certification/Sudden Change in regulation against manufacturers	0.22	1.00	0.27	1.50	0.109690	3
R3	Tax Structure change	0.40	3.75	1.00	4.00	0.313178	2
R4	Policies in financial dealing like TT, Swift, LC	0.33	0.67	0.25	1.00	0.10129	4
						CI	0.058967
						RI	0.9
						consistency	0.065519

Table 4.32: Rank, Consistency index and Consistency value for sub risk under Legal/Regulatory Risk.

From relative weight of the major risk global weight and global rank of each sub risk is calculated.

Main Risk	Relative Weight	Subrisk Sl.	Subrisk Description	Global Weight	Global Rank
Supply Risk (S)	0.31	S1	Quality issue at Supplier end/Major Failure at supplier end	0.14224771	1
		S2	Communication Gap between Supplier & Forwarder/Lack of proper information	0.03458049	10
		S3	Delay in Shipment in Supplier End/Missing Delivery times/Improper shipment timing	0.04762843	7
		S4	Unavailability of alternative supplier/Single Source	0.08849458	3
Operational Risk (O)	0.19	O1	Failure to Conform the Quality Standard/Quality Assurance/Quality Failure	0.09964460	2
		O2	Lack of Skilled Manpower	0.02263442	17
		O3	Breakdown of Machine/Maintenance Time/Machine Maintenance	0.05214017	6
		O4	Labor cost Rise/High Cost of skilled labor	0.01664684	21
Financial Risk (F)	0.12	F1	Change in Exchange Rate	0.04405649	8
		F2	Credit Risk in the Market/Credit Recovery	0.02449148	14
		F3	High Bank Interest/ Change in interest rate	0.03311648	11
		F4	Cash management	0.01576231	22

Customer /Demand Risk (C)	0.09	C1	Change in Sales Trend due to Environmental issue/No defined sales trend/Demand Change due to natural Disaster	0.02723669	13
		C2	Competitor's aggressive campaign/New Product line/Flashy Sales Promotion	0.01189858	24
		C3	Wrong Info related to Market/Lack of market information/Wrong sales information from market	0.03205726	12
		C4	High Forecasting Error/High Forecasting Deviation	0.02321123	16
Inventory & Logistics (L)	0.10	L1	Dent & Scratch during handling/High Handling	0.02222186	18
		L2	Damage of goods due to Warehousing issue/Space Management	0.01488289	23
		L3	Stock accumulation due to Unsuccessful new line up/Design Change	0.02392671	15
		L4	Bullwhip effect/High Inventory due to uncertainty in market	0.04311900	9
Legal/Regulatory Risk (R)	0.18	R1	Change in Duty/Change in Import Duty	0.085651155	4
		R2	Change in Regulatory/Change In regulations like BSTI certification/Sudden Change in regulation against manufacturers	0.01974445	19
		R3	Tax Structure change	0.05637256	5
		R4	Policies in financial dealing like TT, Swift, LC	0.01823350	20

