# OPERATIONAL RISK ASSESSMENT FRAMEWORK FOR CONSUMABLE ICE MANUFACTURING INDUSTRY: A CASE STUDY OF CHIANG RAI, THAILAND

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MASTER OF BUSINESS ADMINISTRATION
IN
INTERNATIONAL LOGISTICS AND
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THIS THESIS IS A PARTIAL FULFILLMENT OF
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## ABSTRACT

The increasing demand for consumable ice in Thailand has been significantly driven by global warming and the post-COVID-19 economic and social recovery. As a result, Thai consumers are incorporating more ice into their daily beverage consumption, particularly within the food and beverage industry. Despite this rising demand, the number of new ice manufacturing facilities has been steadily declining since 2016, highlighting the existence of operational challenges and industry risks that may hinder future growth.

This study aims to identify, assess, and prioritize the potential risks faced by the consumable ice manufacturing industry. Data was collected through field observations and in-depth interviews with key stakeholders in the production sector. The Failure Mode and Effects Analysis (FMEA) method was applied to evaluate the severity, occurrence, and detection of each identified risk, allowing for a structured ranking of risk factors. Subsequently, the findings from the FMEA were integrated with a Multi-Criteria Decision-Making (MCDM) approach to develop strategic recommendations. These recommendations consider both feasibility and operational impact to ensure practical implementation. The study provides actionable insights to enhance risk management practices and support the sustainable development of the ice manufacturing industry in Thailand.

**Keywords:** FMEA, MDCM, COVID-19, Risk Assessment

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# ABBREVIATIONS AND SYMBOLS

| | |
|---|---|
| FMEA | Failure Mode and Effects Analysis |
| MCDM | Multi-Criteria Decision-Making Method |
| RPN | Risk Priority Number |
| GMP | Good Manufacturing Practice |
| HACCP | Hazard Analysis Critical Control Points |

# CHAPTER 1

# INTRODUCTION

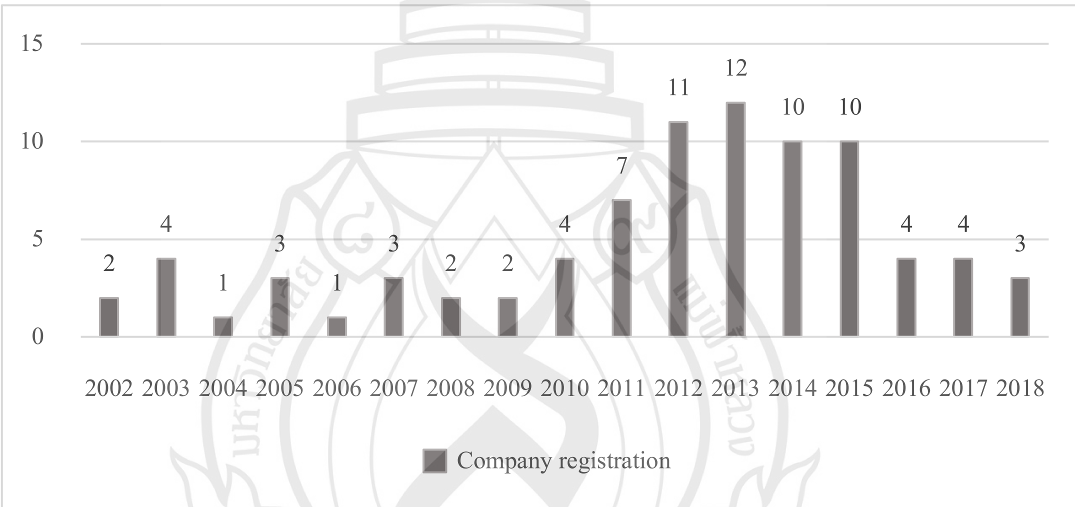
## 1.1 Background

The tropical moist climate and rapid environmental changes are causing temperatures to rise globally, with particularly noticeable effects in Southeast Asia. In countries with hot climates like Thailand, the tendency to consume ice has significantly increased (Nakornsri et al., 2014), and Thai people typically add ice to almost all beverages. This cultural preference creates a strong correlation between the value of the consumable ice market and the broader beverage market size. However, the demand for consumable ice varies across different regions of Thailand due to climatic variations. According to the Climatological Center report, the average winter temperature in the northern provinces of Thailand is 19.9 degrees Celsius, influenced by cold fronts from China. This temperature variation directly impacts the demand for certain beverages and consumable ice throughout the year.

In 2020, Data for Thai reported 1,235 ice factories in Thailand (both operational and non-operational), with 109 factories, or 11.33% of the total, located in the northern part of the country. Between 2008 and 2016, the trend for new businesses in the ice factory sector was steadily increasing but began to decline in 2016, as shown in Figure 1.1 This decline suggests that certain risks are affecting the economic sustainability of the consumable ice factory business, warranting further investigation into the specific challenges faced by this industry.

The COVID-19 pandemic that emerged in 2019 created unprecedented challenges for businesses globally, with Thailand's capital market experiencing significant negative impacts. Interdependence between various industries noticeably decreased during this period, leading to heightened anxiety among new investors and severely limiting investment activities (Inchupong, 2022). This economic uncertainty contributed to the continued decline in new ice manufacturing businesses, exacerbating pre-existing industry challenges.

Despite these challenges, the fundamental demand drivers for ice consumption in Thailand remain strong. The Department of Provincial Administration in Thailand reported an estimated population of 66.16 billion in 2022, all living in a tropical moist climate that encourages consistent beverage and ice consumption. The beverage industry, which directly drives ice consumption, is one of the largest industries in Thailand. According to The Business Research Company (TBRC, 2021), the online food and beverage retail sector has seen remarkable expansion recently, starting at $69.77 billion in 2023 and projected to reach $85.25 billion in 2024, reflecting 22.2% CAGR. This strong momentum is expected to continue, with forecasts showing the market reaching $180.77 billion by 2028, maintaining a CAGR of 20.7%.

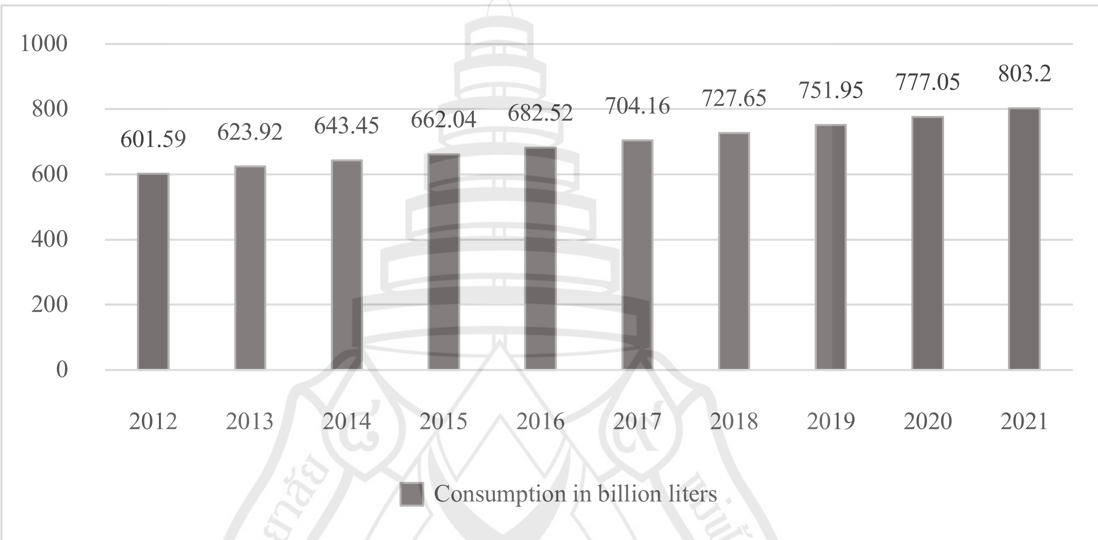



**Source** DATA for Thai (2024)

**Figure 1.1** Amount of new ice manufacturing registration in northern Thailand between 2008-2018

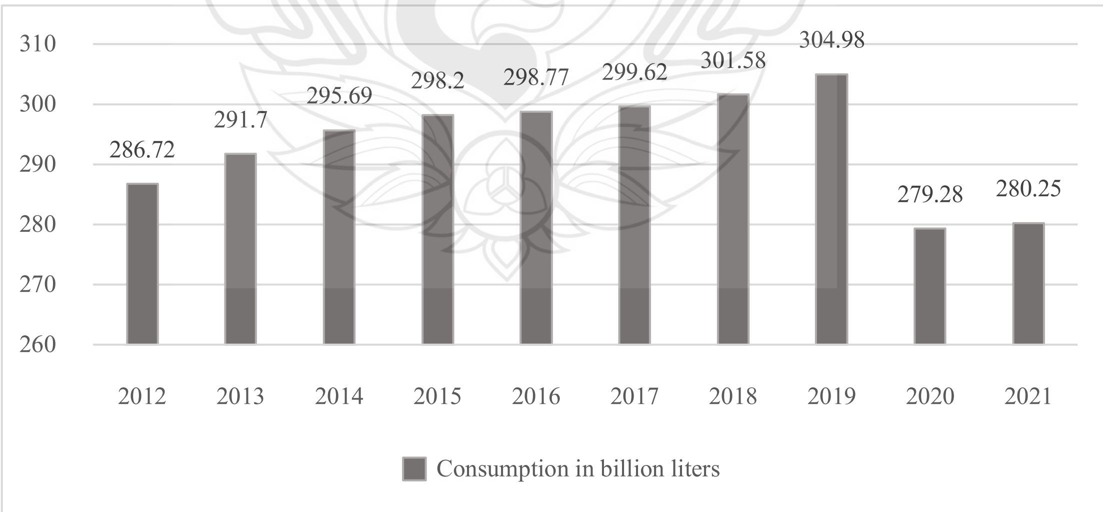
The global consumption trends of both non-alcoholic and alcoholic beverages provide additional context for understanding the potential ice market. In 2012, worldwide consumption of non-alcoholic beverages amounted to 601.59 billion liters and grew to 803.2 billion liters by 2021, as shown in Figure 1.2. These figures indicate a steady increase in the consumption of non-alcoholic beverages, which typically incorporate ice in serving practices.

The alcoholic beverage sector shows a different pattern but remains significant. Worldwide consumption of alcoholic beverages was worth 286.72 billion liters and continued to grow to 304.98 billion liters in 2019 before declining to 279.28 billion liters in 2020 during the COVID-19 pandemic. However, consumption began to recover, increasing to 280.25 billion liters in 2021, as shown in Figure 1.3. This recovery indicates the resilience of the alcoholic beverage market, which also drives ice consumption in Thailand.




**Source** Statista (2024)

**Figure 1.2** Worldwide Consumption of Non-alcoholic beverage between 2012- 2021




**Source** Statista (2024)

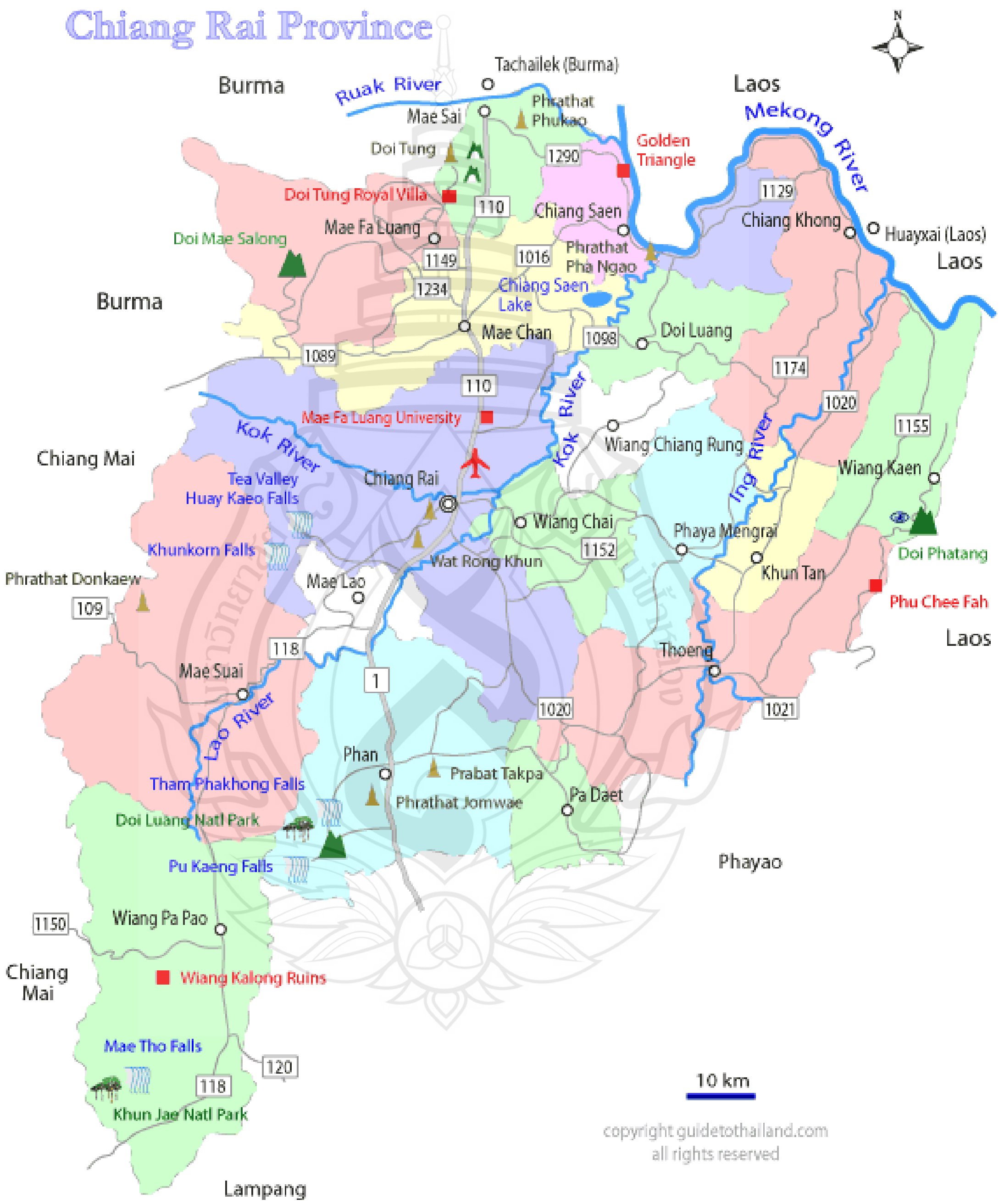
**Figure 1.3** Worldwide Consumption of Alcoholic beverages from 2012-2021

