OPERATIONS AND SUPPLY CHAIN MANAGEMENT
Vol. 14, No. 3, 2021, pp. 320 – 337
ISSN 1979-3561 | EISSN 2759-9363

Analysis of Risk Factors for Temperature-Controlled Warehouses

P. T. Ranil S. Sugathadasa
Department of Transport and Logistics Management,
University of Moratuwa, Katubedda 10400, Sri Lanka
Email: ranils@uom.lk

Deshan Wakkumbura
Department of Transport and Logistics Management,
University of Moratuwa, Katubedda 10400, Sri Lanka
Email: deshan425@gmail.com

H. Niles Perera
Department of Transport and Logistics Management,
University of Moratuwa, Katubedda 10400, Sri Lanka
Email: hniles@uom.lk

Amila Thibbotuwawa
Department of Transport and Logistics Management,
University of Moratuwa, Katubedda 10400, Sri Lanka
Email: amilat@uom.lk *(Corresponding Author)*

ABSTRACT

This paper investigates risk factors associated with temperature-controlled warehouses with the aim of improving long-run performance of cold chains. A risk mitigation strategy is derived through Interpretive Structural Modelling (ISM) and a graphical hierarchy is presented to prioritize the impact levels of the risk factors. The paper also critically examines the contextual relationship between individual potential risk factors associated to temperature-controlled warehouses. The findings provide pathways to predict uncertainties that can lead to operational interruptions in temperature-controlled warehouses alongside expert opinions that lead to the development of risk mitigation strategies. Given its integrated approach considering identification, evaluation, analysis, and risk mitigation in temperature-controlled warehouses, we believe this paper helps to enrich both the practice and the literature. With the profound increase of significance in cold chains within the broader domain of supply chain management, this paper provides inspiration to more research in cold chains and temperature-controlled warehouses.

Keywords: *temperature-controlled warehouses, supply chain risk factors, risk mitigation strategies, Interpretive Structural Modeling (ISM), cold chain, Business Continuity Plan (BCP), epidemics*

1. INTRODUCTION

Supply chains and its effectiveness has become an important competitive tool. Supply Chain Management integrates numerous business functions and processes by managing the material, information, and monetary flow of the company (Perera *et al*., 2020). Supply chain management improves long term performances systematically and strategically (Balachandra *et al*., 2020; Perera *et al*., 2016). It ensures the operation efficiency and effectiveness of the company concerning product transfer and information sharing (Prajogo & Olhager, 2012; Kłosowski *et al., 2018*).

To have an efficient supply chain, management should focus on monitoring and evaluating supply chain risks and ways of mitigation. Core characteristics of the supply chain are to coordinate the activities between organization, customers and suppliers through effective upstream and downstream relationships (Jüttner *et al*., 2003). Disruptions to the supply chain heavily hinder the competence of an organization to satisfy the customer (Jüttner *et al*., 2003). Companies allocate huge sums of money toward supply chain risk mitigation and make the flow smooth and unrestricted from constraints. Risks can arise in unexpected moments which might lead to interrupting the entire supply chain. Risks can severely damage information sharing and delivery of outbound supply chain activities. Previous research has been reported that supply chain risk is one of the most critical areas which lead to severe impacts on the performance of the organizations (Craighead *et al*., 2007; Hendricks & Singhal, 2005). Supply chain risk management has become a central topic in the last decades among scholars (Fahimnia *et al*., 2015).

Temperature-controlled warehouse industry is strategically important in supply chains to handle the complexities associated with perishable products such as food, beverages, and pharmaceuticals which are temperature sensitive (Bishara, 2006). Given the delicate nature of cold chains, supply chain risk management is salient to ensure high performance. Many scholars have studied risk management with relevance to various industry spheres (Ho *et al*., 2015). Limited literature can be found regarding warehouse risk management despite "supply chain risk management" being a highly covered topic in literature

(Farid *et al.*, 2016). Literature connecting risk management and temperature-controlled warehouse industry are even more scarce. This study attempts to fill this vacuum of knowledge.

Organoleptic quality of the food products is being ensured through an effective cold chain since the initial chilling or freezing of its raw ingredients during the stages of storage and transport (James & James, 2010). The cold chain is a network of equipment and processes that create a conditioned environment for perishable food products and once if that has been broken in any stage of the cold chain it severely reduces product quality (Joshi *et al.*, 2012). Maintaining the product quality is the most critical factor for frozen and chilled products in the supply chain which can be dependent on the duration of delivery time and temperature fluctuations in the cold chain (Zhang *et al.*, 2009). The practical scenario of the cold chain always aims to minimize the cost of storage and transportation while engaging with the quality of products. However, most food manufacturers and dealers are small and medium-sized enterprises (SMEs) and they may outsource their cold logistics requirements to third party logistics providers (3PLs) to reduce the cost (Siddh *et al.*, 2017).

Temperature-controlled warehouses are widely used across the globe since it ensures the quality and freshness of products especially in pharmaceutical and perishable food items (Akterian & Fikiin, 1994). Temperature controlled warehouses have become an essential infrastructure in the cold chain. Recent developments in the regulatory frameworks, especially in the pharmaceutical and food sectors have mandated managing risk of temperature-controlled warehouses (Ziance *et al*., 2009). Thus, a malfunction of the cooling system may affect cold chain operations leading to spoilage of products. In this paper, we focus on risk enabling factors that cold chains should consider most and what are the risks that should be afforded priority to make strategies to alleviate in building resilient temperature-controlled warehouses.

The structure of the paper is as follows. Section 2 discusses the literature on supply chain risk management. Section 3 presents the implemented methodology for the study including ISM steps. Section 4 elaborates on the case study while presenting the proposed methodology to prioritize compatible risk mitigation strategies. The paper winds up with the discussion and conclusion in Section 5.

2. LITERATURE REVIEW

With globalization, supply chains have become drastically complex with integrated networks and lengthy supply lines processing within a dynamic business environment. Industry 4.0 revolution has been empowered this dynamic environment connecting with robotic technologies and cloud based cyber physical systems supporting to advance automations (Basl, 2017). This revolution and complexity expose organizations toa greater degree of risks and uncertainties that affected to the supply chain disruptions. Thus, supply chain risk management is still crucial to overcome these ailments. Usage of Cyber physical things, Internet of thinks and Big data have made industry leaders in near future (Zawadzki & Zywicki, 2016). So, it is significant to numerical analysis of potential risk factors while streamlining the operations with industry 4.0. It will help to perceive information to diagnose the findings from data and change the operational procedures accordingly (Shrouf *et al*., 2014).

2.1 Supply Chain Risk Management

Disruptions and uncertainties affect negatively on supply chains which can have a direct effect on a business's ability to continue its operation smoothly (Jüttner *et al*., 2003). Supply chains face a vast variety of inherent risks that can occur instantaneously to interrupt operations (Simchi-Levi *et al*., 2004). Some scholars have suggested that main impacts of interruptions and uncertainties in supply chains had been exacerbated in the last decade (Jüttner *et al*., 2003). Literature exposes that more methodical and structured approach to identify the susceptibilities to hazards and supply chain risks can be traced in current studies (Zsidisin *et al*., 2000).

There are number of severe supply chain disruptions have been occurred. The Tohoku earthquake, tsunami in 2004 and Thai flood in 2011 are some examples for crucial uncertainties that made supply chains more vulnerable (Fahimnia *et al*., 2015). Unexpected supply chain interruptions can be impacted not only for short-run but also long-run. Ericsson had lost 400 Euros in short run when their supplier's semiconductor plant incurred on fire in 2000. 33% to 40% lost can be impacted relative to their industry benchmark in long run when one disruption has been occurred (Tang, 2006).

2.2 Complexity of Cold Chain

Food and pharmaceutical manufacturing and distribution industries rely heavily on maintaining a static temperature of the products to avoid deterioration (Sugathadasa *et al*., 2020). Consumers expect quality and decent shelf-life of food and pharmaceutical products. The retail industry also depends heavily on the quality of products to satisfy customer demands. The temperature ranges vary depends on the product to maintain the shelf-life of varying products, and this need can only be satisfied through temperature controlled warehouses (Smith & Sparks, 2007). Temperature ranges of cold supply chain can be simply classified as frozen, cold chill, medium chill, and exotic chill. Failures to maintain the ideal temperature for products adversely affects to either shelf-life or edibility of the products (Smith & Sparks, 2007).