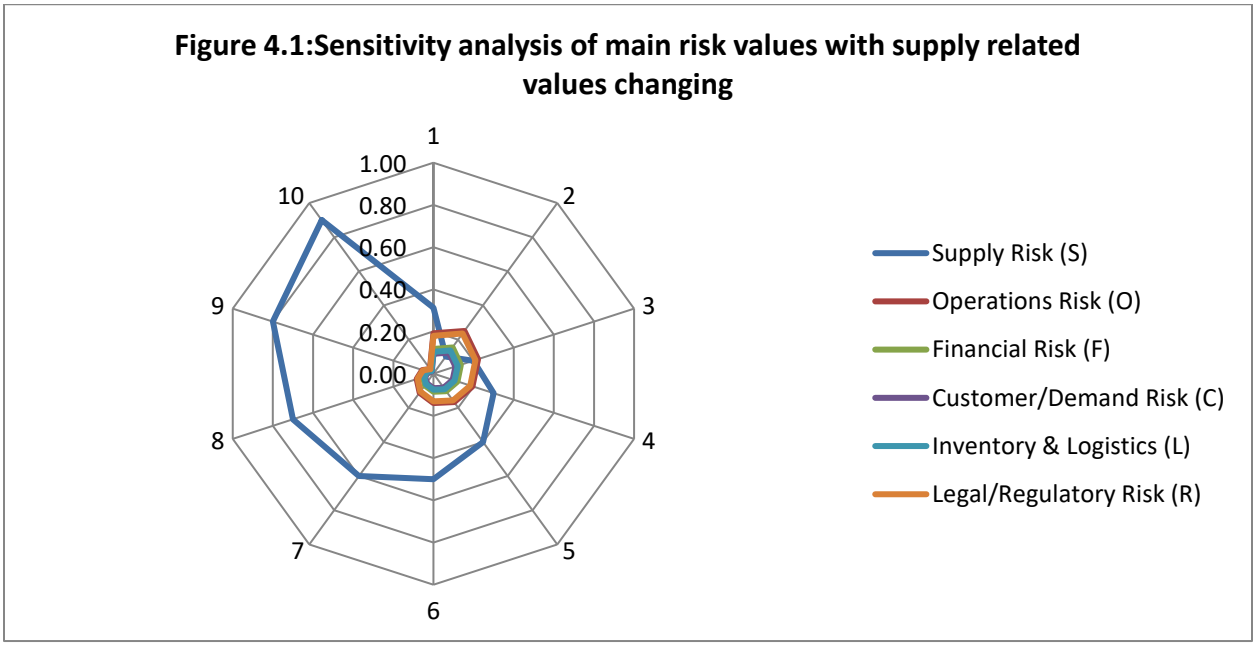
Table 4.33: AHP analysis results for sub risk with global ranking

4.5 Sensitivity Analysis

In this research, among six main risks, supply-related risk holds the utmost priority weight. Moreover, multi criteria decision analysis method cannot deal perfectly to prioritize risk due to human judgment. Small change in relative weights of risks may show the large change in final ranking [29]. Therefore, it is necessary to investigate the ranking for stability of result [47]. A sensitivity analysis was performed by changing weight from 0.1 to 0.9 with 0.1 as incremental value to supply-related risk to examine the changes in ranking of supply chain risks. At the same Sensitivity analysis results show that maximum change occurred in the operational risks (O) weights and closely followed by legal/regulatory risk (R) .

Risk	Supply Risk (S)									
Supply Risk (S)	0.31	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Operational Risk (O)	0.19	0.25	0.22	0.19	0.17	0.14	0.11	0.08	0.06	0.03
Financial Risk (F)	0.12	0.15	0.14	0.12	0.10	0.09	0.07	0.05	0.03	0.02
Customer/Demand Risk (C)	0.09	0.12	0.11	0.10	0.08	0.07	0.05	0.04	0.03	0.01
Inventory & Logistics (L)	0.10	0.14	0.12	0.11	0.09	0.08	0.06	0.05	0.03	0.02
Legal/Regulatory Risk (R)	0.18	0.24	0.21	0.18	0.16	0.13	0.10	0.08	0.05	0.03
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

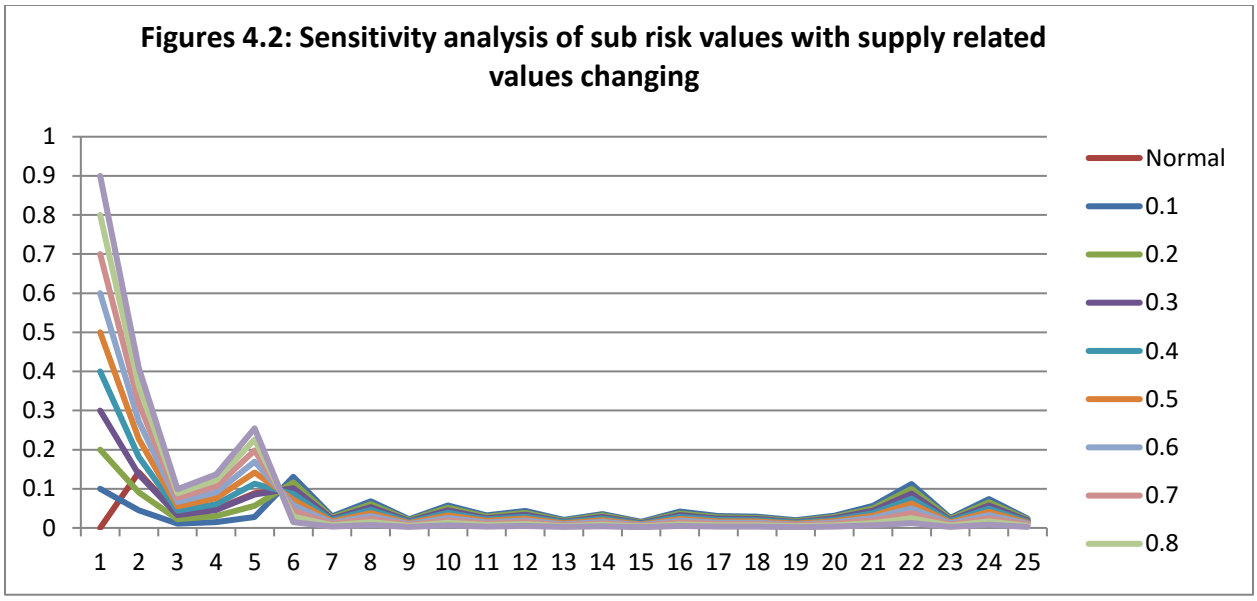
Table 4.34: Sensitivity analysis of main risk values when increasing supply-related risks value from 0.1 to 0.9