The beverage consumption trends in Thailand after the COVID-19 outbreak show continuous growth for both non-alcoholic and alcoholic beverages. This growth is particularly significant because Thai consumers typically add ice to almost all beverages, creating a direct impact on ice consumption throughout the country. However, despite this growing demand, Figure 1.1 indicates that the number of consumable ice manufacturers significantly decreased after 2015, creating a potential supply-demand imbalance in the market.

This paradoxical situation increasing demand coupled with decreasing supply capacity strongly suggests that the consumable ice manufacturing industry faces significant risk factors that impede growth and new market entries. These risks may include operational challenges, regulatory hurdles, resource constraints, and competitive pressures that collectively create barriers to entry and sustainability in the industry.

Furthermore, recent research by Arunyanart and Pruethsan (2022) on food safety infrastructure in Thailand highlights additional complexities faced by ice manufacturers, "Small and medium-sized food-adjacent manufacturers in Thailand face disproportionate challenges in meeting increasingly stringent safety standards while maintaining operational efficiency. This regulatory burden creates additional operational costs that can significantly impact business viability in price-sensitive markets" (Arunyanart & Pruethsan, 2022). This regulatory dimension adds another layer of complexity to the risk landscape for ice manufacturers, particularly for smaller operations with limited resources.

The supply chain vulnerabilities exposed by the COVID-19 pandemic have created additional challenges for manufacturing operations dependent on consistent energy supplies and specialized equipment. As noted by Ivanov and Dolgui (2021), "Manufacturing operations with continuous production processes and temperature-controlled environments experienced unique vulnerabilities during supply chain disruptions, requiring new approaches to resilience planning that extend beyond traditional inventory management" (Ivanov & Dolgui, 2021). These insights provide important context for understanding the declining number of ice manufacturing businesses despite growing market demand. Therefore, this study aims to assess, identify, and provide suggestions and recommendations, as well as develop a new assessment model for the consumable ice manufacturing industry. By applying Failure Mode and Effects Analysis (FMEA) and Multiple-Criteria Decision Making (MCDM), this study focuses on seven out of 14 consumable ice manufacturing companies in 18 districts of Chiang Rai Province, as shown in Figure 1.4.




**Source** My Chiang Mai Travel (2016)

**Figure 1.4** 18 districts of Chiang Rai province Map

## 1.2 Objective of the Study

1.2.1 To identify and assess the risk factors faced by the consumable ice manufacturing industry.

1.2.2 To provide suggestions, recommendations, and a new assessment model for the consumable ice manufacturing industry.

This study aims to identify risks in the consumable ice manufacturing industry. The population for study consists of seven out of 14 consumable ice manufacturers in Chiang Rai, selected based on their daily production capacity of over 150 tons. Risk identification is conducted through observations and interviews with experts, including factory owners, production managers, and experienced engineers. FMEA is employed to analyze, identify, and rank risks based on the gathered information. Subsequently, the identified risk factors are assessed and evaluated using MCDM. Ultimately, a risk assessment framework for consumable ice manufacturing will be developed.

## 1.3 Expected Outcome

1.3.1 The risk factors that are facing by the consumable ice manufacturing industry.

1.3.2 Understand the impacts of risk factors on the consumable ice manufacturing industry.

1.3.3 The policy suggestions for the consumable ice manufacturing industry to immigrate the risks that they are facing.

## 1.4 Scope of Study

This study aims to identify risks in the consumable ice manufacturing industry with a specific focus on operations in Chiang Rai province. The study population consists of seven out of 14 consumable ice manufacturers in Chiang Rai, selected based on their production capacity, which must exceed 150 tons per day. This selection criterion ensures that the study captures data from established operations with significant market presence and comparable operational scales.

Risk identification is conducted through a multi-method approach combining systematic observations of manufacturing processes and in-depth interviews with industry experts. The Failure Mode and Effects Analysis (FMEA) method is employed to identify, analyze, and rank risk factors based on their severity, occurrence frequency, and detectability. This approach enables a structured evaluation of operational vulnerabilities throughout the production process.

Additionally, the study evaluates risk factors using the Multi-Criteria Decision-Making (MCDM) approach, which provides a framework for prioritizing risks and recommendations based on multiple relevant criteria. The MCDM method enhances the practical applicability of the findings by considering both the impact of risks and the feasibility of mitigation strategies.

The study's scope is limited to operational and business risks directly affecting ice manufacturing facilities. While market conditions and broader economic factors are considered as external influences, the primary focus remains on risks that management can potentially address through operational improvements and strategic planning.

The findings will provide actionable recommendations to business owners, local governments, and organizations involved in the consumable ice manufacturing industry, helping them prevent and mitigate risks effectively. These recommendations will be formulated with consideration for practical implementation constraints, including resource limitations and operational realities of manufacturing businesses in the region.

## 1.5 Conceptual Framework

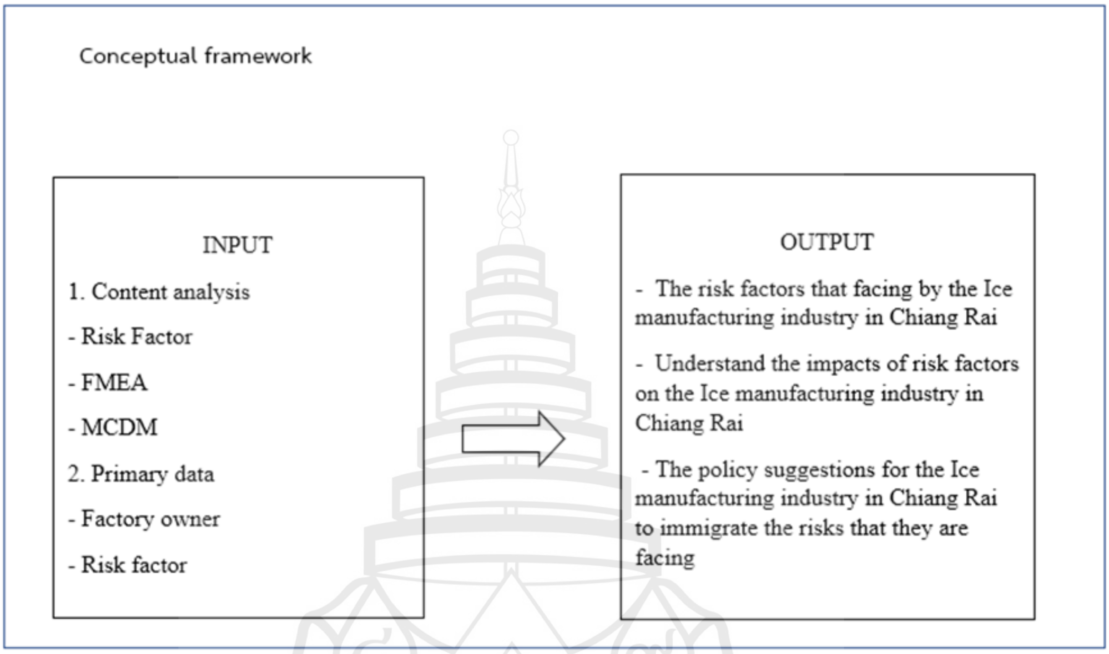



**Figure 1.5** Conceptual Framework

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 The Risk of Consumable Ice Manufacturing Industry

Operational risk identification involves systematically identifying potential risks that could disrupt business operations. This process is essential for effective risk management, as it helps organizations detect and understand risk sources, allowing for proactive measures to be taken. The two main approaches to risk identification are internal and external methods. Internal methods focus on risks within the organization, such as human factors (e.g., employee errors, lack of training), procedural elements (e.g., flawed processes or inadequate controls), and technological aspects (e.g., system failures, cyber threats). External methods focus on risks from outside the organization, such as economic shifts, regulatory changes, or natural disasters. Understanding both internal and external sources of risk is crucial for comprehensive risk management and for minimizing potential operational disruptions (Eaton, 2005).

Hazard risk encompasses those risks that stem from uncontrollable external events which can lead to severe consequences for individuals, assets, or organizational functions. Common examples include environmental catastrophes such as earthquakes and floods, unexpected accidents, disease outbreaks, and infrastructure breakdowns. In contrast to strategic or business risks, hazard risks are classified as non-speculative, indicating that they involve solely negative outcomes without the possibility of gain (Fraser & Simkins, 2016).

Recent research by Jabbari et al. (2020) has expanded on these traditional risk categorizations by proposing a more nuanced framework specifically for food and beverage adjacent industries:

"Risk identification in temperature-controlled manufacturing environments must consider the interconnected nature of biological, chemical, physical, and operational risk factors. This interconnectedness creates potential for cascading failures that can rapidly escalate from minor operational issues to significant safety and quality concerns" (Jabbari et al., 2020).

This perspective is particularly relevant for consumable ice manufacturing, where temperature control and water quality are critical operational parameters that directly affect product safety.

The consumable ice manufacturing industry faces significant sanitation challenges, particularly in less developed and developing countries, where people often avoid beverages with ice due to concerns about contamination. Even in developed nations like the United States, unsafe ice can lead to foodborne illnesses if not properly managed. To ensure ice safety, it is crucial that ice is produced under sanitary conditions, starting with a safe water supply. Commercial ice is typically made using ice machines or makers that are directly connected to a water supply. The responsibility for maintaining the safety of the water supply falls on the operator of the ice machine, ensuring that the water used is clean and free from contaminants. By carefully managing ice production and water safety, many health risks associated with ice can be mitigated (Powitz, 2013).

Building on these sanitation considerations, Pang et al. (2021) conducted a comprehensive analysis of microbial risks in ice production facilities across Southeast Asia, finding that:

"Beyond initial water quality, the most significant contamination risks occur during storage and handling phases, where equipment design, maintenance protocols, and staff hygiene practices play crucial roles in preventing microbial proliferation. Effective risk management must therefore extend beyond water treatment to encompass the entire production and distribution chain" (Pang et al., 2021).

This finding highlights the importance of considering the complete operational process when assessing risks in ice manufacturing, not just the water purification stages.

## 2.2 Risk Management

According to ISO 31000, risk management is a systematic and coordinated process aimed at minimizing, managing, and controlling the likelihood or impact of negative events, as well as maximizing opportunities. It involves identifying, assessing, and addressing uncertainty that could lead to potential losses or disruptions within an organization. Risk management is not only about preventing or mitigating risks but also about optimizing the implementation of opportunities that can lead to positive outcomes. The process includes several components, such as understanding the actions and behaviors that might cause risk, developing safety protocols, and creating emergency response procedures. Financial, legal, and insurance considerations are also integral parts of the risk management system. Organizations must evaluate operations in terms of their potential benefits while weighing the risks of losing valuable resources, including human resources, finances, assets, and reputation (Herman et al., 2004).

Albayati et al. (2022) have extended this understanding of risk management by examining how digital transformation is changing risk management practices in manufacturing:

"Digital technologies are simultaneously creating new risk management opportunities and introducing novel vulnerabilities in manufacturing operations. Effective risk management frameworks must now incorporate digital maturity assessments alongside traditional operational risk evaluations to ensure comprehensive coverage of both physical and cyber-physical risks" (Albayati et al., 2022).

This digital dimension is increasingly relevant for ice manufacturing facilities that are adopting automated systems for monitoring water quality, temperature control, and production processes.