Cold chains have in increasing significance within the retail sector as well. Frozen products in the United Kingdom has grown in volume by 3 to 4 percent on per annum on average in the last 40 years. "Fast food" has captured a huge market share and it depends heavily on frozen products. Most products require some degree of controlled temperature conditions in different aspects along its supply chain to ensure that a healthy product is delivered to the consumer (Smith & Sparks, 2007). Since these products consist of a sensitive nature, it is essential to care about temperature in terms of harvesting, manufacturing, packaging, storing, transportation and handling (Aung & Chang, 2014).

2.3 Temperature-Controlled Warehouse's Risk Management

Warehouses are being critical stage of supply chain risk management (Simchi-Levi *et al*., 2004). Cold chain storage solutions can be identified a special category of warehousing. Cold storages help to eliminate interruptions within controlled temperature ranges while providing better shelf-life for fresh food products and temperature sensitive pharmaceuticals (Ali *et al*., 2018). The warehousing process has lots of associated risks. Uncontrolled storage temperature directly relates to quality of food products (Chaudhuri *et al*., 2018). Temperature is one of the significant factors to measure the quality and safety of freezer products (Fikiin, 2015). Hence, it is necessary to control and monitor temperature of food products over each point in the cold chain (Gligor *et al*., 2018).

With the sudden expansion of frozen food industry, demand for the large scale temperature controlled warehouses demand have been increased correspondingly (For & Storage, 1958). This complexity is impacting not only for frozen food products but also for the pharmaceutical products. Systematic control of temperature and ventilation play a significant role pharmaceutical industry critically in warehousing area (Elias *et al*., 2018). This expansion may lead to increase the potential risks of cold warehouses that associated with its operations and information network.

Therefore, according to literature warehouse risk management is extremely important to manage the process of warehouses as well as the mitigation of supply chain risks that makes the supply chain vulnerable.

Thus, this study is to clearly identify the potential risk factors and assessing the level of impact thorough inter relation between each risk factors. ISM has been used for the approach. ISM is well recognized method to identify and summarize the internal relations among specific factors which describe issues (Talib *et al*., 2011). That method can be used to recognize the interaction among considered factors in the study (Mangla *et al*., 2015). So, Risk Prioritization Number (RPN) and Risk Mitigation Number (RMN) can be used to prioritize the critical risk factors and impactful risk mitigation strategies respectively (Prakash *et al*., 2017). MICMAC analysis support to classify the selected risk factors based on each driving and dependence power (Talib *et al*., 2011).

2.4 Risk Mitigation Strategies

Usually there are two approaches that can be implemented to mitigate supply chain risk in the industry practices; proactive approach and reactive approach (Dehdar *et al*., 2018). Reducing the risk of the frequency of the risk event is often considered part of the proactive approach. In this instance, mitigation planning and execution is conducted before the risk event (Dehdar *et al*., 2018). Reactive approach alludes to the implementation of mitigation strategies after occurrence of risk event. This approach aims to reduce the impact of a risk through effective management of resources and preparation (Dehdar *et al*., 2018). The culture of "supply chain collaboration" which develops long-term cooperation among integrated partners of the supply chain to share information of risks has also been encouraged by the literature. This helps to improve supply chain visibility (Chen *et al*., 2013).

Risk information sharing may execute as warning system of potential risk events and it will help to detection of failures due to future risk events. It can be conducted as proactive approach of risk mitigation (Sodhi *et al*., 2012). Choose of appropriate risk mitigation strategy and prevention procedure is correlated with fundamental process of risk assignment (Prakash *et al*., 2017). The relationship between how far people know about different type of risk factors and what degree they will response to mitigate potential risk has been considered more researchers related to different industries. There is a trade-off of balance between individual's expected damage of hazard and willingness to engage with proper risk mitigation strategy. Most probably personal experience may lead to tend individuals on implementation of particular mitigation strategy for any potential risk factor (Martin *et al*., 2009). Implemented risk mitigation strategy for any subsystem can be impacted to both subsystem and overall system as well (Grabowski & Roberts, 1997).

3. METHODOLOGY

The study was designed to recognize the most impactful risk enabling factor and most suitable mitigation strategies for temperature-controlled warehouses (Perera & Sugathadasa, 2014; Sugathadasa & Rajapaksha, 2011). Quantitative and qualitative methods formed the backbone of the study. Discussions with industry experts and literature survey culminated in the creation of a list of potential risk types and mitigation strategies for the temperature-controlled warehouse industry. Accordingly, 30 potential risk types and 20 mitigation strategies were collected as reported in **Figure 1**.

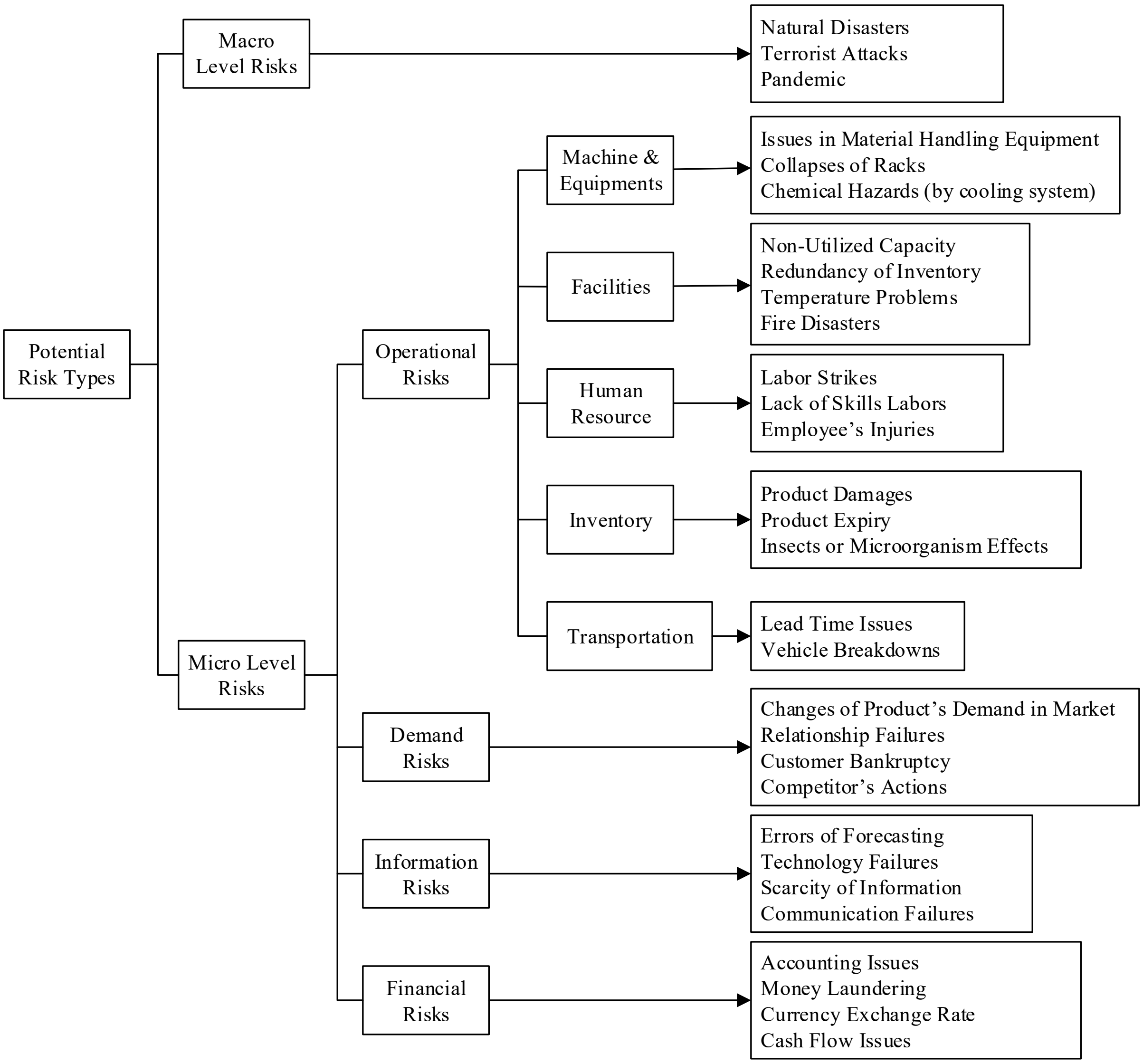

Figure 1 Categorization of risk types

ISM method was deployed to analyze these risk types to create a risk hierarchy. Therefore, a Structural Self-Interaction Matrix (SSIM) should be developed according to perspective of industry experts. SSIM matrix needs to be simple and convenient. The risk types had to be reduced based on the significance level reported by the industry participants. Principle Component Analysis (PCA) was deployed to reduce risk types according to data of the 1st stage questionnaire.17 risk types had been selected after the PCA. These selected risk types were used for implementation of ISM while seeking to find most significant risk types for the industry. **Figure 2** illustrates the research methodology employed for this paper.