Due to changes in main risks weights, sub risks weights and their ranking are also changed, global weights of sub risks when "Supply-Related Risk" value increased from 0.1 to 0.9 are provided in Table 4.35.Graphical illustrations for global weights of sub risks and priority ranking for sub risks based on sensitivity analysis are shown in Figures 4.2 At the end, it can be stated that supply-related risk is more important than other risks. Thus, minimizing supply chain risk is significant for managers to improve the effectiveness

Sub risk Sl	Normal	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
S1	0.14	0.05	0.09	0.14	0.18	0.23	0.27	0.32	0.36	0.41
S2	0.03	0.01	0.02	0.03	0.04	0.06	0.07	0.08	0.09	0.10
S3	0.05	0.02	0.03	0.05	0.06	0.08	0.09	0.11	0.12	0.14
S4	0.09	0.03	0.06	0.08	0.11	0.14	0.17	0.20	0.23	0.25
O1	0.10	0.13	0.12	0.10	0.09	0.07	0.06	0.04	0.03	0.01
O2	0.02	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.00
O3	0.05	0.07	0.06	0.05	0.05	0.04	0.03	0.02	0.02	0.01
O4	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.00
F1	0.04	0.06	0.05	0.04	0.04	0.03	0.03	0.02	0.01	0.01
F2	0.02	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.00
F3	0.03	0.04	0.04	0.03	0.03	0.02	0.02	0.01	0.01	0.00
F4	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.00
C1	0.03	0.04	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.00
C2	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00
C3	0.03	0.04	0.04	0.03	0.03	0.02	0.02	0.01	0.01	0.00
C4	0.02	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.00
L1	0.02	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.00
L2	0.01	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.00
L3	0.02	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.00
L4	0.04	0.06	0.05	0.04	0.04	0.03	0.03	0.02	0.01	0.01
R1	0.09	0.11	0.10	0.09	0.07	0.06	0.05	0.04	0.02	0.01
R2	0.02	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.00
R3	0.06	0.07	0.07	0.06	0.05	0.04	0.03	0.02	0.02	0.01
R4	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.00

Table 4.35: Sensitivity analysis of sub risk values when increasing supply-related risks value from 0.1 to 0.9



4.6 Deductions from the evolutions

The order of preference for the major risk in supply chain management of refrigerator industry is summarized in Table 4.36 in accordance with the TOPSIS and AHP methods

Risk	Ranking by TOPSIS	Ranking by AHP
Supply Risk (S)	1	1
Operational Risk (O)	2	2
Financial Risk (F)	5	4
Customer/Demand Risk (C)	6	6
Inventory & Logistics (L)	4	5
Legal/Regulatory Risk (R)	3	3

Table 4.36: Ranking comparison analysis of major risk with TOPSIS and AHP.

In both methods top 3 risks are marked same, and later 3 is changed by slightest of margin. Similarly ranking are compared for sub risk under each major risk and global weight is being considered.