The risk management process requires continuous engagement across various departments within the organization, such as operations, finance, legal, and human resources. A comprehensive risk review helps ensure that the organization can identify and respond to risks effectively, thus ensuring the safety, security, and long-term success of the business. This integrated approach to risk management supports decision-making and helps protect the organization from both internal and external threats (Herman et al., 2004).

Risk management allows organizations to achieve their objectives with greater assurance, as it ensures that potential risks are recognized and actively managed. In today's complex business environment, companies face increasing pressure to scrutinize and address risks more thoroughly than ever before. Enterprise risk management (ERM) plays a key role in this process by helping businesses assess and mitigate risks across all areas of operation. By proactively managing risks, organizations can enhance stakeholder trust and confidence, as they demonstrate a commitment to maintaining stability and protecting assets. Effective risk management not only safeguards the company's interests but also fosters transparency, accountability, and long-term sustainability. As a result, ERM is essential in building resilience and ensuring that the organization can achieve its strategic goals while managing uncertainties (Committee of Sponsoring Organizations of the Treadway Commission, 2017).

The objective of risk management is to establish a framework that enables businesses to deal with risk and uncertainty. Risks exist in nearly all financial and economic activities of businesses. The process of risk identification, assessment, and management is an integral part of a company's strategic development; it must be designed and planned by the board of directors. An integrated approach to risk management must evaluate, control, and monitor all risks and their interdependencies to which the organization is exposed (Dionne, 2013).

Shankar et al. (2021) have further emphasized the importance of risk management in ensuring business continuity, particularly in the wake of the COVID-19 pandemic:

"The pandemic has transformed risk management from a periodic planning exercise to an essential operational capability that requires continuous monitoring and adaptation. Organizations with mature risk management capabilities demonstrated significantly greater resilience during supply chain disruptions, highlighting the business value of comprehensive risk frameworks beyond mere regulatory compliance" (Shankar et al., 2021).

This perspective underscores the strategic importance of the risk assessment framework being developed in this study for the ice manufacturing industry.

## 2.3 Industry Standards Relevant to the Ice and Drinking Water Manufacturing Sector

Good Manufacturing Practice (GMP) is a globally recognized system for ensuring that products are consistently produced and controlled according to quality standards. In Thailand, GMP guidelines are regulated by the Food and Drug Administration (FDA) under the Ministry of Public Health. For the production of drinking water and ice, GMP compliance covers areas such as facility hygiene, production equipment, water quality control, personnel hygiene, and sanitation procedures. These practices are designed to minimize contamination risks and ensure consumer safety (Thai FDA, 2021).

The Thai Food and Drug Administration (FDA) is the primary authority responsible for the registration, licensing, and inspection of food and beverage manufacturing operations. Manufacturers of ice and drinking water must obtain FDA approval, including facility registration and product licensing. Compliance requirements include regular water quality testing, implementation of hygiene protocols, and traceability of raw materials. The FDA enforces safety standards to ensure the final products are free from harmful contaminants such as bacteria, heavy metals, and chemical residues (Thai FDA, 2022).

The Thai Industrial Standards Institute (TISI) issues mandatory and voluntary industrial standards under the Ministry of Industry. For example, TISI 17–2561 specifies the technical and safety requirements for rigid PVC pipes used in drinking water systems. Adherence to TISI ensures that materials used in water and ice production do not introduce chemical or physical hazards. Other TISI standards also relate to packaging, labeling, and structural materials in food-grade environments (TISI, 2018).

ISO 22000 is an international standard that outlines the requirements for a food safety management system (FSMS). It integrates principles from HACCP and other preventive programs to ensure safe food production across the supply chain. Ice and drinking water producers often adopt ISO 22000 to manage food safety risks more comprehensively.

In addition, ISO/IEC 17025 applies to laboratories that perform testing and calibration, particularly in quality control of water and food samples. This standard ensures that testing results are accurate, reproducible, and scientifically valid, supporting both regulatory compliance and consumer confidence (ISO, 2018).

## 2.4 The Failure Mode and Effects Analysis (FMEA) method

The Failure Mode and Effects Analysis (FMEA) technique, developed in the late 1940s, was first applied by the U.S. military as part of their effort to improve manufacturing processes, particularly in the production of weapons. The primary goal was to eliminate sources of variance and prevent potential failures that could affect the functionality and safety of military equipment. This early application of FMEA proved to be highly effective, laying the foundation for its adoption in other industries.

In the mid-1970s, the automotive industry became one of the first sectors to apply FMEA more widely. Ford Motor Company was a pioneer in using this method, particularly as an internal response to the safety issues associated with the Ford Pinto. The Pinto's fuel tank design, which was prone to exploding during rear-end collisions, sparked a public relations crisis. Ford's use of FMEA aimed to identify and address the potential failure modes in the vehicle's design, marking a turning point in the automotive industry's approach to safety and quality management.

Following Ford's lead, other automakers in the United States, Europe, and the United Kingdom quickly began adopting FMEA as a tool to improve their design and manufacturing processes. The goal was to minimize the risks of product failures and enhance the overall safety of vehicles.

In 1982, the Automotive Industry Action Group (AIAG) was established to promote collaboration among U.S. automakers. AIAG's primary objective was to standardize the use of quality improvement tools like FMEA, Statistical Process Control (SPC), and Measurement System Analysis (MSA). By bringing together fierce competitors in the automotive industry, AIAG created a platform for sharing best practices and fostering continuous improvement across the sector.

The widespread adoption of FMEA in the automotive industry and other sectors has led to its success as a critical tool for identifying, prioritizing, and mitigating potential risks in product design and manufacturing. Today, FMEA is considered an essential part of risk management, particularly in industries where safety and reliability are of paramount importance.

Liu et al. (2019) have examined recent advancements in FMEA methodologies, noting:

"Traditional FMEA approaches often struggle with interdependencies between failure modes and subjective expert assessments. Advanced FMEA methodologies now incorporate fuzzy logic, cognitive mapping, and Bayesian networks to capture complex relationships between failure modes and provide more robust risk prioritization metrics beyond the classic Risk Priority Number calculation" (Liu et al., 2019).

These methodological advancements offer potential improvements for risk assessment in complex manufacturing environments like ice production facilities, where multiple failure modes may interact in non-linear ways.

Failure Mode and Effects Analysis (FMEA) is an analytical method used to identify and evaluate potential issues or failures within a product or process, ensuring that these risks are considered and addressed during the development and production stages. The main objective of FMEA is to improve the reliability and quality of a product by proactively identifying possible failure modes, their causes, and their effects. By assessing these risks, organizations can take corrective actions before problems occur, reducing the likelihood of costly failures or safety incidents.

FMEA is widely used in product design and manufacturing processes, where its potential advantages are clear and significant. For example, in product design, FMEA helps teams identify weaknesses in a product's design or functionality, which can then be addressed early in the development process, before the product goes into mass production. Similarly, in manufacturing, FMEA helps to evaluate and mitigate risks related to production processes, ensuring that any issues, such as defective parts or system failures, are minimized.

While traditionally associated with manufacturing, FMEA has been adapted for use in a variety of other sectors as well. For instance, in the healthcare industry, FMEA is used to assess risks in safety systems, such as medical equipment, or even administrative processes, such as patient intake and scheduling. In these contexts, FMEA helps organizations improve the safety and efficiency of their systems by identifying areas where errors could lead to serious consequences, such as patient harm or operational disruptions.

The method is also valuable in non-manufacturing sectors like service industries, where it can be applied to assess risks in customer service processes, logistics, or supply chain management. FMEA's adaptability across different sectors makes it a versatile and powerful tool for improving quality, safety, and reliability.

FMEA is particularly useful when the potential risks are substantial, and the cost of failure could be high. By systematically analyzing each step of the product or process and assessing its potential failure modes, organizations can prioritize their actions based on the severity, likelihood, and detectability of these risks. This helps ensure that critical issues are addressed first and allows for more efficient risk management overall (AIAG, 2008).

Samanlioglu et al. (2022) have expanded on the application of FMEA in small to medium manufacturing enterprises:

"The effective implementation of FMEA in small and medium enterprises requires adaptation to resource constraints and operational realities. Simplified FMEA approaches that maintain methodological rigor while reducing implementation complexity have shown promising results in improving risk identification and mitigation without overwhelming limited management resources" (Samanlioglu et al., 2022).

This perspective is particularly relevant for the ice manufacturing industry in Chiang Rai, where many operations may have limited resources for implementing comprehensive risk management frameworks.

## 2.5 Multi-Criteria Decision Making (MCDM) method

Multi-Criteria Decision Making (MCDM) refers to a set of methods used to address decision-making problems that involve multiple criteria or objectives. In real-world situations, decision-makers often face complex problems where they need to evaluate and select from several alternatives, each of which is assessed based on various factors. MCDM methods aim to help in selecting, ranking, or classifying these alternatives by considering multiple criteria and balancing trade-offs between them. The main goal is to identify the best alternative that meets the decision-maker's priorities and preferences, considering all the criteria involved.

MCDM techniques can be applied to a wide variety of fields, such as business, engineering, healthcare, and environmental management, where decisions typically need to account for different aspects such as cost, quality, time, and safety. These methods provide a structured approach to decision-making, allowing for more informed and objective choices. Some common MCDM methods include Analytic Hierarchy Process (AHP), TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), and the VIKOR method.

A considerable body of literature has focused on MCDM and its various methods. Researchers have explored various applications, theoretical foundations, and extensions of MCDM techniques in different fields. Studies have also examined how these methods can be adapted to address different decision-making scenarios, improving the quality of decisions in complex, multi-criteria environments (Behzadian et al., 2010). The evolution of MCDM methods continues to contribute significantly to decision support systems and organizational strategy development.

Yazdani et al. (2020) have examined how MCDM methods are evolving to address sustainability challenges in manufacturing contexts:

"Contemporary MCDM applications in manufacturing are increasingly incorporating sustainability dimensions alongside traditional performance metrics. This evolution reflects growing recognition that operational decisions must balance economic viability with environmental impact and social responsibility to ensure long-term business sustainability" (Yazdani et al., 2020).

This integration of sustainability considerations into decision frameworks is particularly relevant for water-intensive industries like ice manufacturing, which must manage resources responsibly.

MCDM methods are widely used to prioritize alternatives by weighing conflicting criteria, helping decision-makers evaluate different options based on multiple factors. These methods aim to identify the optimal solution by considering trade-offs between conflicting objectives. Despite their usefulness, MCDM methods have faced scrutiny over their reliability, as some critics argue that they can be sensitive to subjective judgments, such as weight assignments or the choice of criteria. This has raised concerns about the consistency and accuracy of the results, especially when used in complex decision-making scenarios. However, when applied correctly, MCDM methods have proven valuable in various fields, including business, engineering, and healthcare, for identifying the most effective and balanced choices (Asadabadi et al., 2019).

The approach combines Failure Mode and Effects Analysis (FMEA) with fuzzy Multi-Criteria Decision-Making (MCDM) to address uncertainty in risk evaluation, particularly when dealing with imprecise or subjective data. Applied to general anesthesia risk analysis, this method allows hospitals to assess and prioritize potential failure modes more effectively. By using fuzzy logic, the approach accounts for uncertainty in risk assessment, helping to identify high-risk failure modes that may otherwise be overlooked. Sensitivity analysis is conducted to test how sensitive the results are to changes in input data, ensuring the robustness of the method. Additionally, comparison with other methods further validates its reliability. The proposed approach provides hospitals with a clear priority ranking of failure modes, improving patient safety and risk management during general anesthesia (Liu et al., 2015).

Govindan and Jepsen (2021) have highlighted methodological considerations that improve the robustness of MCDM applications in manufacturing settings:

"Effective MCDM implementation requires careful attention to criteria selection, weight determination methods, and sensitivity analysis. These methodological considerations significantly impact the reliability and practical utility of the prioritization outcomes, particularly when working with limited expert inputs as is common in specialized manufacturing contexts" (Govindan & Jepsen, 2021).

These insights provide important guidance for the MCDM implementation in this study, ensuring the methodology produces reliable and actionable recommendations for ice manufacturers.

## 2.6 Related Research

**2.5.1 Rapid Responding to the COVID-19 Crisis: Assessing the Resilience in the German Restaurant and Bar Industry**

The study by Neise et al. (2021) examines the impact of the COVID-19 crisis on the perceptions of resilience within the German restaurant and bar industry, using the theory of organizational resilience. The research focuses on understanding how owners of these establishments view their ability to withstand and recover from the crisis. It emphasizes the importance of ex-ante conditions, or pre-crisis factors, such as organizational structure, leadership, and financial stability, in shaping an organization's response to challenges. The study reveals that businesses with stronger resilience capabilities before the crisis were better able to adapt to the pandemic's disruptions. The findings offer valuable insights into how businesses can better prepare for future crises by fostering resilience from within.

This research is particularly relevant to the ice manufacturing industry, as both sectors face challenges related to food safety, customer confidence, and operational disruptions. The emphasis on pre-crisis resilience capabilities provides an important framework for understanding why some ice manufacturers might be better positioned to navigate industry challenges than others.