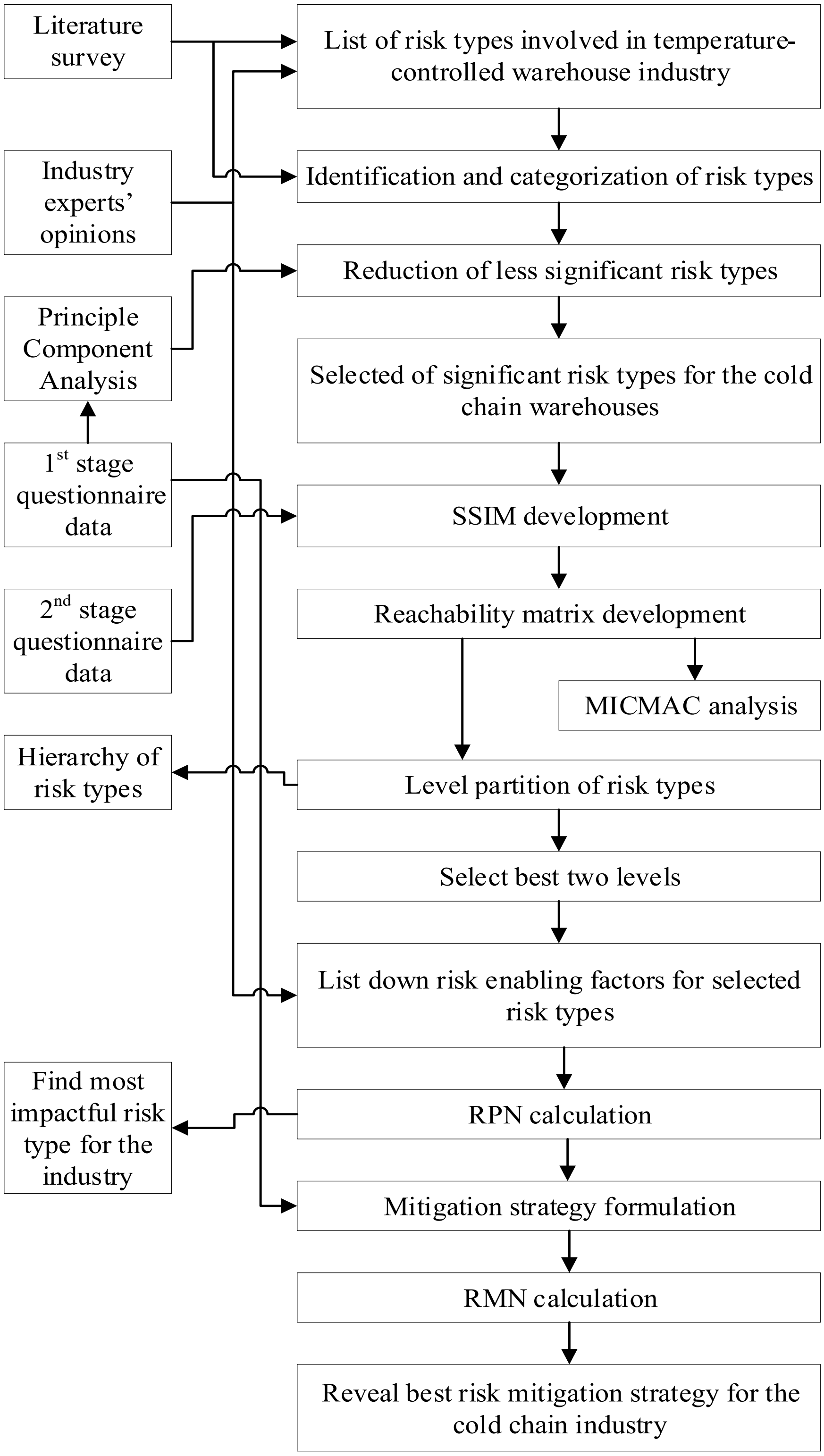

Figure 2 Research process

3.1 Principle Component Analysis

Six components had Eigenvalues greater than 1. 73.084% of the total variance had been explained by these 6 components as **Table 1**. 1st component of the analysis explained 43.227% of the total variance of the data. Scree plot of the components provided information about Eigenvalues of each component.

Thirty potential risk types were divided to selected components which had Eigenvalues greater than 1. Rotated component matrix was utilized for factor loading of each risk type across the 6 components and risk factors have been prioritized accordingly.

Table 1 Initial eigenvalues of first six components

Component	Initial Eigenvalues		
	Total	**% of Variance**	**Cumulative %**
1	12.968	43.227	43.227
2	2.649	8.828	52.055
3	2.172	7.241	59.296
4	1.536	5.119	64.415
5	1.390	4.633	69.048
6	1.211	4.035	73.084

3.2 Interpretive Structural Modelling (ISM) Implementation

Seventeen risk types were selected from the results of PCA to develop the SSIM while considering contextual relationships of these 17 selected risk types which were associated with the cold chain warehouses comprised in SSIM.

3.2.1 Structural Self-Interaction Matrix (SSIM) Development

Direct and indirect relationships among the variables were identified. Matrix indicates pair wise comparison of relationships between variables. Expert opinions and panel discussions were deployed to develop the SSIM while considering relations among set of risks. **Table 2** shows the relations of set of risks for the cold chain warehouse industry. Directions of the relations were donated by the symbols as follows.

V – Incidence of risk "*i*" will lead the incident of risk "*j*" in one direction only.

A – Incidence of risk "*j*" will lead the incident of risk "*i*" in one direction only.

X – Incidence of risk "*i*" will lead the incident of risk "*j*" and incident of risk "*j*" will lead to incident of risk "*i*" in both directions.

.

O – Risk "*i*" and risk "*j*" are unrelated in both directions.

Where, "*i*" represents the type of risks in rows of the matrix and "*j*" represents the type of risks in columns in the matrix.

As an example, if a natural disaster occurred then there is a potential for issues to arise in material handling equipment but opposite will not be true. Such types of cells in the matrix will be represented by V. Nevertheless, there are some indirect relations between a particular pair of risk factors that can be identified but they do not show direct relation between both at first sight.

3.2.2 Reachability Matrix

Reachability matrix was developed according to completed SSIM while transforming the cell information to binary digits. The transformation was done in line with the following rules.

- If the entry of the SSIM is either "V" or "X" then the relevant cell of the reachability matrix becomes 1.
- If the entry of the SSIM is either "A" or "O" then the relevant cell of the reachability matrix becomes 0.

Table 2 SSIM with indirect relations

Type of Risk	R1	R2	R3	R4	R6	R8	R9	R10	R13	R15	R18	R19	R22	R23	R24	R29	R30
(R1) Natural Disasters	X	O	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V
(R2) Terrorist Attacks		X	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V
(R3) Epidemic			X	V	A	X	X	V	V	A	X	V	V	V	V	V	V
(R4) Issues in Material Handling Equipment				X	X	A	X	X	V	X	X	X	X	V	A	A	V
(R6) Chemical Hazards (by cooling system)					X	V	V	V	V	V	X	V	V	V	X	V	V
(R8) Redundancy of Inventory						X	A	X	V	V	X	A	X	X	A	A	X
(R9) Temperature Problems							X	A	V	V	A	V	V	V	A	X	V
(R10) Labor Strikes								X	X	A	A	X	X	V	X	A	X
(R13) Product Damages									X	A	A	X	V	V	A	A	V
(R15) Insects or Microorganism Effects										X	X	V	X	V	A	X	V
(R18) Fire Disasters											X	V	X	V	X	V	V
(R19) Changes of Product's Demand in Market												X	V	V	A	A	V
(R22) Competitor's Actions													X	V	X	A	V
(R23) Errors of Forecasting														X	A	A	X
(R24) Technology Failures															X	A	V
(R29) Currency Exchange Rate																X	V
(R30) Cash Flow Issues																	X

