Analysis of Risk Factors for Temperature-Controlled Warehouses

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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; Klosowski 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 to a 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 (Jütten 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 disruptions and uncertainties in supply chains had been exacerbated in the last decade (Jütten 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 of 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.
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.
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.
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  | V  |
| (R3) Epidemic                              | X  | V  | A  | X  | X  | V  | A  | X  | V  | V  | V  | 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  | V  | V  | V  |
| (R6) Chemical Hazards (by cooling system)  | X  | V  | V  | V  | V  | V  | V  | V  | X  | V  | V  | V  | X  | V  | V  | V  | V  |
| (R8) Redundancy of Inventory               | X  | A  | X  | V  | V  | X  | A  | X  | X  | A  | A  | A  | X  | V  | V  | V  | V  |
| (R9) Temperature Problems                  | X  | A  | V  | V  | A  | V  | V  | V  | A  | V  | A  | X  | V  | V  | V  | V  | V  |
| (R10) Labor Strikes                        | X  | X  | A  | A  | X  | X  | V  | X  | A  | X  | A  | X  | X  | V  | V  | V  | V  |
| (R13) Product Damages                      | X  | A  | A  | X  | V  | V  | A  | A  | V  | V  | V  | V  | V  | V  | V  | V  | V  |
| (R15) Insects or Microorganism Effects     | X  | X  | V  | X  | V  | A  | X  | V  | V  | V  | V  | V  | V  | V  | V  | V  | V  |
| (R18) Fire Disasters                       | X  | V  | V  | A  | A  | V  | V  | V  | V  | V  | V  | V  | V  | V  | V  | V  | V  |
| (R19) Changes of Product’s Demand in Market| X  | V  | V  | A  | A  | V  | V  | V  | V  | V  | V  | V  | V  | V  | V  | V  | V  |
| (R22) Competitor’s Actions                 | X  | V  | X  | A  | V  | V  | V  | V  | V  | V  | V  | V  | V  | V  | V  | V  | V  |
| (R23) Errors of Forecasting                | X  | A  | A  | X  | V  | V  | V  | V  | V  | V  | V  | V  | V  | V  | V  | V  | V  |
| (R24) Technology Failures                  | X  | A  | A  | V  | V  | V  | V  | V  | V  | V  | V  | V  | V  | V  | V  | V  | V  |
| (R29) Currency Exchange Rate               | X  | V  | V  | V  | V  | V  | V  | V  | V  | V  | V  | V  | V  | V  | V  | V  | V  |
| (R30) Cash Flow Issues                     | X  | V  | V  | V  | V  | V  | V  | V  | V  | V  | V  | V  | V  | V  | V  | V  | V  |
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  | 1  | 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  | 0  | 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  | 0  | 1  | 1  | 0  | 0  | 1  | 1  | 10             |
| (R9) Temperature Problems                        | 0  | 0  | 1  | 1  | 0  | 1  | 1  | 0  | 1  | 1  | 0  | 1  | 1  | 0  | 1  | 1  | 1  | 11             |
| (R10) Labor Strikes                              | 0  | 0  | 0  | 1  | 0  | 1  | 1  | 1  | 0  | 0  | 1  | 1  | 1  | 0  | 1  | 1  | 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  | 0  | 1  | 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  | 0  | 1  | 1  | 9              |
| (R23) Errors of Forecasting                      | 0  | 0  | 0  | 0  | 0  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 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  | 0  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 12             |
| (R30) Cash Flow Issues                           | 0  | 0  | 0  | 0  | 0  | 1  | 0  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 1  | 0  | 0  | 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:

\[
\text{Equation 1 Formula for the proximity to similarity} \\
\text{Percentage of proximity to similarity} = \frac{\text{Number of elements consisted in Intersection}}{\text{Number of elements consisted in Reachability set}} \times 100\%
\]

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.

| 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 | 5     | 100%                    |
| (R5) 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    | 7     | 75%                     |
| (R9) Temperature Problems        | 3,9,15,29        | 1,2,3,6,8,19,24,29 | 3,9,29      | 6     | 100%                    |
| (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.

| 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.

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.

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.
(R1) Natural Disasters
(R2) Terrorist Attacks

(R3) Pandemic

(R6) Chemical Hazards (by cooling system)

(R8) Redundancy of Inventory
(R10) Labor Strikes

(R9) Temperature Problems
(R15) Insects or Microorganism Effects
(R29) Currency Exchange Rate

(R19) Changes of Product’s Demand in Market

(R4) Issues in Material Handling Equipment

(R13) Product Damages

(R22) Competitor’s Actions

(R23) Errors of Forecasting
(R30) Cash Flow Issues

Levels

1

2

3

4

5

6

7

8

9

10

11

Figure 3 ISM Risk Hierarchy
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.

| 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  |
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 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 |

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   | 1   | 0   | 1   | 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   | 1   | 0   | 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   | 0   | 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   | 0   | 1   | 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   | 1   | 1   | 0   | 1   | 0   | 1   | 943 |
| M20 | 0   | 0   | 0   | 0   | 0   | 1   | 1   | 0   | 0   | 1   | 0   | 1   | 0   | 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](image)

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.

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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).

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