Subrisk	Ranking by TOPSIS	Ranking by AHP
S1	1	1
S2	8	10
S3	7	7
S4	2	3
O1	3	2
O2	14	17
O3	6	6
O4	22	21
F1	10	8
F2	16	14
F3	12	11
F4	23	22
C1	20	13
C2	24	24
C3	11	12
C5	13	16
L1	18	18
L2	21	23
L3	15	15
L4	9	9
R1	5	4
R2	17	19
R3	4	5
R4	19	20

Table 4.37: Ranking comparison analysis of sub risk with TOPSIS and AHP.

The proposed methodology aimed to recommend a systematic evaluation model to identify and rank the supply chain risks that occur in refrigerator manufacturing/assembly industry as well as the TOPSIS and AHP comparison. An approach to slandering the number of risks types and to facilitate the decision making process is prescribed by the proposed method.

Chapter 5: Results and Discussions

5.1 Results and discussions

Results validate the obtained results and feedback from the experts. From Table 5.1 it can be seen that supply and operational risks possess the highest position among the supply chain risks encountered in refrigerator manufacturing/assembly industry of Bangladesh. As per Bangladesh Refrigerator Manufacturers and Exporters Association (BRMEA), Bangladesh's refrigerator industry is mostly dependent on import of raw materials from China, Korea, Thailand, India and other countries from ASEAN region. So ensuring consistent raw materials quality at a competitive price is challenging. Moreover due to current COVID situation, freight situation has got worse, and suppliers are struggling to maintain the commitments due their raw material supply. As most of the spares are customized so it's also difficult to develop alternative source in short span of time.

Risk	Ranking by TOPSIS	Ranking by AHP
Supply Risk (S)	1	1
Operational Risk (O)	2	2
Financial Risk (F)	5	4
Customer/Demand Risk (C)	6	6
Inventory & Logistics (L)	4	5
Legal/Regulatory Risk (R)	3	3

Table 5.1: Ranking comparison between TOPSIS and AHP

As refrigerator manufacturing industry is relatively new industry in Bangladesh so there is lack of skilled manpower in this sector. Companies have to spend a healthy amount in developing the required skill of the manpower. Lack of quality develops with the lack of skill, so it is really a challenge to meet the global quality. As new companies are coming up in this technology sector, so there is always a demand for skilled labor, due to scarcity the value of manpower is also high compared to other developed industrial sector.

Regulatory risk arises due to unstable policies, being a new sector policies are being shaped gradually. Moreover there is differentiation between assembly and manufacturing, so several works has to be done with HS code as well to distinguish the import duties. Moreover for internal market specifications of the product is not regulated so there is lots of competition from grey market as well with low quality products. Moreover many foreign company is

uncomfortable is starting the business with Bangladeshi companies, due to difficulties in financial transaction. Due to this many a times business deal has to be cancelled as well.

As raw materials for refrigerator is mostly imported so financial factors are very important. Slight change in exchange rate will have very high impact on the COGS of the goods and hence the profitability. As this sector is relatively new and local brands have just started to make an impact so local banks are reluctant to invest in the business with high seasonal impact. So cash management is very critical for the local manufacturer, sometimes especially in winter it gets really hard to generate cash and manage working capital from local market. Due to market nature company also had to rely heavily on the credit sales and hire sales to grab the market share, so a considerable amount of working capital is being invested as market development expenditure.

Inventories are held by firms to satisfy demand. Inventory risk arises from keeping inventories for future uses or from stock out of inventories which leads to excess handling cost or loss of opportunity cost [49]. Inventory can be damaged because of mishandling and for incorrect storing methods [48]. As the product by nature is a seasonal one so there is high risk in building up unnecessary inventory due to uncertainty in market leading to bullwhip effects. This particular research also shows that damaged inventory is one of the risk factors in the supply chain and this perspective is also supported via existing literature

Demand risk often is influenced by a change in the market, and as a major risk factor in SCRM in refrigerator industry. Demand risk includes sale withdrawal, changes in market demand, changes in product preference etc. sometimes exotic offers from competitors can change the customer's mind set. There is also a risk of natural calamity and might cause sudden decline in market demand. These sort of uncertainties lead to high forecasting error and may provide deceiving data for the market demand. This outcome is also in line with the previous literature on SCRM.