Table 3 Reachability matrix

Type of Risk	R1	R2	R3	R4	R6	R8	R9	R10	R13	R15	R18	R19	R22	R23	R24	R29	R30	Driving Power
(R1) Natural Disasters	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16
(R2) Terrorist Attacks	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16
(R3) Epidemic	0	0	1	1	0	1	1	1	1	0	1	1	1	1	1	1	1	13
(R4) Issues in Material Handling Equipment	0	0	0	1	1	0	1	1	1	1	1	1	1	1	0	0	1	11
(R6) Chemical Hazards (by cooling system)	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
(R8) Redundancy of Inventory	0	0	1	1	0	1	0	1	1	1	1	0	1	1	0	0	1	10
(R9) Temperature Problems	0	0	1	1	0	1	1	0	1	1	0	1	1	1	0	1	1	11
(R10) Labor Strikes	0	0	0	1	0	1	1	1	1	0	0	1	1	1	1	0	1	10
(R13) Product Damages	0	0	0	0	0	0	0	1	1	0	0	1	1	1	0	0	1	6
(R15) Insects or Microorganism Effects	0	0	1	1	0	0	0	1	1	1	1	1	1	1	0	1	1	11
(R18) Fire Disasters	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
(R19) Changes of Product's Demand in Market	0	0	0	1	0	1	0	1	1	0	0	1	1	1	0	0	1	8
(R22) Competitor's Actions	0	0	0	1	0	1	0	1	0	1	1	0	1	1	1	0	1	9
(R23) Errors of Forecasting	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	1	3
(R24) Technology Failures	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	1	13
(R29) Currency Exchange Rate	0	0	0	1	0	1	1	1	1	1	0	1	1	1	1	1	1	12
(R30) Cash Flow Issues	0	0	0	0	0	1	0	1	0	0	0	0	0	1	0	0	1	4
Dependence Power	1	1	8	14	6	14	10	15	14	11	10	13	15	17	9	8	17	183

According to **Table 3**, these binary digits amplify the true or false status of each scenario (*i, j*). If any binary "1" is included in a cell of reachability matrix, it means that corresponding risk factor in row number makes considerable impact on occurrence of corresponding risk factor in column number. However, that does not mean there is any impact on the corresponding risk factor in row number from corresponding risk factor in column number.

Therefore, the total value of each row in reachability matrix is describing the driving power of each risk factor that belongs to corresponding row number. Accumulation of each column in reachability matrix describes the dependent power of each risk factor that belongs to corresponding column number in reachability matrix.

3.2.3 *Level Partitioning*

The ultimate target of the reachability matrix is to develop a hierarchy for each risk types that associate with temperature-controlled warehouses. A Reachability set and an Antecedent set for each risk type were obtained from the reachability matrix. The reachability set of a particular risk type consists of a risk type and other risk types which may cause the risk under scrutiny. The antecedent set of an exact risk type consists of a risk type and other risk types which are triggered by the risk type under question. Subsequently, the intersection set can be obtained using risk types that belongs to both the reachability set and antecedent set. If the particular type of risk elements of reachability set and intersection are similar then that risk type will be prioritized in the hierarchy (Talib *et al.*, 2011). Then the prioritized risk type is excluded from the subsequent iterations as we build the hierarchy to include all risk types. The percentage value of proximity to similarity factor was used to level partitions over the iterations. The percentage of proximity to similarity was calculated using the following equation:

Equation 1 Formula for the proximity to similarity

$$\text{Percentage of proximity to similarity} = \frac{\text{Number of elements consisted in Intersection}}{\text{Number of elements consisted in Reachability set}} \times 100\%$$

Highest percentage of proximity to similarity risk types were assigned as high levels of the hierarchy. Iterations of the risk prioritization was conducted and the summary of the 11 iteration results are given in **Table 4**.

Table 4 Risk level prioritization

Type of Risk	Reachability set	Antecedent set	Intersection	Level	Proximity to similarity
(R1) Natural Disasters	1	1	1	11	100%
(R2) Terrorist Attacks	2	2	2	11	100%
(R3) Epidemic	3	1,2,3,6	3	9	100%
(R4) Issues in Material Handling Equipment	4,6,9,10,15,18,19	1,2,3,4,6,8,9,10,15, 18,19,24,29	4,6,9,10,15,18,19	4	100%
(R6) Chemical Hazards (by cooling system)	6	1,2,6	6	10	100%
(R8) Redundancy of Inventory	3,8,10,15,18	1,2,3,6,8,9,10,18,19,24,29	3,8,10,18	5	80%
(R9) Temperature Problems	3,9,15,29	1,2,3,6,9,18,24,29	3,9,29	7	75%
(R10) Labor Strikes	8,9,10,19,24	1,2,3,6,8,10,15,18,19,24,29	8,10,19,24	5	80%
(R13) Product Damages	10,13,19	1,2,3,4,6,8,9,10,13,15,18, 19,24,29	10,13,19	3	100%
(R15) Insects or Microorganism Effects	3,15,18,29	1,2,6,9,15,18,24,29	15,18,29	7	75%
(R18) Fire Disasters	3,6,18,24	1,2,3,6,18,24	3,6,18,24	8	100%
(R19) Changes of Product's Demand in Market	19	1,2,3,6,9,15,18,19,24,29	19	6	100%
(R22) Competitor's Actions	4,8,10,15,18,22,24	1,2,3,4,6,8,9,10,13,15,18, 19,22,24,29	4,8,10,15,18,22,24	2	100%
(R23) Errors of Forecasting	8,23,30	1,2,3,4,6,8,9,10,13,15,18, 19,22,23,24,29,30	8,23,30	1	100%
(R24) Technology Failures	6,18,24	1,2,3,6,18,24	6,18,24	8	100%
(R29) Currency Exchange Rate	9,15,24,29	1,2,3,6,9,15,18,29	9,15,29	7	75%
(R30) Cash Flow Issues	8,10,23,30	1,2,3,4,6,8,9,10,13,15,18, 19,22,23,24,29,30	8,10,23,30	1	100%

3.2.4 Risk Hierarchy Development

Hierarchy of the risk level relevant to type of risks was designed while considering the level partition data according to information from the study. The risk elements were arranged graphically based on risk types identified through the PCA. Relationship between each level of the hierarchy is illustrated in **Figure 3** considering the antecedent set of each risk factor.

3.2.5 MICMAC Analysis

Identification and classification of potential risk factors is significantly impacted to develop systematic approach on implementation of suitable risk mitigation strategies (Qureshi et al., 2007). This technique helps to develop a critical investigation of risk types that has been selected in this study. **Figure 4** provides the scatter plot graph of each risk type that coordinated the driving power of each risk type against the dependence power.

Table 5 Driving Power and Dependence Power of Risk Types

Type of Risk	Dependence Power	Driving Power
(R1) Natural Disasters	1	16
(R2) Terrorist Attacks	1	16
(R3) Epidemic	8	13
(R4) Issues in Material Handling Equipment	14	11
(R6) Chemical Hazards (by cooling system)	6	15
(R8) Redundancy of Inventory	14	10
(R9) Temperature Problems	10	11
(R10) Labor Strikes	15	10
(R13) Product Damages	14	6
(R15) Insects or Microorganism Effects	11	11
(R18) Fire Disasters	10	15
(R19) Changes of Product's Demand in Market	13	8
(R22) Competitor's Actions	15	9
(R23) Errors of Forecasting	17	3
(R24) Technology Failures	9	13
(R29) Currency Exchange Rate	8	12
(R30) Cash Flow Issues	17	4

Based on their driving power and dependence power each risk type can be classified into four categories as follows.

Autonomous risk types: These risk types have weak driving power and weak dependence power. They are comparatively disconnected risk types which have been functioning as absolute variables. These risk types are representing quadrant I.

Dependent risk types: These risk types consist weak driving power but strong dependence power which have been placed in quadrant II.

Linkage risk types: This category includes both strong driving power and strong dependence power. These risk types are unstable and any mitigation strategy that will have an effect on other risk types (Mathiyazhagan *et al.*, 2013). Quadrant II of **Figure 4** bears these risk types.

Independent risk types: The category of risk types that have strong driving power but weak dependence power. These risk types are risk enablers in the system which belongs to quadrant IV.

A detailed inquiry of **Figure 4** reveals that there are no autonomous risk factors in the risks pool that are considered for the study. Dependent elements such as, product damages, changes of product's demand in market, forecasting errors, cashflow issues have significant dependence power and weak driving power. Hence, these risk factors are known as dependent elements.

Similarly, natural disasters, terrorist attacks, epidemics, currency exchange rates have less dependence power and high driving power. Hence these elements need to be recognized as independent elements. Since issues in material handling equipment, redundancy of inventory, temperature problems, labor strikes, effects from insects or microorganism, fire disasters, competitor's actions, technological failures have both high driving and dependence power. These elements are known as linkage elements among the considered risk factors.

We find that mitigation strategies should be developed for linkage and dependent elements in the study due to risk enablers. Mitigation of independent risks is not a proactive approach in cold chain risk management. Therefore, most probably level 1 and 2 risk factors in the risk hierarchy belong to these two categories in the MICMAC chart.