**2.5.2 Failure Mode and Effect Analysis (FMEA) for Confectionery Manufacturing in Developing Countries: Turkish Delight Production as a Case Study**

Ozilgen (2012) applied the Failure Mode and Effects Analysis (FMEA) method to assess risks in a small-sized candy manufacturing firm, with a focus on Turkish delight production. FMEA was used to identify and evaluate potential failure modes throughout the manufacturing process, which is highly integrated with specific methodologies and equipment. The research emphasized the importance of identifying risks at each phase of production, from raw materials to finished products, to ensure quality and safety. Ozilgen's findings underscored the need for a comprehensive and systematic control system in the candy manufacturing industry. By applying FMEA, the study revealed how such a system could help identify critical failure points and prevent operational disruptions. The approach ultimately helped improve the firm's risk management practices and production reliability, offering valuable insights for small-scale manufacturers. The research highlights that even in small businesses, systematic risk management can significantly enhance operational efficiency and product safety.

This case study demonstrates the applicability of FMEA to food-adjacent manufacturing contexts similar to ice production, particularly in developing economies where resources for sophisticated risk management may be limited. The emphasis on a process-oriented approach to risk identification aligns well with the methodology employed in the current study.

**2.5.3 Food Safety Control of Halloumi Type Cheese Production**

The research paper by Kapshakbayeva et al. (2019) explores the integration of Hazard Analysis and Critical Control Points (HACCP), Fault Tree Analysis (FTA), and Failure Mode and Effects Analysis (FMEA) to improve the production process of goat milk-based semi-firm Halloumi-style cheese. The study's primary objective was to identify the critical control points (CCPs) in the production process and evaluate the associated risk factors to ensure the safety and quality of the cheese. By implementing a HACCP-based control system, the research aimed to systematically monitor and mitigate risks at each stage of production. Through the application of FTA and FMEA, potential hazards, such as contamination or equipment failure, were identified, and corresponding preventive measures were proposed. The study also highlighted the importance of monitoring the critical steps where risks were highest, ensuring better control over product quality. The research findings demonstrated that the combined use of these methodologies not only improved the overall production efficiency but also led to a significant enhancement in the quality and safety of the final product. Moreover, the integration of these risk management strategies resulted in better labor management, as employees were more aware of potential hazards and how to prevent them, fostering a safer and more efficient work environment.

This research provides valuable insights for the current study on ice manufacturing, as it demonstrates the effectiveness of combining multiple risk assessment methodologies to address food safety concerns. The focus on critical control points is particularly relevant for ice production, where water quality and temperature control represent critical parameters that must be carefully monitored.

**2.5.4 Risk Assessment in Cold Chain Logistics: A Systematic Review**

Wei et al. (2022) conducted a comprehensive systematic review of risk assessment methodologies specifically applied to cold chain logistics, which has direct relevance to ice manufacturing operations:

"Temperature-controlled supply chains face unique vulnerabilities that extend beyond traditional logistics risks. Effective risk assessment in these contexts must consider both the transportation network's integrity and the product-specific temperature requirements that directly impact product safety and quality. Our analysis identified that integrated approaches combining quantitative risk prioritization with qualitative expert assessment provided the most robust framework for cold chain risk management" (Wei et al., 2022).

This research highlights the importance of temperature control throughout the production and distribution process for products like ice, where maintaining the cold chain is essential for product integrity.

**2.5.5 Implementation of Risk Management in Southeast Asian Food Manufacturing: A Comparative Analysis**

Suppadit and Lertrat (2022) examined how food manufacturing companies across Southeast Asia implement risk management frameworks, finding significant regional variations:

"Risk management maturity in Southeast Asian food manufacturing varies considerably based on regulatory environments, company size, and export orientation. Small to medium enterprises producing primarily for domestic markets demonstrated the largest gaps in risk management implementation, particularly in systematic hazard identification and quantitative risk assessment. The discrepancy between formal risk management documentation and operational implementation was most pronounced in these smaller operations" (Suppadit & Lertrat, 2022).

This research provides important context for understanding the current state of risk management in Thailand's ice manufacturing industry, particularly for smaller operations that may lack formal risk assessment frameworks.

# CHAPTER 3

# RESEARCH METHODOLOGY

The identification of risk factors in the ice manufacturing process is conducted using the Failure Mode and Effects Analysis (FMEA) method, which systematically detects, evaluates, and classifies potential failures based on their impact on both secondary and major failures. Through this approach, the FMEA method helps in understanding how failures in the production process can trigger a chain reaction, leading to more significant issues. Information gathered from the business owners of the seven selected ice manufacturing factories is integral to this process, as it allows for the estimation of failure modes specific to their operations. The data provided by these owners helps in assessing and documenting potential failures across the entire design and operational processes, offering a comprehensive view of the risks involved.

Once the failures are identified, the results of the FMEA analysis are used to prioritize corrective actions, with a focus on addressing the most critical risks that could have the greatest impact on operations, safety, and quality. The risks identified are then categorized into internal and external factors, helping businesses understand whether the risks originate within their operations or from external influences such as market conditions or environmental factors. Additionally, the Multi-Criteria Decision-Making (MCDM) method is employed to assign weights to each identified risk factor, helping to prioritize actions and allocate resources effectively. MCDM method to weight and provide recommendations, ensuring that business owners can make informed decisions on how to mitigate the most pressing issues and improve the overall resilience of their operations.

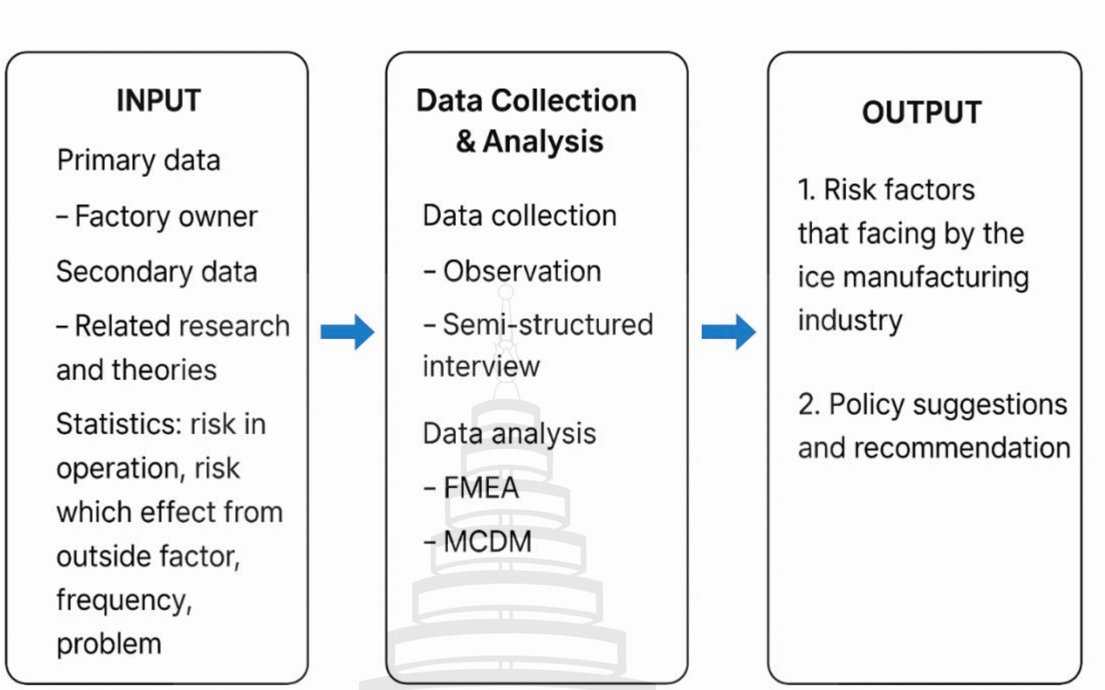



**Figure 3.1** Analysis Framework

## 3.1 Data Collection

The study specifically targets seven consumable ice factories in Chiang Rai, selected through a snowball sampling method from an initial pool of 14 manufacturers. This method was employed to ensure the sample size was manageable while still capturing a broad representation of the industry's key challenges. By using snowball sampling, the researchers were able to identify factories that were not only large enough to provide valuable insights but also faced a range of common issues in the consumable ice manufacturing sector. The focus of the study was on understanding the operational risks, both internal and external, and identifying the most critical risks affecting production processes.

To gather data, the researchers conducted direct observations and interviews with experts, including business owners, managers, and employees from the selected factories. This allowed them to gain firsthand insights into the operational difficulties faced by these manufacturers. Topics covered in the interviews included common production issues, risk factors related to equipment failure, and external challenges such as market competition, regulatory changes, or environmental concerns. Additionally, the study delved into the frequency and severity of potential failures, using qualitative and quantitative measures to assess the risks.

This combination of observation and expert input helped to provide a comprehensive understanding of the challenges within the industry. By narrowing the study to seven representative factories, the research was able to maintain a practical scope while still offering valuable insights into the operational risks and failures that affect the consumable ice manufacturing process. The findings are expected to inform risk management strategies and offer solutions to mitigate the identified risks.

## 3.2 Data Analysis

The ice manufacturing industry faces two types of risks: internal and external. Internal risks include human resources challenges like employee issues and skill gaps, along with operational problems that affect daily production. External risks consist of natural disasters, market competition, and rising costs from economic conditions.

Applying FMEA, major failures were identified and ranked. Nine criteria were then weighted using MCDM, and actions were prioritized with the MCDM method. Business owners from seven out of the 14 ice manufacturers were surveyed to evaluate the importance of three main criteria and nine sub factors. The main criteria categorized into 3 criteria which is Risk priority number, Action feasibility, Operational impacts.

Failure Mode and Effects Analysis (FMEA) is a systematic and proactive risk assessment methodology employed to identify potential failure modes within a system, product, or manufacturing process, and to evaluate their causes and effects. The process commences with a comprehensive review of the system to define its boundaries and gather input from relevant cross-functional stakeholders. Subsequently, potential failure modes are identified for each component or process step, followed by the assessment of their respective consequences. Each failure mode is analyzed to determine its root causes, after which three numerical scores are assigned to reflect its Severity (S), Occurrence (O), and Detection (D). These values are then multiplied to calculate the Risk Priority Number (RPN), which serves as a quantitative metric for ranking the significance of each potential failure.

FMEA Formula: The Risk Priority Number (RPN) is calculated as: RPN=S×O×D

Following the calculation of RPNs, failure modes are prioritized in accordance with their risk levels, thereby facilitating the allocation of resources toward high-risk issues. Recommended corrective and preventive actions are proposed to reduce the severity of the failure’s impact, lower the likelihood of occurrence, or enhance the detectability of potential faults. These actions are then implemented and subject to ongoing monitoring to evaluate their effectiveness. The FMEA document is treated as a living document and must be updated regularly to reflect changes in system design, operational processes, or new failure data. Overall, FMEA contributes significantly to improving product reliability, process safety, and regulatory compliance in various industrial sectors.

Risk priority number are number that describes the severity of the risk, the frequency of occurrence, and the ability to detect the failure which is Severity (S), Occurrence (O), Detectability (D).

Action feasibilities are feasibility of implementation, such as cost, ease of implementation, and implementation time. which is Cost (C), Easiness (E), Duration (D).

Operational impacts are affects operations such as operational safety, operational reliability, and employee satisfaction, which is Operation safety, Operation reliable, Employee satisfaction.

In this study, the FMEA assessment employs a 1 to 10 scoring scale to enable a more comprehensive and granular evaluation of risk and feasibility across each criterion. For risk-related factors such as Severity, Occurrence, and Detectability, higher scores correspond to increased levels of risk, while lower scores indicate lesser risk. Similarly, for criteria including Cost, Easiness, and Duration, lower scores denote more favorable conditions characterized by lower expense, ease of implementation, and shorter time requirements, whereas higher scores reflect greater complexity and resource demands (Smith & Lee, 2020).

**Table 3.1** The Nine criteria and description of each score

| Category | The linguistic descriptions of each score<br>The descriptions of the scores | | | | |
|---|---|---|---|---|---|
| | **1-2** | **3-4** | **5-6** | **7-8** | **9-10** |
| Severity (S) | Negligible | Minor | Moderate | Major | Catastrophic |
| Occurrence (O) | Rare | Unlikely | Possible | Likely | Almost certain |
| Detectability (D) | Very easy to detect | Easy to detect | Moderate to detect | Difficult to detect | Almost impossible to detect |
| Cost (C) | Very high | High | Moderate | Low | Very low |
| Easiness (E) | Almost impossible to implement | Difficult to implement | Moderate to implement | Easy to implement | Very easy to implement |
| Duration (D) | The time required very high | The time required High | The time required Moderate | The time required Low | The time required Very low |
| Operation safety | Very low | Low | Moderate | High | Very high |
| Operation reliable | Very low | Low | Moderate | High | Very high |
| Employee satisfaction | Very low | Low | Moderate | High | Very high |

**Source** NPSA (2008) and Perks et al. (2012)

Conversely, for benefit-oriented criteria such as Operational Safety, Operational Reliability, and Employee Satisfaction, higher scores signify more desirable outcomes, including enhanced safety performance, improved system reliability, and greater employee acceptance. This structured scoring methodology supports objective and systematic analysis, thereby facilitating informed decision-making and prioritization of corrective actions to improve overall process effectiveness (Johnson, 2018; Kumar et al., 2021).