Chapter 6 : Conclusions, Managerial Implications and Recommendations

6.1 Conclusions

SCRM practices are gaining popularity widely in various manufacturing industries. Due to the emerging pressures from local and international markets, the manufacturing industries have started to adopt risk assessment methods in their traditional supply chains. The fast increasing challenges like global competition, raw materials sources, increased product diversity, demanding customer and, globalization have a key impact on the refrigerator industry. Refrigerator manufacturing industry of Bangladesh is vulnerable to various risks. Risks may arise in any position of the supply chain, and thus may harm the overall efficiency of it. Therefore, it is necessary to take preventive measure to mitigate those risks and their effects. The following conclusions are drawn from this study.

- A TOPSIS and AHP based model is proposed for evaluating the supply chain risks in the context of refrigerator manufacturing sector.
- Forty six relevant supply chain risks in the context of refrigerator manufacturing sector were identified through the existing literature review and from the expert's feedback. From there twenty four has been selected with consensus from participating experts. After that, TOPSIS and AHP methods were used to rank these risks.
- The results show that supply related risk, operational risk and regulatory risk are the major risk. Lack of material quality, quality issues during manufacturing and inadequate material supplier are the top three sub risks among the twenty four risk factors.
- There are some variations in ranking of risks using TOPSIS and AHP methods, and it is suggested that AHP method's ranking is desired option for vague and inaccurate performance ratings

6.2 Managerial Implications

This study's finding will provide significant guidance to the refrigerator manufacturing industries of Bangladesh to determine the supply chain risk in their organizations. If the risks are tackled strategically and the action plans are initiated systematically, the refrigerator industries of Bangladesh will be able to reduce the unnecessary risk and make some financial gains. The action plans will assist the policy makers to formulate strategies to make the initiatives to avoid supply chain risk . Thus, the insights of the risk and course of the action plans will assist the policy makers to adopt SCRM activities in their traditional supply chain and make better utilization of resources which will lead to a promising profitability.

Some issues are provided for assisting managers to reduce the occurrence of supply chain risks as follows:

Providing quality products is very crucial for any business firm and any compromise in quality will cause severe loss both in reputation and finance. So, managers of refrigerator manufacturing industry must scrutinize every step in the supply chain to ensure the quality.

Managers in the refrigerator manufacturing must be wary about supply related risks. Raw materials are purchased from other countries and that requires the managers to be very careful about lead time and quality.

Managers in refrigerator industry must look into developing efficient man power, as export is growing so the operation must be as lean as possible, at the same time product must meet the international standards. so operational excellence is must.

Refrigerator is a household product and customer wants their product to be as furnished as possible, from the managerial context, it is suggested to use appropriate handling method and proper storage to minimize the loss of produced items as well as raw material.

As an emerging sector and Bangladesh having a possibilities to become a tech hub must look into the regulatory issues very carefully. Managers must always be aware of any change in regulations or legal issues.

Furthermore, for improving the supply chain resilience, performance and effectiveness it is necessary for the managers to understand the supply chain risks. This research will assist them in this context. The ranking established by this research would be helpful for risks mitigation process and thus, it will also be helpful for escalating the efficiency of the supply chain in Refrigerator manufacturing sector of Bangladesh.

6.3 Future Recommendations

Despite the contributions made by this study, a number of limitations and concerns do exist. Yet, these limitations do provide fertile grounds for future and additional empirical investigations. For example, the risks in this study were identified using the extant literature review and industrial manager's opinions. A more scientific approach and empirical validation is required, especially in the refrigerator manufacturing industry of Bangladesh. Given that only a handful of managers were asked their opinion, a more robust and scientific evaluation covering a broader set of organizations are necessary to ascertain how much of these risks are really hindering the supply chain. Progressively, many new risks may hinder the implementation of SCRM practices. Those barriers can be taken into account and ranked systematically.

From a methodological perspective, this study used TOPSIS And AHP to evaluate the risks. These tools, although potentially useful, may require more thorough comparative analysis with other tools. For example, other weighting schemes/ models such as the Interpretive Structural Modeling (ISM), the Structural Equation Modeling (SEM) or the Graph Theory and Matrix Approach (GTMA), ,VIKOR, the fuzzy TOPSIS, the Fuzzy-AHP, the fuzzy-VIKOR,

Elimination and Choice Expressing Reality (ELECTRE), and Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE) can also be used to rank the risks in the future and similar study, and compared. The methodology and framework developed in this study can be applied to other industries i.e. Air conditioner, cosmetics , motorcycle, automobile industries etc. to assess and rank the risk in SCRM practices and potential action plans to mitigate these risk.