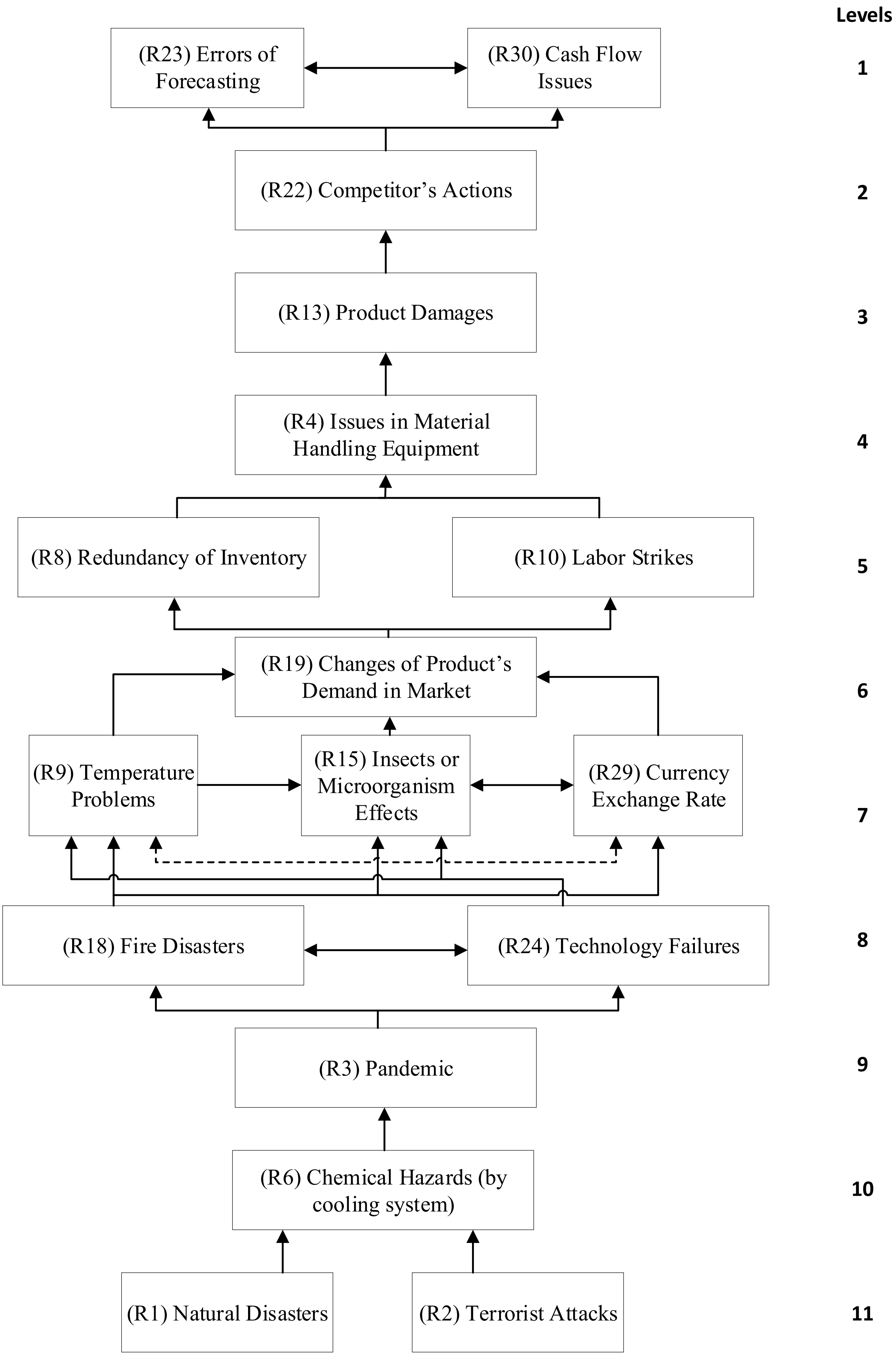

Figure 3 ISM Risk Hierarchy

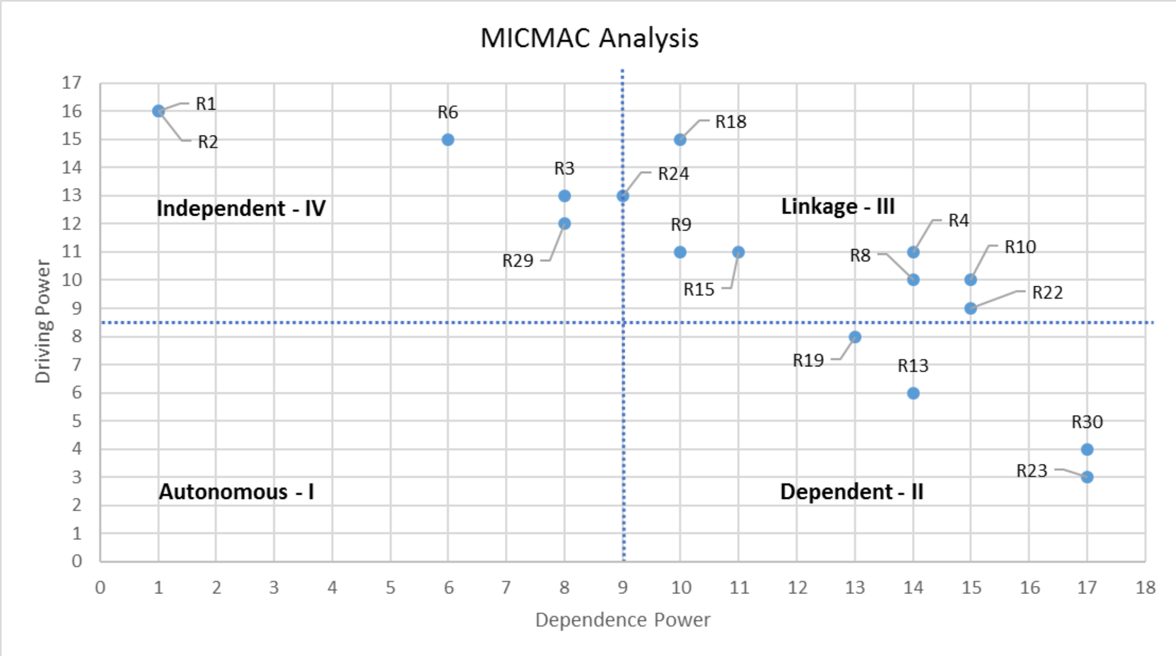

Figure 4 Driving Power and Dependence Power Diagram of Risk Factors

4 CASE STUDY

4.1 Overview of the Cold Warehouse

A leading temperature-controlled warehouse service provider was selected to assemble the Risk Enabling Factors (REF) pertaining to the selected risk factors from the risk hierarchy. This warehouse is the largest and most technologically advanced temperature-controlled logistics service provider in Sri Lanka. They have been operating for 15 years. The facility is fully racked with refrigerated air bag enclosed dock areas, electrical material handling equipment, clean and hygienic environment and cold chain compliance while offering controlled temperature ranges for freezer, chiller and ambient. Risk mitigation strategy prioritization was implemented considering the logistics processes and cold chain expertise of this warehouse.

4.2 Identification of Risk Enabling Factors and RPN Calculation

After development of the hierarchy, level 1 and level 2 risk types had been selected to find the risk enabling factors for those risk types which have been associated with a temperature-controlled warehouse. Risk enabling factors had been retrieved relevant to level 1 and level 2 risk types according to industry experts' knowledge and experiences. RPN was calculated by the product of Severity (S), Occurrence (O) and Detection (D) using 1-10 scale as depicted in **Table 6**.

Table 6 RPN values of risk enabling factors

Type of Risk	Risk Enabling Factors	Severity (S)	Occurrence (O)	Detection (D)	RPN
(R23) Errors of Forecasting	Uncertain demand	8	6	6	288
	Lack of information	10	5	5	250
	Poor method of forecasting	7	5	3	105
	Seasonal variation	7	4	7	196
	Bullwhip effect	6	5	3	90
(R30) Cash Flow Issues	Allowing customers to credit	6	5	5	150
	Unexpected financial issues	8	3	3	72
	Decline profit margins	5	5	3	75
	High overhead expenses	4	4	3	48
	Poor inventory management	7	3	3	63
(R22) Competitor's Actions	Technology changes	5	3	3	45
	New market entrants	3	5	5	75
	Lower customer satisfaction and service level	7	6	5	210
	High waiting time to obtain the service	8	7	7	392

Table 7 Ranking REFs

Rank	ID	Risk Enabling Factors	RPN
1	F1	Long waiting time to obtain the service	392
2	F2	Uncertain demand	288
3	F3	Lack of information	250
4	F4	Lower customer satisfaction and service level	210
5	F5	Seasonal variation	196
6	F6	Allowing customers to credit	150
7	F7	Poor method of forecasting	105
8	F8	Bullwhip effect	90
9	F9	Decline profit margins	75
10	F10	New market entrants	75
11	F11	Unexpected financial issues	72
12	F12	Poor inventory management	63
13	F13	High overhead expenses	48
14	F14	Technology changes	45

According to RPN values, these risk enabling factors were sorted down in descending order and factors were notated as mention in **Table 7** (F1, F2, F3 etc.).