The study focused on seven out of 14 consumable ice manufacturers in Chiang Rai, selected based on their production capacity of over 150 tons per day. Ice factories are classified by production capacity based on guidelines from the Department of Industrial Promotion (DIP), Thailand. Small factories produce less than 50 tons per day and serve local markets. Medium factories produce 50–150 tons per day, catering to provincial markets and moderate exports. Large factories produce over 150 tons per day, targeting large-scale markets such as industries, major retailers, and national exports, often using advanced technology to manage high volumes. This selection criterion ensured that the study targeted larger manufacturers with significant production operations selecting ice manufacturers with a production capacity greater than 150 tons per day allows the research to concentrate on the principal players within the industry. This enhances the study's relevance, data quality, and overall efficiency, thereby producing more meaningful and actionable insights. Risk identification was carried out through a combination of observations and interviews with industry experts and employees. These methods allowed the researchers to gather first-hand insights into the challenges faced by the manufacturers in their day-to-day operations, as well as the risks associated with production processes, safety concerns, and operational inefficiencies.

By interviewing experts and employees, the study was able to capture a comprehensive range of perspectives on potential risks, including human, operational, and environmental factors. The information gathered was then analyzed to identify common issues and vulnerabilities in the production process, which were critical for implementing effective risk management strategies. The details of the selected manufacturers, including their production capacity, operational scale, and risk-related challenges, were presented in Table 3.2, providing context for the findings and analysis. This approach enabled a detailed understanding of the risks faced by larger ice manufacturing businesses.

**Table 3.2** List of consumable ice manufacturing industry production capacity exceeds 150 tons per days

| No. | Name of manufacturers | Job Position |
|---|---|---|
| 1 | HongSawan LIMITED PARTNERSHIP | Business owner |
| 2 | U.P.ICE (2003) LIMITED PARTNERSHIP | Business owner |
| 3 | SAKOL ICEBERG CO., LTD. | Business owner |
| 4 | KO TI NAMKHEANG LIMITED PARTNERSHIP | Business owner |
| 5 | D.D DRINRK LTD., PARTNERSHIP | Business owner |
| 6 | SAKOL ICE-DRINKING WATER (1980) COMPANY LIMITED | Business owner |
| 7 | RATANASUWAN ICE FACTORY LIMITED PARTNERSHIP | Business owner |

# CHAPTER 4

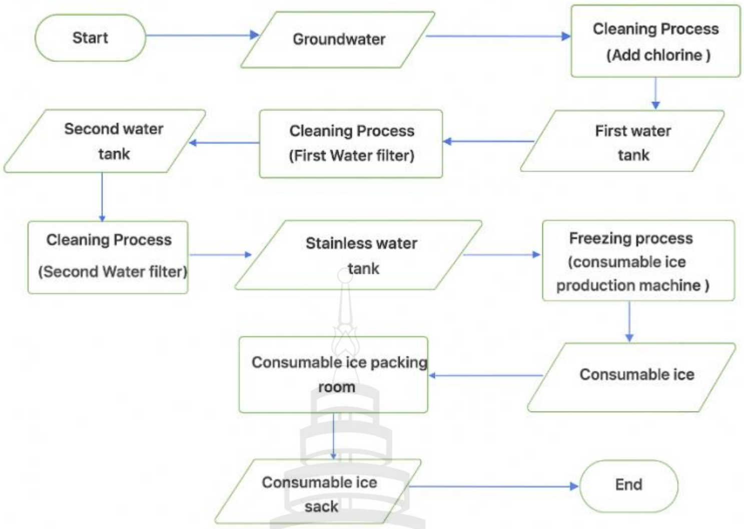
# RESEARCH RESULTS

## 4.1 Observations and Interviews Results

Prior to conducting the formal risk assessment, a preliminary round of interviews was carried out with relevant expert to identify potential risks. These interviews explored both internal and external risks that could affect the operations of ice manufacturing industries. The aim was to gather comprehensive insights into real world issues and risk perceptions from individuals directly involved in the industry.

Following this initial stage, a risk evaluation was then conducted by business owner from all seven ice factories. Each participant was asked to assess the identified risks based on their likelihood and potential impact. From this process, only the risks deemed to have significant impact and critical importance to ice manufacturing were selected for further analysis. This approach ensured that the final assessment focused on high-priority risks with substantial operational relevance.

After conducting interviews with seven consumable ice manufacturing business owners about their work processes, the results revealed that the production procedures across these manufacturers were either exactly the same or very similar to the process shown in Figure 4.1. These common processes highlight the standard practices used in the industry, which include key stages such as water treatment, freezing, storage, and distribution. By analyzing the responses, it became clear that despite variations in scale and resources, the fundamental steps of production were consistent across the businesses. This uniformity indicates a shared approach to managing the complexities of consumable ice manufacturing, suggesting that industry standards are widely adopted.




**Source** Researcher (2024)

**Figure 4.1** Chart of consumable ice manufacturing industry

First, groundwater is pumped and stored in a storage pond. The transferred to a cleaning pond, where chlorine is added to kill bacteria and purify the water in the first round of treatment. The water is then left to settle for 8 hours before further processing.

**Source** Researcher (2024)

**Figure 4.2** Cleaning process and stored in the second clean water reservoir

After that, the water from the first reservoir is transferred to the second water cleaning process and stored in the second clean water reservoir. In the third step, clean water from this second reservoir undergoes another round of cleaning and filtration before being transferred into a stainless steel well for further processing.


**Source** Researcher (2024)

**Figure 4.3** Stainless steel clean water storage tank prepare for freezing process

After the third filtration, the clean water is placed in the stainless-steel tank. The next step is the freezing process in the ice machine, where the water is transformed into ice for consumption. Once the freezing process is complete, the ice is ready for use. The final step involves processing the ice and packaging it according to its type, ready for distribution.

**Source** Researcher (2024)

**Figure 4.4** The freezing process tank

Interviews with seven owners of consumable ice manufacturing facilities revealed that their operational processes are either identical or very similar. Observations and interviews conducted to identify risks faced by these manufacturers showed that the risk factors and their consequences are also similar with literature. The major risks identified can be categorized into internal and external risks, as shown in Table 4.1.

**Table 4.1** Reliability and Convergent Validity Assessment.

| Types of risk | No. | Source of risk |
|---|---|---|
| Internal risks | 1 | Human resources issues |
| | 2 | Operation issues |
| External risks | 1 | Natural disaster |
| | 2 | Competitor |
| | 3 | Higher cost |

The selection of these internal and external risks is grounded in their substantial relevance and potential impact on the operational performance and sustainability of ice manufacturing businesses. Internal risks, including human resources issues and operation issues, were identified due to their direct influence on organizational efficiency, staff productivity, and the overall reliability of internal processes. These risks are within the organization's scope of control and can be managed through effective administrative and operational strategies.

In contrast, external risks such as natural disasters, market competition, and rising costs were chosen based on their prevalence and disruptive nature in the industrial context. Natural disasters pose sudden threats to infrastructure and logistics; competitors exert constant pressure on market share and innovation; and increasing costs, often driven by external economic factors, directly affect profitability. Addressing these risks is essential for maintaining business continuity and achieving long-term strategic objectives.

Human resources issues and Operation issues are considered internal risks because they are related to factors within the organization, such as personnel, work systems, or internal processes that the organization can directly control. This contrasts with external risks, which arise from factors outside the organization's environment, such as natural disasters, competitors, or cost increases due to external influences.

Natural disaster, Competitor, and Higher cost are considered external risks because these risks arise from factors outside the organization that cannot be directly controlled. Natural disaster results from unpredictable natural events beyond the organization's control. Competitor refers to market competition, an external factor that affects the business environment. Higher costs usually stem from external factors such as raw material prices, economic issues, or market changes.

Natural disasters, competitors, and higher costs are key external risks that organizations cannot control but must manage effectively. Natural disasters such as floods or earthquakes can severely disrupt operations and supply chains. Competitors create market pressure through new products and strategies, forcing companies to adapt to stay competitive. Meanwhile, rising costs often stem from external economic factors like inflation or raw material price fluctuations, directly affecting profit margins. These risks collectively pose significant challenges to organizational stability and require proactive risk management strategies to mitigate their impact.

Intense competition from larger factories with higher production capacities, as well as the import of cheaper ice from other regions, has intensified the pressure on smaller factories. Changing consumer behavior also plays a role, with more people using home water filters and ice machines, reducing their reliance on factory-produced ice. By interviewing with experts, we were able to learn about the severity, occurrence, and detectability of each risk and received the scoring results from experts by using Table 4.1. to describe as shown in Table 4.2-4.4. However, severity, occurrence and detection of each ice manufacturer varies in terms of management, location, and strategy.

Observations and interviews conducted for the purpose of identifying risks faced by seven manufacturers of consumable ice revealed that the risk factors and consequences of each risk faced by the seven manufacturers of consumable ice are similar or heading in the same direction. After identifying the internal and external risk factors affecting consumable ice manufacturers, the Failure Modes and Effects Analysis (FMEA) method was applied to determine the weights for Severity, Occurrence, and Detection, as outlined in Table 4.2-4.3. This approach allowed for prioritizing each risk, enabling a deeper analysis of the most critical issues affecting the consumable ice manufacturing industry.

**Table 4.2** Severity of each risk in ice manufacturers

| **Types of risk** | **Risk** | **Severity (Score)** | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Internal risks | Human resources issues | 8 | 7 | 5 | 9 | 4 | 7 | 5 |
| | Operation issues | 6 | 5 | 6 | 5 | 7 | 5 | 5 |
| External risks | Natural disaster | 7 | 9 | 7 | 9 | 9 | 8 | 8 |
| | Competitor | 8 | 7 | 4 | 6 | 9 | 6 | 6 |
| | Higher cost | 10 | 8 | 8 | 9 | 9 | 7 | 9 |

**Table 4.3** Occurrence of each risk in ice manufacturers

| Types of risk | Risk | Occurrence (Score) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Internal risks | Human resources issues | 10 | 8 | 4 | 9 | 2 | 7 | 2 |
| | Operation issues | 3 | 4 | 3 | 5 | 3 | 3 | 2 |
| External risks | Natural disaster | 3 | 5 | 4 | 4 | 5 | 5 | 3 |
| | Competitor | 6 | 9 | 3 | 9 | 9 | 6 | 5 |
| | Higher cost | 10 | 8 | 8 | 9 | 9 | 7 | 9 |

**Table 4.4** Detection of each risk in ice manufacturers

| Types of risk | Risk | Detection (Score) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Internal risks | Human resources issues | 3 | 6 | 7 | 4 | 8 | 6 | 5 |
| | Operation issues | 3 | 3 | 5 | 5 | 7 | 5 | 4 |
| External risks | Natural disaster | 3 | 5 | 8 | 5 | 3 | 3 | 4 |
| | Competitor | 8 | 8 | 6 | 7 | 8 | 8 | 9 |
| | Higher cost | 8 | 9 | 8 | 7 | 9 | 9 | 8 |

## 4.2 Apply FMEA to Assess Operation Risk

The results from observations and interviews with experts of 7 factories displayed the same discussion results as literature review. Which are the operational risks being the major risk for manufacturers of consumable ice. From interviews with experts, the operational risks are the factors that can be easily planned, controlled, and prevented. While other factors are sensitive and uncontrollable. In the next section, we apply FMEA to assess operational risks, identifying potential product and process related failure modes and analyzing the effects of prospective failures on the process, product, and business. The lists of failures and problems identified in the ice manufacturing industry through observations and interviews are shown in Table 4.5.

**Table 4.5** List of operation risks and problems of ice manufacturing industry

| No. | List of operation risks and problems of ice manufacturing industry |
|---|---|
| 1 | Groundwater transport pipe leaks, clogged pipe |
| 2 | Ammonia pipe leak |
| 3 | The water valve cannot be completely closed |
| 4 | Failure of transformer electrical system |
| 5 | Failure of water pump |

Groundwater transport pipe leaks present a significant challenge, impacting infrastructure, water conservation efforts, and environmental sustainability. Since these leaks often occur underground, they contribute to substantial water loss, rising utility expenses, and potential environmental harm. The issue of groundwater transport pipe leaks is becoming increasingly prevalent worldwide, especially as aging infrastructure struggles to meet modern demands. These leaks not only deplete valuable water resources but also threaten ecosystems, public health, and economic stability. According to the American Water Works Association (AWWA), a large portion of the drinking water distribution system in the United States is over 50 years old and approaching the end of its lifespan. The combination of aging pipes, environmental stressors, and insufficient maintenance has led to a sharp increase in underground pipe failures.