I believe this study is one of the very first and few that focuses on the Bangladesh's refrigerator manufacturing industry. It sets the stage for additional and needed research investigation and practical application of the action plans to mitigate these risks. Clearly more works in this area is required in the present economic, social and technological context of the country.

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Appendices

Name of organization	Designation	Years of experience	Brief Company Information
XYZ1	Head of Supply Chain, Executive Director	10 years	Factory Area: 1200 Acres+ Total Employees: 25000+ Annual Turnover(2019) : 4500 Crores from refrigerator
	Head of Sourcing (Refrigerator), Sr. Additional Director	9 Years	
XYZ2	Supply chain Manager, (product head)	10 Years	Factory Area : 75 Acres+ Total Employees: 5000+ Annual Turnover(2019): 300 Crore from Refrigerator products
XYZ3	Operations Manager	9 Years	Factory Area : 100 Acres+ Total Employees: 6000+ Annual Turnover(2019): 500 Crore from Refrigerator products
XYZ4	Project and development manager	5 Years	Factory Area : 100 Acres+ Total Employees: 5000+ Annual Turnover(2019): 180 Crore from Refrigerator products
XYZ5	Associate Professor	8 Years+	Academician

Table A1: profile of the experts

Table A2: Questionnaire for data collection

Interview questionnaire for M.Eng Project "Supply chain risk assessment in the refrigerator industry of Bangladesh: A case study" under Bangladesh University of Engineering and Technology (BUET)

Name of the Company:

1. **Name:**
2. **Designation:**
3. **Years of experience:**
4. **Role in the Company:**
5. **Working Years in Refrigerator Industry:**
6. **Year of Establishment of business:**
7. **Year of starting Manufacturing locally:**
8. **Tentative Revenue from Refrigerator Segment:**
9. **Tentative Yearly Sales Volume:**
10. **Installed Plant Capacity:**
11. **Yearly Production:**
12. **NO. of SKUs:**
13. **Total No. of employees:**
14. **Tentative Floor Space (Factory Area) :**

15. Please Mention major Risk according to you in managing the supply chain of refrigerator industry in Bangladesh

Risk	Sub Risk	Weightage of Risk	Severity	Probability
Supply Risk (S)				
Operational Risk (O)				
Financial Risk (F)				
Customer/Demand Risk (C)				
Inventory & Logistics (L)				
Legal/Regulatory Risk (R)				

Note: Weightage of risk to be given as Likert Scale where 5 means Very Important and 1 means Least Important.

Probability of occurring is to be marked as Low(0.1) Medium (0.5) and High (0.9)

Severity of impact is also be rated as Low(0.1) Medium (0.5) and High (0.9)

Please Refer to the Table Below:

Intensity of importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective
3	Somewhat more important	Experience and judgement slightly favour one over the other.
5	Much more important	Experience and judgement strongly favour one over the other.
7	Very much more important	Experience and judgement very strongly favour one over the other. Its importance is demonstrated in practice.
9	Absolutely more important.	The evidence favouring one over the other is of the highest possible validity.
2,4,6,8	Intermediate values	When compromise is needed

Please fill the following comparison matrix using the scale mentioned above:

Risk	S	O	F	C	L	R
S	1					
O		1				
F			1			
C				1		
L					1	
R						1

Please also fill comparison Matrix for the Sub risk mentioned:

Sub Risk (Supply)	S1	S2	S3	S4
S1	1			
S2		1		
S3			1	
S4				1

Sub Risk (Operational)	O1	O2	O3	O4
O1	1			
O2		1		
O3			1	
O4				1

Sub Risk (Finance)	F1	F2	F3	F4
F1	1			
F2		1		
F3			1	
F4				1

Sub Risk (Customer/Demand Risk (C))	C1	C2	C3	C4
C1	1			
C2		1		
C3			1	
C4				1

Sub Risk (Inventory & Logistics(L))	L1	L2	L3	L4
L1	1			
L2		1		
L3			1	
L4				1

Sub Risk (Legal/Regulatory Risk (R))	R1	R2	R3	R4
R1	1			
R2		1		
R3			1	
R4				1