Long waiting times to obtain the service (F1) is the most predominant risk factor for the selected case study. Mitigation strategies should be formulated to reduce the impact level of these risk factors. High ranked risk enabling factors requires more attention to control the impact for the industry. Addressing above mentioned risk factors will create positive results for policy makers and business development managers in the cold chain industry to make their logistics process robust.

Table 8 REFs addressed by risk mitigation strategies

Code	Risk Mitigation Strategy	REF Addressed
M1	Enforcing security system	F4, F12, F13, F14
M2	Developing emergency plans	F14
M3	Obtain effective standard certificates	F1, F4, F7, F10, F12, F14
M4	Proper maintenance of MHEs and pallet racks	F1, F2, F4, F12, F14
M5	Better inspection of the stored products	F1, F2, F3, F7, F8, F9, F12, F13
M6	Inspection scheduling of chemical hazards	No addressed REFs
M7	Using better human resource practices	F1, F2, F4, F5, F10, F11, F12
M8	Make comfortable working environment	F10, F14
M9	Maintain multiple facilities for storage	F2, F5, F10, F12, F14
M10	Strategic inventory control	F1, F2, F5, F7, F8, F9, F10, F12
M11	Regular inspection of vehicle feasibility	F1, F2, F13
M12	Keep sufficient fire extinguishers	No addressed REFs
M13	Evacuation planning and regular fire drills	No addressed REFs
M14	Signing legal contract with customers	F3, F4, F6, F9, F10, F14
M15	Customer evaluation	F1, F3, F4, F6, F9, F10
M16	Inspection of market	F2, F3, F5, F7, F8, F9, F10, F14
M17	Make robust forecast	F2, F3, F5, F7, F8, F11, F12, F13
M18	Maintenance of information systems	F1, F2, F3, F5, F6, F7, F8, F9, F10, F12, F13, F14
M19	Investment for communication infrastructures	F2, F3, F6, F10, F11, F12, F14
M20	Financial auditing	F6, F7, F11, F13

Table 9 Risk Mitigation Matrix

REF	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	RMN
RPN	392	288	250	210	196	150	105	90	75	75	72	63	48	45	
M1	0	0	0	1	0	0	0	0	0	0	0	1	1	1	366
M2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	45
M3	1	0	0	1	0	0	1	0	0	1	0	1	0	1	890
M4	1	1	0	1	0	0	0	0	0	0	0	1	0	1	998
M5	1	1	1	0	0	0	1	1	1	0	0	1	1	0	1311
M6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M7	1	1	0	1	1	0	0	0	0	1	1	1	0	0	1296
M8	0	0	0	0	0	0	0	0	0	1	0	0	0	1	120
M9	0	1	0	0	1	0	0	0	0	1	0	1	0	1	667
M10	1	1	0	0	1	0	1	1	1	1	0	1	0	0	1284
M11	1	1	0	0	0	0	0	0	0	0	0	0	1	0	728
M12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M14	0	0	1	1	0	1	0	0	1	1	0	0	0	1	805
M15	1	0	1	1	0	1	0	0	1	1	0	0	0	0	1152
M16	0	1	1	0	1	0	1	1	1	1	0	0	0	1	1124
M17	0	1	1	0	1	0	1	1	0	0	1	1	1	0	1112
M18	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1777
M19	0	1	1	0	0	1	0	0	0	1	1	1	0	1	943
M20	0	0	0	0	0	1	1	0	0	0	1	0	1	0	375

4.3 Risk Mitigation and Decision Making

RMN calculation was conducted to find the best mitigation strategies according to ability of alleviating a high number of risk factors that identified in the research. The concept of RMN was formulated to prioritize risk mitigation strategies (Prakash *et al*., 2017). Mitigation strategy prioritization was conducted according to the mitigation matrix analysis. The matrix cells consist of the Risk Mitigation Index (RMI). RMI value becomes "1" if the relevant risk factor is being mitigated by the strategy, if else it assumes "0". RMN value of each risk mitigation strategy was calculated using cumulative value of corresponding RPN values relevant to all the risk factors that are being mitigated by the particular risk mitigation strategy. Considered risk mitigation strategies and REFs which are being addressed by each risk mitigation strategy were correspondingly listed as follows.According to the results of **Table 9**, risk mitigation strategies can be prioritized using RMN values. These values describe the significance of the implementation of each risk mitigation strategy for the considered cold chain solution provider. Risk mitigation strategies were listed down in descending order as per **Table 10**.

Table 10 Risk Mitigation Strategy Prioritization

Code	Risk Mitigation Strategies	RMN	Rank
M18	Maintenance of information systems	1777	1
M5	Better inspection of the stored products	1311	2
M7	Using better human resource practices	1296	3
M10	Strategic inventory control	1284	4
M15	Customer evaluation	1152	5
M16	Inspection of market	1124	6
M17	Make robust forecast	1112	7
M4	Proper maintenance of MHEs and pallet racks	998	8
M19	Investment for communication infrastructures	943	9
M3	Obtain effective standard certificates	890	10
M14	Signing legal contract with customers	805	11
M11	Regular inspection of vehicle feasibility	728	12
M9	Maintain multiple facilities for storage	667	13
M20	Financial auditing	375	14
M1	Enforcing security system	366	15
M8	Make comfortable working environment	120	16
M2	Developing emergency plans	45	17
M6	Inspection scheduling of chemical hazards	0	18
M12	Keep sufficient fire extinguishers	0	19
M13	Evacuation planning and regular fire drills	0	20

Maintenance of information systems (M18) is the best risk mitigation strategy for the considered cold warehouse. Obtaining effective standard certificates (M3), Proper maintenance of MHEs and pallet racks (M4), Better inspection of the stored products (M5), Using better human resource practices (M7), Strategic inventory control (M10), Regular inspection of vehicle feasibility (M11), Customer evaluation (M15), Maintenance of information systems (M18) support to mitigate High waiting time to obtain the service (F1) which is the most impactful risk enabling factor of the study. Prioritization of the risk mitigation strategies is significant to promote awareness regarding these strategies and to create suitable policies to alleviate the potential risk factors to the cold warehouse. This is while increasing the performances of the cold storage logistics process and aiming to build capacity.

5. DISCUSSION AND CONCLUSION

Identification of potential risks for the temperature-controlled warehouse industry and finding risk mitigation strategies to alleviate those risks was the scope of this study. The warehousing sector plays a major role in the supply chain (Öztürkoglu & Hoser, 2019). Meanwhile, temperature-controlled warehouse solutions are becoming popular around the globe, with developing countries also recording an accumulation of new assets. Thus, temperature-controlled warehouses are a critical asset to reduce post-harvest losses and store temperature-controlled consumer products by building a resilient supply chain (Ganguly & Kumar, 2019). The demand for the cold chain industry is gradually increasing with augmentation of the population as well as economic prosperity. Considering these new developments, risk mitigation strategies should be formulated in a strategic manner to improve the performance of the cold chain sector that is vital to many other consumer-oriented supply chains.

Risks related to the temperature-controlled warehouse industry have been identified in this study. Thirty risk types were identified through literature and industry experts. Seventeen significant risk types were selected using PCA. ISM methodology was implemented on the selected risk types and risk prioritization hierarchy was subsequently developed. Errors of forecasting and Cash flow issues were identified to be in level 1 and Competitor's actions were understood to be in level 2 in the hierarchy vertex.

MICMAC analysis provides categorization of each risk types as Autonomous, Dependent, Linkage and Independent. This categorization makes a significant managerial implication to recognize the attributes of each risk type that makes the cold chain warehousing industry more vulnerable. It needs to be picked out that Dependent elements of the MICMAC diagram should be alleviated. These risk types are positioned on the top and middle level of the ISM hierarchy. Therefore, more risk factors in the system enable other risk factors which belong to this category while making significant impacts on business continuity. Therefore, elements in this category have a significant impact to reduce the performances of the cold warehouses. Autonomous elements can spring up in different uncertainties. Mitigation strategies are not significantly addressing these risk types. There are no Autonomous elements as depicted in MICMAC chart relative to the study. Risk mitigation strategies should be developed to mitigate impact of leading risk types (Ganguly & Kumar, 2019). Cold chains should be subjected to more strategic planning and scheduled training programs to reduce the impact level of independent risk elements. This is because these risk types cannot be eliminated due to instantaneous result of various hazards. However, autonomous risk factors are difficult to find due to the network of relations among any risk factors that are considered for this study. It is important to prioritize mitigation strategies that affect on Linkage elements since these risk types are the system connectors in the risk hierarchy. Most Independent elements can occur without any warnings. Therefore, it is imperative to have preplanned mitigation strategies to reduce the impact of these risk types.