Ammonia is commonly utilized in industrial settings, particularly in refrigeration systems, because of its affordability and excellent cooling performance. However, leaks from ammonia pipes present serious hazards to human health, the environment, and industrial processes. These leaks can result from multiple causes, including mechanical malfunctions, human mistakes, and the deterioration of aging infrastructure. Ammonia is a hazardous gas that can pose serious health risks. Exposure to low levels may cause irritation in the eyes, nose, and throat, while higher concentrations can lead to breathing difficulties, lung fluid buildup, and dead. Additionally, acute exposure can result in lasting damage to the lungs, eyes, and skin (Dongachem, 2025) and ammonia leaks can cause expensive disruptions in industrial processes. In critical situations, facilities may need to halt operations for repairs and decontamination, leading to substantial financial setbacks.

The water valve cannot be completely closed is a common plumbing problem that can result in continuous leaks. This not only wastes water but also raises utility costs over time. Persistent dripping may lead to mold growth and structural harm to walls or floors. The issue often stems from worn-out washers, sediment accumulation, or internal corrosion. Sometimes, improper installation or misalignment prevents proper closure. Routine maintenance and prompt repairs can help avoid such problems. If the valve remains defective, replacing it is usually the most effective solution.

A failure in a transformer's electrical system refers to its inability to operate efficiently due to defects or malfunctions within its electrical components. These failures often result from insulation degradation, short circuits, or other electrical faults. The consequences can range from reduced performance and efficiency to severe hazards such as explosions or fires. Transformers are very important to electrical infrastructure, enabling efficient power transmission and distribution by adjusting voltage levels. Although they are designed for durability and reliability, they can still experience failures. Electrical system failures are especially severe, as they can result in major power outages, equipment damage, and significant safety risks. Such failures can disrupt the entire electrical network of the businesses.

Water pump failure refers to the inability of the pump to circulate water effectively, which can disrupt cooling, irrigation, or other water-dependent systems. Common causes include mechanical wear, seal or bearing failure, corrosion, clogged impellers, or motor malfunctions. Symptoms may include overheating, unusual noises, leaks, or reduced water flow. If not addressed promptly, pump failure can lead to system damage, reduced efficiency, or even complete operational shutdown.

The 4.3 potential failure modes as shown in Table 4.5 will be used in the FMEA. The result shows the severity, occurrence, and detection of each risk in the list, then we can obtain FMEA result as provide recommended actions. The result is shown in Table 4.6-4.8. by calculating Risk Priority Number (RPN) using formula:

**RPN** = Severity**(S)** x Occurrence**(O)** x Detection **(D)**

**Table 4.6** List of operation risks and problems of ice manufacturing industry

| FAILURE MODE AND EFFECTS ANALYSIS | | | | | |
|---|---|---|---|---|---|
| **Potential Failure Mode** | **Potential Effect(s) of Failure** | **S** | **Potential Cause(s)** | **O** | **D** |
| Groundwater transport pipe leaks, clogged pipe | Make the water unclean, wastewater | 5 | Lack of inspection and maintenance | 4 | 3 |
| Ammonia pipe leak | Causing chemical pollution in the surrounding area | 9 | Lack of inspection and maintenance | 3 | 5 |
| Failure of water pump | Can't pump water into pond or tank | 6 | water pump machine failure | 2 | 4 |
| The water valve cannot be completely closed | Can’t retention clean water in tank and wasting water | 6 | expired of water valve | 6 | 3 |
| Failure of transformer electrical system | Can’t use electrical devices | 8 | The machine is broken or a short circuit | 3 | 2 |

After using Failure mode and effects analysis (FMEA) to identify and analyze from observation and interview with expert or business owner of ice manufacturers, the risk can be ranked by RPN value as shown in Table 4.7. And recommended actions for each risk as shown in Table 4.8.

**Table 4.7** Ranked list of operation risks and problems of ice manufacturing industry

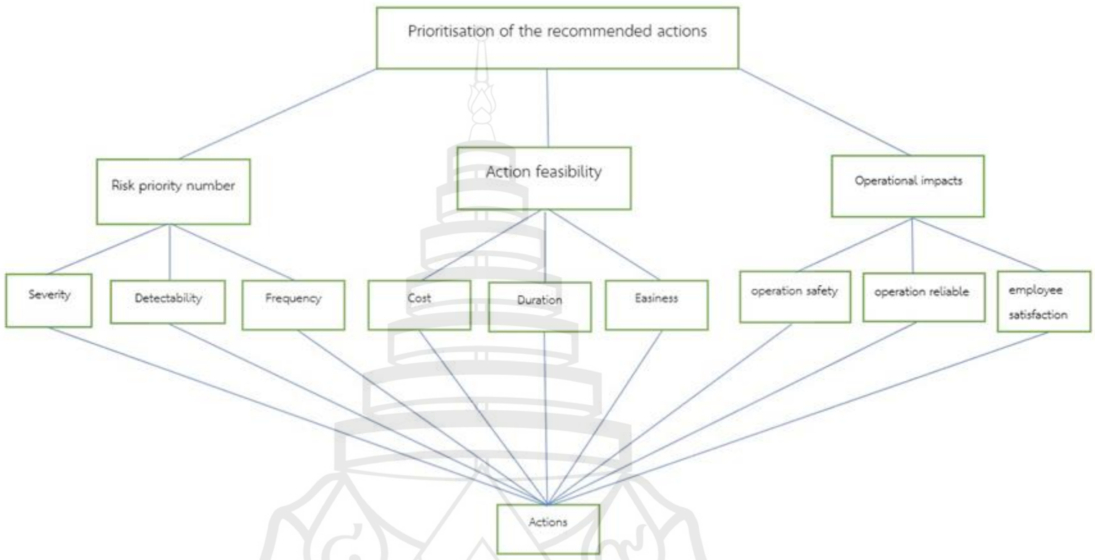
| No. | List of operation risks and problems of ice manufacturing industry | RPN |
|---|---|---|
| 1 | Ammonia pipe leak | 135 |
| 2 | The water valve cannot be completely closed | 108 |
| 3 | Groundwater transport pipe leaks, clogged pipe | 60 |
| 4 | Failure of water pump | 48 |
| 5 | Failure of transformer electrical system | 48 |

**Table 4.8** Selected risks and recommended actions in the ice manufacturers process

| **Failure mode/ Risk** | **Recommended actions** |
|---|---|
| F1. Groundwater transport pipe leaks, clogged pipe | R1. Set a schedule to check the conditions and maintain |
| F2. Ammonia pipe leak | R2. Create a specialized team to oversee, prevent, and control risks.<br>R3. Set up Portable gas detector<br>R4. Choose the correct seamless pipe and pressure resistant pipe (according to the standard)<br>R.5.Control the construction process correctly according to engineering principles with certification from an engineer |
| F3. Faliure of water pump | R6. Prepare backup pump routes<br>R7. Prepare backup pump equipment |
| F4. The water valve cannot be completely closed | R8. Post a warning sign for employees |
| F5. Faliure of transformer electrical system | R9. Prepare a backup electrical generator<br>R10.Always follow the news from Provincial Electricity Authority |

This model introduces the simple step to evaluate risks faced by ice manufacturers, provide feasibility actions, and assess the impact of those actions in the ice manufacturing operation.

Additionally, the ice manufacturers used their expert judgment to prioritize the actions independently of other methods. This approach aimed to validate the findings from the RPN and MCDM methods. Subsequently, the results from the three approaches (expert judgment, RPN, and MCDM methods) were compared.




**Source** Researcher (2024)

**Figure 4.5** Prioritization of the recommended actions

The seven ice manufacturers provided the local weight for each main criteria and sub-criteria for conducting MCDM method as shown in Chapter 5. The local weight values come from an expert judgment approach from business owners. The calculation of the global weight using local weight of main criteria multiply by local weight of sub-criteria. Table 11-18 shows the results from expert judgment to give weight to 3 main criteria and 9 sub-criteria.

## 4.3 Results

The interview with experts revealed several risks that consumable ice manufacturers face found that groundwater transport pipe leaks, clogged pipes, ammonia pipe leaks, water pump failures, the water valve cannot be completely closed, and transformer electrical system failures. These risks were identified as critical in the ice manufacturing process and can significantly impact operations. To prioritize these risks, the study applied Failure Mode and Effects Analysis (FMEA) to evaluate each risk's severity, occurrence, and detectability, resulting in a Risk Priority Number (RPN) for each risk. According to the FMEA analysis, the highest RPN value was assigned to ammonia pipe leaks, followed by issues with the water valve that cannot be fully closed, groundwater transport pipe leaks, clogged pipes, water pump failures, and finally, transformer electrical system failures.

In addition to FMEA, the study used a Multi-Criteria Decision-Making (MCDM) approach to rank and prioritize actions based on various criteria. The seven ice manufacturers provided local weights for each of the main and sub-criteria based on their relevance and importance to the business. These local weights were then used to calculate global weights, which were obtained by multiplying the local weight of each main criterion by the local weight of the corresponding sub-criterion. The results of this analysis were presented in Tables 4.9-4.18, which showed the global weights for each risk factor and helped to prioritize actions. This comprehensive approach allowed for a more precise risk assessment, facilitating better decision-making for risk management in the ice manufacturing industry. The combination of FMEA and MCDM methods helped ensure that the most critical risks were addressed first, leading to more effective risk mitigation strategies.

**Table 4.9** The local weight U.P.ICE (2003) LIMITED PARTNERSHIP

| U.P.ICE (2003) LIMITED PARTNERSHIP | | | | |
|---|---|---|---|---|
| **Main criteria** | **Local weight** | **Sub-criteria** | **Local weight** | **Global weight** |
| C1. Risk priority number | 0.4 | C1.1. Severity | 0.45 | 0.18 |
| | | C1.2. Occurrence | 0.20 | 0.08 |
| | | C1.3. Detectability | 0.35 | 0.14 |
| C2. Action feasibility | 0.5 | C2.1. Cost | 0.40 | 0.20 |
| | | C2.2. Duration | 0.35 | 0.18 |
| | | C2.3 Easiness | 0.25 | 0.13 |
| C3. Operational impacts | 0.1 | C3.1 Operation safety | 0.50 | 0.05 |
| | | C3.2 Operation reliable | 0.30 | 0.03 |
| | | C3.3 Employee satisfaction | 0.20 | 0.02 |

**Table 4.10** The local weight SAKOL ICEBERG CO., LTD.

| SAKOL ICEBERG CO., LTD. | | | | |
|---|---|---|---|---|
| **Main criteria** | **Local weight** | **Sub-criteria** | **Local weight** | **Global weight** |
| C1. Risk priority number | 0.4 | C1.1. Severity | 0.40 | 0.16 |
| | | C1.2. Occurrence | 0.30 | 0.12 |
| | | C1.3. Detectability | 0.30 | 0.12 |
| C2. Action feasibility | 0.2 | C2.1. Cost | 0.20 | 0.04 |
| | | C2.2. Duration | 0.40 | 0.08 |
| | | C2.3 Easiness | 0.40 | 0.08 |
| C3. Operational impacts | 0.4 | C3.1 Operation safety | 0.50 | 0.20 |
| | | C3.2 Operation reliable | 0.30 | 0.12 |
| | | C3.3 Employee satisfaction | 0.20 | 0.08 |

**Table 4.11** The local weight KO TI NAMKHEANG LIMITED PARTNERSHIP

| KO TI NAMKHEANG LIMITED PARTNERSHIP | | | | |
|---|---|---|---|---|
| **Main criteria** | **Local weight** | **Sub-criteria** | **Local weight** | **Global weight** |
| C1. Risk priority number | 0.50 | C1.1. Severity | 0.30 | 0.15 |
| | | C1.2. Occurrence | 0.40 | 0.20 |
| | | C1.3. Detectability | 0.30 | 0.15 |
| C2. Action feasibility | 0.30 | C2.1. Cost | 0.40 | 0.12 |
| | | C2.2. Duration | 0.20 | 0.06 |
| | | C2.3 Easiness | 0.40 | 0.12 |
| C3. Operational impacts | 0.40 | C3.1 Operation safety | 0.40 | 0.16 |
| | | C3.2 Operation reliable | 0.40 | 0.16 |
| | | C3.3 Employee satisfaction | 0.20 | 0.08 |

**Table 4.12** The local weight D.D. DRINRK LTD., PARTNERSHIP

| **D.D DRINRK LTD., PARTNERSHIP** | | | | |
|---|---|---|---|---|
| **Main criteria** | **Local weight** | **Sub-criteria** | **Local weight** | **Global weight** |
| C1. Risk priority number | 0.35 | C1.1. Severity | 0.40 | 0.14 |
| | | C1.2. Occurrence | 0.20 | 0.07 |
| | | C1.3. Detectability | 0.40 | 0.14 |
| C2. Action feasibility | 0.35 | C2.1. Cost | 0.50 | 0.18 |
| | | C2.2. Duration | 0.10 | 0.04 |
| | | C2.3 Easiness | 0.40 | 0.14 |
| C3. Operational impacts | 0.30 | C3.1 Operation safety | 0.40 | 0.12 |
| | | C3.2 Operation reliable | 0.50 | 0.15 |
| | | C3.3 Employee satisfaction | 0.10 | 0.03 |