Risk enabling factors were listed down in alignment to the case study and RPN values were calculated using product of severity, occurrence and detection of each risk enabling factor. RMN values were generated and prioritization was conducted while completing the final research objective which was "to reveal the best risk mitigation strategy in order to minimize most impactful risk enabling factor". Most impactful risk enabling factor is Long waiting time to obtain the service (F1) and the best mitigation strategy to alleviate this risk factor is Maintenance of information systems (M18) while addressing some other risk enabling factors of the case study.

Business uncertainty is created through potential risk factors. Thus, the warehouse industry increasingly pays attention on potential risks and to alleviate the impact of these risk factors (Öztürkoglu & Hoser, 2019). The ability to mitigate risks would enforce organizations to comply with their future business targets and goals. The Business Continuity Plan (BCP) is extremely important for smooth operations of cold chains. It consists of risk analysis and risk mitigation strategies that can be conducted to reduce the impact of uncertainties (Wieteska, 2020). This paper will provide guidance to develop an effective business continuity plan for the cold chain industry policy makers. Strategic level leaders should aim to provide more leadership in strategic planning and training decision makers to reduce the impact level of risk factors which are positioned on the Independent elements of MICMAC analysis. Namely (R1) Natural Disasters, (R2) Terrorist Attacks, (R3) Epidemic (R6) Chemical Hazards (by cooling system), (R29) Currency Exchange Rate are extremely important to consider as critical for the development of proper risk mitigation strategies. Safety programs, regular fire drills, regular inspection schedules, developing occupational hygiene rules are important to be practical in proactive and reactive approaches of the cold chain industry while focusing on survival in unexpected molestations.

It is important to note that the authors considered epidemics as a risk factor for this analysis. This was ahead of the manifestation of the COVID-19 pandemic that has made a huge impact to all supply chains, including cold chains (Ahlqvist *et al*., 2020; Enyinda, 2018). Our analysis shows that the epidemic risk factor (which could also be elongated to a pandemic) belongs to quadrant IV which indicates the Independent elements. Also, the epidemic risk factor is included in level 9 of 11 in the risk hierarchy. That means epidemics can be accountable for 73% of risk factors' levels in this hierarchy. Thus, our findings show that an epidemic/pandemic can make a serious impact to any supply chain while driving other risk factors to an active level. However, according to the MICMAC analysis the pandemic risk does not directly impact cold chains (Ahlqvist *et al*., 2020). Instead, other risk factors are triggered by it to derail the cold chain. These depending risk factors create undesired vulnerability in the cold chain warehouses. We find that it is salient to follow reactive approaches while implementing safety methods to avoid spread of a pandemic to escape from any interruptions to the cold chain which is vital to the proper functioning of the healthcare industry and food industry also.

ACKNOWLEDGEMENT

The authors wsih to thank University of Moratuwa, Sri Lanka's Senate Research Committee Grant ID SRC/LT/2020/20 for supporting this research.

REFERENCES

Ahlqvist, V., Norrman, A., & Jahre, M. (2020). Supply chain risk governance: Towards a conceptual multi-level framework. *Operations and Supply Chain Management*, *13*(4), 382–395. https://doi.org/10.31387/oscm0430278

Akterian, S. G., & Fikiin, K. A. (1994). Numerical simulation of unsteady heat conduction in arbitrary shaped canned foods during sterilization processes. Journal of Food Engineering, 21(3), 343-354.

Ali, I., Nagalingam, S., & Gurd, B. (2018). A resilience model for cold chain logistics of perishable products. *International Journal of Logistics Management*, *29*(3), 922–941. https://doi.org/10.1108/IJLM-06-2017-0147

Aung, M. M., & Chang, Y. S. (2014). Temperature management for the quality assurance of a perishable food supply chain. *Food Control*, *40*, 198–207.

Balachandra, K., Perera, H. N., & Thibbotuwawa, A. (2020). Human Factor in Forecasting and Behavioral Inventory

Decisions: A System Dynamics Perspective. In International Conference on Dynamics in Logistics (pp. 516-526). Springer, Cham.

Basl, J. (2017). Pilot Study of Readiness of Czech Companies to Implement the Principles of Industry 4.0. *Management and Production Engineering Review*, *8*(2), 3–8. https://doi.org/10.1515/mper-2017-0012

Bishara, R. H. (2006). Cold chain management - An essential component of the global pharmaceutical supply chain. *American Pharmaceutical Review*, *9*(1), 105–109.

Chaudhuri, A., Dukovska-Popovska, I., Subramanian, N., Chan, H. K., & Bai, R. (2018). Decision-making in cold chain logistics using data analytics: a literature review. *International Journal of Logistics Management*, *29*(3), 839–861. https://doi.org/10.1108/IJLM-03-2017-0059

Chen, A., Hsieh, C.-Y., & Wee, H. M. (2013). Mitigation of Losses through Regional Purchasing Strategy: A Case Study for an Automobile Company. *Information Technology and Computer Science*, *4*, 563–569.

Craighead, C. W., Blackhurst, J., Rungtusanatham, M. J., & Handfield, R. B. (2007). The severity of supply chain disruptions: design characteristics and mitigation capabilities. Decision Sciences, 38(1), 131-156.

Dehdar, E., Azizi, A., & Aghabeigi, S. (2018). Supply Chain Risk Mitigation Strategies in Automotive Industry : A Review. *2018 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*, 84–88.

Elias, N., Yahya, N. M., & Sing, E. H. (2018). Numerical analysis of fuzzy logic temperature and humidity control system in pharmaceutical warehouse using MATLAB fuzzy toolbox. In *Lecture Notes in Mechanical Engineering* (Vol. 0, Issue 9789811087875). Springer Singapore. https://doi.org/10.1007/978-981-10-8788-2_56

Enyinda, C. I. (2018). Modeling enterprise risk management in operations and supply chain: A pharmaceutical firm context. *Operations and Supply Chain Management*, *11*(1), 1–12. https://doi.org/10.31387/oscm0300195

Fahimnia, B., Tang, C. S., Davarzani, H., & Sarkis, J. (2015). Quantitative models for managing supply chain risks: A review. *European Journal of Operational Research*, *247*(1), 1–15. https://doi.org/10.1016/j.ejor.2015.04.034

Farid, M. F., Elbarky, A. M., & Saeed, A. M. (2016). Superior rectus and lateral rectus muscle union surgery in the treatment of myopic strabismus fixus: three sutures versus a single suture. *Journal of American Association for Pediatric Ophthalmology and Strabismus*, *20*(2), 100–105.

Fikiin, K. (2015). Temperature control strategies for smarter energy use in refrigerated warehouses. *Refrigeration Science An*, *18*(4), 76–79.

For, W., & Storage, C. (1958). *A Lomv2o b4 Aua'a*.

Ganguly, K. K., & Kumar, G. (2019). Supply chain risk assessment: A fuzzy AHP approach. *Operations and Supply Chain Management*, *12*(1), 1–13. https://doi.org/10.31387/oscm0360217

Gligor, D., Tan, A., & Nguyen, T. N. T. (2018). The obstacles to cold chain implementation in developing countries: insights from Vietnam. *International Journal of Logistics Management*, *29*(3), 942–958. https://doi.org/10.1108/IJLM-02-2017-0026

Grabowski, M., & Roberts, K. (1997). Risk mitigation in large-scale systems: Lessons from high reliability organizations. California management review, 39(4), 152-161.

Hendricks, K. B., & Singhal, V. R. (2005). An empirical analysis of the effect of supply chain disruptions on long-run stock price performance and equity risk of the firm. Production and Operations management, 14(1), 35-52

Ho, W., Zheng, T., Yildiz, H., & Talluri, S. (2015). Supply chain risk management: A literature review. In *International Journal of Production Research* (Vol. 53, Issue 16, pp. 5031–5069). Taylor and Francis Ltd. https://doi.org/10.1080/00207543.2015.1030467

James, S. J., & James, C. J. F. R. I. (2010). The food cold-chain and climate change. Food Research International, 43(7), 1944-1956.

Joshi, R., Banwet, D. K., Shankar, R., & Gandhi, J. (2012). Performance improvement of cold chain in an emerging economy. Production Planning & Control, 23(10-11), 817-836.