**Table 4.13** The local weight SAKOL ICE-DRINKING WATER (1980) COMPANY LIMITED

| **SAKOL ICE-DRINKING WATER (1980) COMPANY LIMITED** | | | | |
|---|---|---|---|---|
| **Main criteria** | **Local weight** | **Sub-criteria** | **Local weight** | **Global weight** |
| C1. Risk priority number | 0.40 | C1.1. Severity | 0.45 | 0.18 |
| | | C1.2. Occurrence | 0.20 | 0.08 |
| | | C1.3. Detectability | 0.35 | 0.14 |
| C2. Action feasibility | 0.35 | C2.1. Cost | 0.40 | 0.14 |
| | | C2.2. Duration | 0.35 | 0.12 |
| | | C2.3 Easiness | 0.25 | 0.09 |
| C3. Operational impacts | 0.25 | C3.1 Operation safety | 0.50 | 0.13 |
| | | C3.2 Operation reliable | 0.30 | 0.08 |
| | | C3.3 Employee satisfaction | 0.20 | 0.05 |

**Table 4.14** The local weight RATANASUWAN ICE FACTORY LIMITED PARTNERSHIP

| RATANASUWAN ICE FACTORY LIMITED PARTNERSHIP | | | | |
|---|---|---|---|---|
| **Main criteria** | **Local weight** | **Sub-criteria** | **Local weight** | **Global weight** |
| C1. Risk priority number | 0.40 | C1.1. Severity | 0.40 | 0.16 |
| | | C1.2. Occurrence | 0.30 | 0.12 |
| | | C1.3. Detectability | 0.30 | 0.12 |
| C2. Action feasibility | 0.20 | C2.1. Cost | 0.20 | 0.04 |
| | | C2.2. Duration | 0.40 | 0.08 |
| | | C2.3 Easiness | 0.40 | 0.08 |
| C3. Operational impacts | 0.40 | C3.1 Operation safety | 0.50 | 0.20 |
| | | C3.2 Operation reliable | 0.30 | 0.12 |
| | | C3.3 Employee satisfaction | 0.20 | 0.08 |

**Table 4.15** The local weight HongSawan LIMITED PARTNERSHIP

| HongSawan LIMITED PARTNERSHIP | | | | |
|---|---|---|---|---|
| **Main criteria** | **Local weight** | **Sub-criteria** | **Local weight** | **Global weight** |
| C1. Risk priority number | 0.30 | C1.1. Severity | 0.70 | 0.21 |
| | | C1.2. Occurrence | 0.10 | 0.03 |
| | | C1.3. Detectability | 0.20 | 0.06 |
| C2. Action feasibility | 0.30 | C2.1. Cost | 0.40 | 0.12 |
| | | C2.2. Duration | 0.10 | 0.03 |
| | | C2.3 Easiness | 0.50 | 0.15 |
| C3. Operational impacts | 0.40 | C3.1 Operation safety | 0.60 | 0.24 |
| | | C3.2 Operation reliable | 0.30 | 0.12 |
| | | C3.3 Employee satisfaction | 0.10 | 0.04 |

**Table 4.16** The global weights of all criteria

| The global weights of all criteria | | | | |
|---|---|---|---|---|
| **Main criteria** | **Local weight** | **Sub-criteria** | **Local weight** | **Global weight** |
| C1. Risk priority number | 0.39 | C1.1. Severity | 0.44 | 0.17 |
| | | C1.2. Occurrence | 0.24 | 0.10 |
| | | C1.3. Detectability | 0.31 | 0.12 |
| C2. Action feasibility | 0.31 | C2.1. Cost | 0.36 | 0.11 |
| | | C2.2. Duration | 0.27 | 0.09 |
| | | C2.3 Easiness | 0.37 | 0.12 |
| C3. Operational impacts | 0.32 | C3.1 Operation safety | 0.49 | 0.16 |
| | | C3.2 Operation reliable | 0.34 | 0.11 |
| | | C3.3 Employee satisfaction | 0.17 | 0.06 |

**Note** The local weight summary does not equal 1 because the average weight for all seven ice manufacturers has been rounded up.

The seven ice manufacturers were asked to assign a numerical rating between 1 and 5 for each recommended action related to various sub-criteria, reflecting how important or feasible each action was from their perspective. These ratings, which are shown in Table 4.17, provided a quantitative basis for evaluating each proposed action. The data were then used in the Multi-Criteria Decision-Making (MCDM) method to assess and rank the actions based on their effectiveness in mitigating risks. Using these ratings, the Risk Priority Number (RPN) for each action was calculated. The RPN allowed for the comparison of the different actions by factoring in the severity, occurrence, and detectability of risks. The results helped identify which actions should be prioritized based on their potential impact on improving safety and reducing operational risks in the ice manufacturing process.

To prioritize recommended actions, this study applied the concept of Failure Mode and Effects Analysis (FMEA), a widely used risk assessment tool in quality management systems. The prioritization is based on the calculation of the Risk Priority

Number (RPN), which is derived from three key factors: Severity (S), Occurrence (O), and Detectability (D). The standard formula is as follows:

RPN = S × O × D

However, to ensure a more comprehensive evaluation of the actions proposed, additional decision-making criteria were incorporated. These include aspects of Action Feasibility, which assess the practicality and ease of implementation, and Operational Impacts, which consider the severity, frequency, and effectiveness of operational outcomes. The operational criteria are represented as:

Operational Impacts = Operational Severity (OS) x Operational Rate (OR) x Operational Effectiveness (OE)

To integrate all relevant factors into a unified decision-making framework, the study adopted a multi-criteria aggregation approach. A composite score was calculated by multiplying all ten criteria values provided by industry experts:

Multiply all ten criteria score = S × O × D × C × E × D × OS × OR × OE × R

This extended formula aligns with the principles of Multi-Criteria Decision Making (MCDM), which allows for simultaneous evaluation of diverse criteria in complex decision environments. The resulting scores were then used to generate a ranking of the recommended actions, with lower scores indicating higher priority for implementation.

This enhanced version of FMEA is consistent with prior academic research that recommends integrating additional variables such as cost, feasibility, and operational consequences to improve the practical relevance and robustness of risk evaluations (Chin et al., 2009; Liu et al., 2013).

Table 4.17 presents the composite scores and priority rankings of recommended actions based on the assessment provided by seven ice manufacturing companies. The total score for each recommendation was calculated by multiplying ten evaluation criteria. These included the traditional FMEA components Severity (S), Occurrence (O), and Detectability (D) alongside extended factors such as Cost (C), Effectiveness (E), Feasibility (D), Operational Severity (OS), Operational Rate (OR), and Operational Effectiveness (OE).

**Table 4.17** The average scores and rankings provided by seven ice manufacturers

| **The average scores and rankings provided by seven ice manufacturers** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Recommended actions** | **RPN** | | | **Action feasibility** | | | **Operational impacts** | | | **Multiply all ten criteria score** | **Ranking** |
| | **S** | **O** | **D** | **C** | **E** | **D** | **OS** | **OR** | **ES** | | |
| R1. | 2 | 3 | 4 | 2 | 5 | 4 | 5 | 4 | 2 | 38.40 | 2 |
| R2. | 5 | 1 | 1 | 4 | 2 | 4 | 3 | 4 | 3 | 5.76 | 10 |
| R3. | 5 | 1 | 1 | 4 | 4 | 3 | 5 | 5 | 5 | 30.00 | 4 |
| R4. | 5 | 1 | 1 | 4 | 4 | 3 | 5 | 5 | 4 | 24.00 | 5 |
| R5. | 5 | 1 | 1 | 4 | 3 | 3 | 5 | 4 | 5 | 18.00 | 6 |
| R6. | 3 | 2 | 1 | 3 | 4 | 2 | 5 | 5 | 3 | 10.80 | 8 |
| R7. | 4 | 2 | 1 | 3 | 4 | 2 | 5 | 5 | 3 | 14.40 | 7 |
| R8. | 3 | 3 | 2 | 1 | 5 | 5 | 5 | 5 | 3 | 33.75 | 3 |
| R.9 | 5 | 2 | 5 | 5 | 3 | 2 | 5 | 3 | 3 | 67.50 | 1 |
| R.10 | 5 | 2 | 5 | 1 | 1 | 5 | 5 | 4 | 2 | 10.00 | 9 |

However, multiplying all ten integer-based criteria yields relatively large numbers. For example, in the case of recommendation R1, the unadjusted score is:

R1 = 2 × 3 × 4 × 2 × 5 × 4 × 5 × 4 × 2 = 38,400

To enhance interpretability and allow for easier comparison, the scores were normalized by dividing each raw total by a constant factor (1,000). This normalization does not affect the relative differences or rankings between the alternatives but helps present the data in a more digestible and visually balanced form. For instance, the adjusted score for R1 is displayed as 38.40, which corresponds to the original raw score of 38,400 divided by 1,000.

This normalization technique aligns with common practices in multi-criteria decision-making (MCDM) literature, where large multiplicative values are scaled to improve clarity in reporting while maintaining the integrity of relative comparisons. It supports decision-makers in evaluating the feasibility and impact of each proposed action more effectively

# CHAPTER 5

# CONCLUSION AND DISCUSSION

## 5.1 Discussion

Seven out of the 14 consumable ice manufacturers in Chiang Rai were selected for the study, with the criterion that their production capacity exceeds 150 tons per day. The risk factor analysis, conducted through observations and interviews with industry experts, identified several key risks affecting the consumable ice manufacturing sector. These include groundwater transport pipe leaks, clogged pipes, ammonia pipe leaks, water pump failures, issues with water valves not closing properly, and transformer electrical system malfunctions.

To evaluate and prioritize these risks, FMEA was used. The results ranked the risks based on their RPN values. The analysis showed that ammonia pipe leaks had the highest RPN, marking it as the most critical risk, followed by issues with water valves not closing properly, groundwater transport pipe leaks, clogged pipes, water pump failures, and transformer electrical system failures. This ranking offers a comprehensive overview of the risks and their implications for the industry, and it also includes 10 recommended actions, as shown in Chapter 4.

After identifying and ranking the risks with the greatest impact on the consumable ice manufacturing business, MCDM methods were applied to provide recommendations. The study results include ten recommendations along with the weights for each recommendation, as detailed in Table 5.9.

This study's findings align with existing research on risk management in industrial settings, particularly in ammonia refrigeration systems. The use of FMEA to prioritize risks, such as ammonia pipe leaks, is supported by previous studies and also emphasizes the importance of leak detection and safety measures (Hasson et al., 2019). Additionally, the focus on water system and electrical maintenance is consistent with findings and highlight the need for regular equipment checks and backup systems (Yang et al., 2017). The application of MCDM for prioritizing actions reflects broader trends in risk management (Zavadskas et al., 2012). Lastly, the recommendation for continuous monitoring and adapting to industry changes mirrors insights and stressing the importance of ongoing updates to risk strategies (Neumeyer et al., 2020). Overall, the study contributes to the academic discourse by advocating for proactive, data-driven, and adaptive risk management practices in consumable ice manufacturing.

## 5.2 Conclusion

In this study, FMEA was used to calculate and rank risks based on RPN values, identifying, and prioritizing the risk factors faced by the consumable ice manufacturing industry. Additionally, 10 recommendations were provided. Nine criteria and the recommendations were weighed using the MCDM method, which was then applied to prioritize the actions. The results showed that ammonia pipe leaks are the most significant concern for consumable ice manufacturers. This risk is particularly challenging to detect, occurs frequently, and leads to increased production costs. Furthermore, ammonia pipe leaks pose the greatest severity risk to the production line, as ammonia is a highly dangerous chemical that can cause severe injury or even death.

To ensure safe and efficient ice production operations, several critical recommendations have been identified for various system components. For ammonia pipe leak prevention, it is crucial to establish a specialized risk management team, implement portable gas detectors, use standard-compliant seamless pressure-resistant pipes, and ensure proper construction oversight by certified engineers. Regarding water system issues, which directly impact both ice production costs and equipment longevity, the facility should address water valve closure problems and implement preventive measures for groundwater transport pipe leaks. This can be achieved by creating a dedicated maintenance team and ensuring correct pipe installation with appropriate water pressure monitoring. Although water pump and transformer electrical system failures present operational risks, their low RPN values indicate that these issues occur infrequently and are easily detected. Nevertheless, recommended actions include regular equipment maintenance, the installation of appropriate water pumps with backup systems, and preparation for power disruptions by installing backup electrical generators and maintaining communication with the Provincial Electricity Authority.

To support effective risk mitigation, this study employed a modified version of Failure Mode and Effects Analysis (FMEA) to prioritize recommended actions. The traditional FMEA method calculates a Risk Priority Number (RPN) using three primary factors: Severity (S), Occurrence (O), and Detectability (D). The RPN is determined by the following formula:

$$RPN = S \times O \times D$$

(IEC, 2006; SAE, 2009)

While the original RPN method provides a useful basis for risk ranking, it has been criticized for limitations in scope—particularly its inability to account for other practical decision-making factors (Liu et al., 2013). To overcome these limitations and allow for a more holistic evaluation, this study incorporates additional criteria based on expert judgment.