Jüttner, U., Peck, H., & Christopher, M. (2003). Supply chain risk management: outlining an agenda for future research. *International Journal of Logistics: Research and Applications*, *6*(4), 197–210.

Kłosowski, G., Gola, A., & Amila, T. (2018). Computational intelligence in control of AGV multimodal systems. Ifac-papersonline, 51(11), 1421-1427

Mangla, S. K., Kumar, P., & Barua, M. K. (2015). Risk analysis in green supply chain using fuzzy AHP approach: A case study. *Resources, Conservation and Recycling*, *104*, 375–390. https://doi.org/10.1016/j.resconrec.2015.01.001

Martin, W. E., Martin, I. M., & Kent, B. (2009). The role of risk perceptions in the risk mitigation process: The case of wildfire in high risk communities. *Journal of Environmental Management*, *91*(2), 489–498. https://doi.org/10.1016/j. jenvman. 2009.09.007

Mathiyazhagan, K., Govindan, K., NoorulHaq, A., & Geng, Y. (2013). An ISM approach for the barrier analysis in implementing green supply chain management. *Journal of Cleaner Production*, *47*, 283–297. https://doi.org/10.1016/j.jclepro.2012.10.042

Öztürkoglu, Ö., & Hoser, D. (2019). An evaluation of order-picking tour efficiency in two-block warehouses. *Operations and Supply Chain Management*, *12*(2), 74–87. https://doi.org/10.31387/oscm0370225

Perera, H. N., Fahimnia, B., & Tokar, T. (2020). Inventory and ordering decisions: a systematic review on research driven through behavioral experiments. International Journal of Operations & Production Management.

Perera, H. N., & Sugathadasa, P.T.R.S. (2014). Investigating manufacturing supply chain transformations: a Sri Lankan context. *International Symposium on Logistics 2014*.

Perera, H. N., Thibbotuwawa A., Rajasooriyar C., & Sugathadasa, P.T.R.S. (2016) Managing Supply Chain Transformation Projects in the Manufacturing Sector: Case-based Learning from Sri Lanka, *Research for Transport & Logistics Industry Conference* (R4TLI), 2016, Colombo, Sri Lanka

Prakash, S., Soni, G., Rathore, A. P. S., & Singh, S. (2017). Risk analysis and mitigation for perishable food supply chain: a case of dairy industry. *Benchmarking*, *24*(1), 2–23. https://doi.org/10.1108/BIJ-07-2015-0070

Prajogo, D., & Olhager, J. (2012). Supply chain integration and performance: The effects of long-term relationships, information technology and sharing, and logistics integration. International Journal of Production Economics, 135(1), 514-522.

Qureshi, M. N., Kumar, D., & Kumar, P. (2007). Modeling the logistics outsourcing relationship variables to enhance shippers' productivity and competitiveness in logistical supply chain. *International Journal of Productivity and Performance Management*, *56*(8), 689–714.

Shrouf, F., Ordieres, J., & Miragliotta, G. (2014). Smart factories in Industry 4.0: A review of the concept and of energy management approached in production based on the Internet of Things paradigm. *IEEE International Conference on Industrial Engineering and Engineering Management*, *2015-Janua*, 697–701.

Siddh, M. M., Soni, G., Jain, R., Sharma, M. K., & Yadav, V. (2017). Agri-fresh food supply chain quality (AFSCQ): a literature review. Industrial Management & Data Systems.

Simchi-Levi, D., Kaminsky, P., & Simchi-Levi, E. (2004). *Managing the Supply Chain: Definitive Guide*. Tata McGraw-Hill Education.

Smith, D., & Sparks, L. (2007). Temperature Controlled Supply Chains. In *Food Supply Chain Management*. https://doi.org/10.1002/9780470995556.ch12

Sodhi, M. S., Son, B.-G., & Tang, C. S. (2012). Researchers' perspectives on supply chain risk management. *Production and Operations Management*, *21*(1), 1–13.

Sugathadasa, P. T. R. S., Perera, H. N., & Liyanage, A. K. (2020). Effective Management of Manufacturing Supply Chain Risks: A Sri Lankan Perspective. ENGINEER, 53(03), 63-76.

Sugathadasa, P.T.R.S. & Rajapaksha, S. S. (2011). *An investigation on relationship between third party logistics user and provider at FMCG industry in Sri Lanka*.

Talib, F., Rahman, Z., & Qureshi, M. N. (2011). An interpretive structural modelling approach for modelling the practices of total quality management in service sector. *International Journal of Modelling in Operations Management*, *1*(3), 223. https://doi.org/10.1504/ ijmom.2011.039528

Tang, C. S. (2006). Perspectives in supply chain risk management. *International Journal of Production Economics*, *103*(2), 451–488. https://doi.org/10.1016/j.ijpe.2005.12.006

Wieteska, G. (2020). The impact of supplier involvement in product development on supply chain risks and supply chain resilience. *Operations and Supply Chain Management*, *13*(4), 359–374. https://doi.org/10.31387/oscm0430276

Zawadzki, P., & Zywicki, K. (2016). Smart product design and production control for effective mass customization in the industry 4.0 concept. *Management and Production Engineering Review*, *7*(3), 105–112. https://doi.org/10.1515/mper-2016-0030

Zhang, J., Liu, L., Mu, W., Moga, L. M., & Zhang, X. (2009). Development of temperature-managed traceability system for frozen and chilled food during storage and transportation. Journal of Food, Agriculture & Environment, 7(3&4), 28-31.

Ziance, R., Chandler, C., & Bishara, R. H. (2009). Integration of temperature-controlled requirements into pharmacy practice. Journal of the American Pharmacists Association, 49(3), e61-e69.

Zsidisin, G. A., Panelli, A., & Upton, R. (2000). Purchasing organization involvement in risk assessments, contingency plans, and risk management: an exploratory study. *Supply Chain Management: An International Journal*, *5*(4), 187–198.

APPENDIX 1:

Ten likert scale used to calculate the Risk Prioritization Number (RPN) for the analysis.

Category	Severity (S)	Occurrence (O)	Detection (D)
10	Without warning	Always (1 in 5)	Never detectable
9	With warning	Every time (1 in 10)	Rarely detectable
8	Very high	Usually (1in 20)	Very difficult to detectable
7	High	Very frequently (1 in 50)	Difficult to detectable
6	Moderate	Frequently (1 in 100)	Occasionally detectable
5	Low	Less frequently (1 in 500)	Sometimes detectable
4	Very low	Sometimes (1 in 1000)	Often detectable
3	Miner	Occasionally (1 in 3000)	Frequently detectable
2	Very miner	Rarely (1 in 5000)	Always detectable
1	None	Never (1 in 10000)	Highly detectable

Note: RPN value can be a number value between 1 (Forsooth No Risk) to 1000 (Excessively Risk).

P. T. Ranil S. Sugathadasa, PhD is a Senior Lecturer at the Department of Transport and Logistics Management, University of Moratuwa in Sri Lanka. He holds a Bachelors degree and a Masters degree in Civil Engineering and a PhD in Construction Supply Chain Risk Management from University of Moratuwa in addition to an MBA from University of Colombo, Sri Lanka. His research interests are supply chain risk management, project management and construction supply chains. He is a Chartered Engineer (CEng) and Project Management Professional (PMP).

DeshanWakkumbura is a graduate of the Department of Transport and Logistics Management, University of Moratuwa in Sri Lanka. Presently he is working as an executive in a leading multinational company dealing with temperature-controlled warehouses.

H. Niles Perera, PhD is a Senior Lecturer at the Department of Transport and Logistics Management, University of Moratuwa in Sri Lanka. Niles is an award-winning graduate of the same department who graduated as the Most Outstanding Graduate of the University of Moratuwa, Sri Lanka. He also holds a Graduate Certificate in Business Administration from the Australian Institute of Business and a PhD on Supply Chain Optimisation from The University of Sydney, Australia. Niles is a Member of the Institute of Electrical and Electronics Engineers. His research has appeared in journals such as *European Journal of Operational Research, Energy Policy* and *International Journal of Operations and Production Management*. His primary research interests lie in behavioral supply chain operations, system dynamics, energy operations, forecasting and inventory optimisation.

Amila Thibbotuwawa, PhD is a Senior Lecturer at the Department of Transport and Logistics Management, University of Moratuwa in Sri Lanka. He holds his Bachelors degree from the same department. Amila received his Masters degree in Industrial Engineering from École des Mines de Nantes in France and his PhD in Mechanical & Manufacturing Engineering from Aalborg University, Denmark. His research interests lie in supply chain and logistics optimization and he is a Member of the Institute of Electrical and Electronics Engineers.