The combination of these ten criteria enables a multi-faceted evaluation of each proposed action. A composite score was calculated by multiplying all ten factors, as shown below:

$$\text{Composite Score} = S \times O \times D \times C \times E \times D \times OS \times OR \times OE \times R$$

To simplify interpretation, the composite scores were normalized (e.g., divided by 1,000 or scaled) and used to rank the actions from highest to lowest priority. Lower scores represent higher-priority actions due to lower associated risks and greater feasibility and impact.

This extended scoring system aligns with Multi-Criteria Decision Making (MCDM) principles, which are widely used to support complex decisions involving both qualitative and quantitative factors. The approach also reflects recommendations from recent studies advocating for improved FMEA models that incorporate additional strategic and operational dimensions (Chin et al., 2009).

## 5.3 Suggestion

### 5.3.1 Suggestion for Further Study

Data collection in the consumable ice industry is challenging due to seasonal fluctuations in demand. Future research should segment data by season to better capture these variations and associated risks and This study relied on expert interviews, potentially overlooking some risks. Further research should involve a wider range of employees, such as factory workers, to improve risk identification and recommendations.

### 5.3.2 Suggestion of This Study Results

To apply the study's findings in the consumable ice manufacturing industry, integrate FMEA into daily operations for risk assessment and prioritize risks like ammonia leaks, water system issues, and electrical failures. Establish a dedicated risk management team focused on ammonia safety, ensure ongoing training, and implement robust safety measures, such as portable gas detectors and high-quality pipes. Improve water system maintenance with regular inspections and pressure monitoring and maintain electrical systems with backup pumps and generators. Use MCDM to prioritize actions and continuously assess the effectiveness of risk mitigation strategies. Stay updated on industry trends and adapt your strategies to address emerging risks and regulatory changes.

Table 4.17 presents the composite scores and rankings of the proposed actions. From the analysis, [insert the highest-ranked action] received the lowest composite score, indicating its high suitability for immediate implementation. Conversely, [insert lowest-ranked action] exhibited the highest score, suggesting lower feasibility or effectiveness.

The results suggest that actions with moderate RPN values can sometimes be more desirable when combined with high feasibility, low cost, and strong operational impact. This observation confirms the value of expanding beyond conventional FMEA criteria for better decision support in real-world applications.

## 5.4 Research Limitations

### 5.4.1 Seasonal Variations in Consumer Demand

The demand for consumable ice is highly influenced by seasonal changes. For example, during summer, demand spikes due to higher temperatures, while in colder months, demand may decline. This variation makes it challenging to analyze risks based on yearly aggregated data, as it may mask seasonal trends. This research used data collected throughout the entire year to get an overall picture of industry risks. However, future studies should segment data by season to identify seasonal-specific risks and trends. This approach would help businesses better prepare for fluctuations in demand, supply chain disruptions, and operational risks unique to different seasons.

### 5.4.2 Application of AIAG & VDA FMEA (1st Edition, 2019)

The AIAG & VDA FMEA (Failure Modes and Effects Analysis) 1st Edition (2019) introduced a more structured approach to risk assessment, including a new "Action Priority (AP)" ranking system. This method aims to help industries prioritize risks more effectively. However, this study did not extensively explore the applicability of this framework in the consumable ice industry. Future research should analyze whether these risk assessment techniques are beneficial for ice manufacturers, how well they integrate with existing risk management practices, and whether they help in reducing operational risks. A detailed case study or industry-wide implementation analysis could provide deeper insights into its advantages and limitations.

### 5.4.3 Scope of Observations and Interviews

This research primarily gathered data through observations and interviews with experts and business owners in the ice manufacturing industry. While these individuals provide valuable insights into strategic and operational risks, other crucial perspectives—such as those from factory workers, machine operators, and logistics personnel—were not considered. These personnel are directly involved in daily operations and may identify risks that higher management overlooks. For example, safety hazards, machine inefficiencies, or quality control issues might be more apparent to frontline workers. Future studies should include interviews and observations from a diverse range of employees to improve risk identification and develop more effective solutions.

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# APPENDIX A

## FACTORY PROFILE

| No. | Name of Factory | Type of Business | Address | Telephone |
|---|---|---|---|---|
| 1 | HongSawan LIMITED PARTNERSHIP | Limited Partnership | 456 Moo 3, Ban Du Subdistrict, Mueang District, Chiang Rai 57100 | 053-123456 |
| 2 | U.P.ICE (2003) LIMITED PARTNERSHIP | Limited Partnership | 78 Moo 5, Rim Kok Subdistrict, Mueang District, Chiang Rai 57000 | 053-234567 |
| 3 | SAKOL ICEBERG CO., LTD. | Company Limited | 12 Moo 2, Wiang Subdistrict, Mueang District, Chiang Rai 57000 | 053-345678 |
| 4 | KO TI NAMKHEANG LIMITED PARTNERSHIP | Limited Partnership | 89/1 Mae Korn Subdistrict, Mueang District, Chiang Rai 57100 | 053-456789 |
| 5 | D.D DRINK LTD., PARTNERSHIP | Limited Partnership | 102 Moo 4, Pa O Don Chai Subdistrict, Mueang District, Chiang Rai 57000 | 053-567890 |
| 6 | SAKOL ICE-DRINKING WATER (1980) COMPANY LIMITED | Company Limited | 200 Moo 6, Ban Du Subdistrict, Mueang District, Chiang Rai 57100 | 053-678901 |
| 7 | RATANASUWAN ICE FACTORY LIMITED PARTNERSHIP | Limited Partnership | 55 Moo 1, Mae Yao Subdistrict, Mueang District, Chiang Rai 57000 | 053-789012 |

# APPENDIX B

# PUBLICATION RECORD

## Risk Assessment Framework for Consumable Ice Manufacturing Industry

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**Abstract**

The demand for ice in Thailand has been increasing, driven by global warming and the post-COVID-19 expansion. Consequently, Thai consumers are consuming more ice into their beverages. Despite this growing demand, the number of new ice factories has been declining since 2016. This study aims to identify and rank the risks faced by the ice manufacturing industry. Data was collected through observations and interviews, and the Failure Mode and Effects Analysis (FMEA) was employed to assess and prioritize these risks. The findings from the FMEA were then used to formulate recommendations using Multi-Criteria Decision-Making Method (MCDM) for various main and sub-criteria. The study proposes actionable recommendations considering feasibility and operational impact to support the consumable ice manufacturing industry.

**Keywords:** FMEA, MDCM, COVID-19, Risk Assessment

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**Introduction**

The tropical moist climate and rapid environmental changes are causing temperatures to rise. In countries with hot climates, the tendency to consume ice has increased (Nakornsri, Suntivarakorn, & Thanutwutthigorn, 2014), and Thai people typically add ice to almost all beverages. Consequently, the value of the consumable ice market correlates with the beverage market size. However, the demand for consumable ice varies across different regions of Thailand. According to the Climatological Center report the average winter temperature in the northern provinces of Thailand is 19.9 degrees Celsius, influenced by a cold front from China. This directly impacts the demand for certain beverages and consumable ice. In 2020, Data for Thai reported 1,235 ice factories in Thailand both operational and non-operational, with 109 factories, or 11.33% of the total, located in the northern part of the country. Between 2008 and 2016, the trend for new businesses in the ice factory sector was steadily increasing but began to decline in 2016, as shown in Figure 1. These numbers indicate that certain risks are impacting the consumable ice factory business.

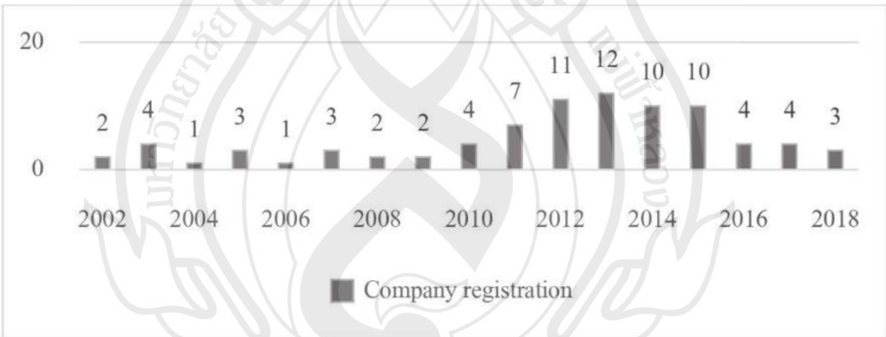


**Figure 1** Amount of new ice manufacturing registration in northern Thailand between 2008-2018

(Source: DATA for Thai, 2024)

During the COVID-19 outbreak in 2019, the Thai capital market was significantly negatively impacted. The interdependence between various industries noticeably decreased, leading to heightened anxiety among new investors, which severely limited their investments during this period. This resulted in a continued decline in the number of new businesses during this time (Inchupong, 2022).

The Department of Provincial Administration in Thailand reported an estimated population of 66.16 billion in 2022, with the country experiencing a tropical moist climate. Consequently, beverage and ice consumption in Thailand remains strong and continues to grow consistently each year. The beverage industry is one of the largest industries in Thailand. According to The Business Research Company, the online food and beverage retail sector has seen remarkable expansion lately. Starting at $69.77 billion in 2023, the market is projected to reach $85.25 billion in 2024, reflecting a 22.2% CAGR. This strong momentum is expected to continue, with forecasts showing the market reaching $180.77 billion by 2028, maintaining CAGR of 20.7%. In 2012, worldwide consumption of non-alcoholic beverages amounted to 601.59 billion liters and is expected to grow to 803.2 billion liters by 2021, as shown in Figure 2. These figures indicate a steady increase in the consumption of non-alcoholic beverages.

In contrast with non-alcoholic beverage, worldwide consumption of alcoholic beverages was worth 286.72 billion liters and continued to grow to 304.98 billion liters in 2019 and decline to 279.28 billion liters in 2020 during COVID-19, increasing to 280.25 billion liters in 2021, as shown in Figure 3. The value shows that consumption of alcoholic beverages is increasing after the COVID-19 situation.

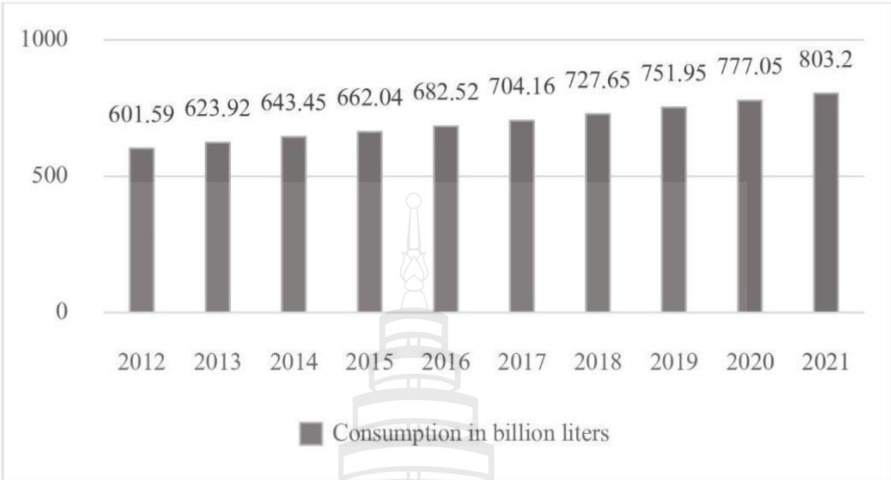


**Figure 2** Worldwide Consumption of Non-alcoholic beverage between 2012- 2021

(Source: Statista, 2024)

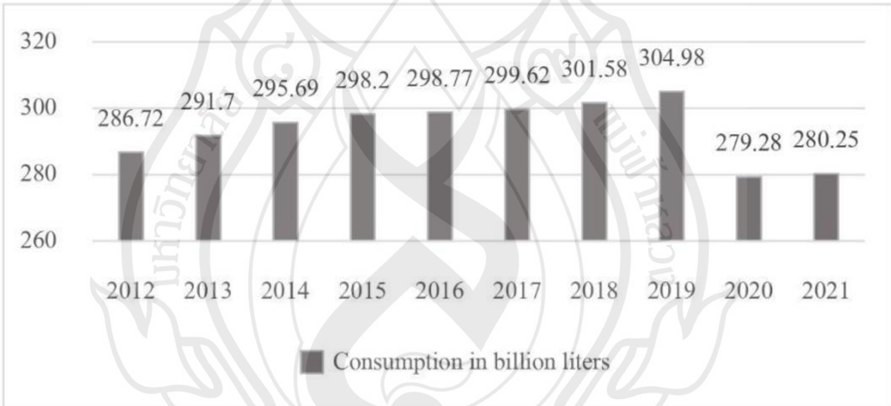


**Figure 3** Worldwide Consumption of Alcoholic beverage from 2012-2021

(Source: Statista, 2024)

According to Figures 2 we can see an increasing of non-alcoholic beverage consumption, in contrast with Figure 3, it shows that an alcoholic beverage consumption was decrease during the COVID-19 outbreak. However, the trend of beverage consumption in Thailand is continuously increasing for both non-alcoholic and alcoholic beverages. In general, Thai people typically add ice to almost all beverages, directly impacting ice consumption in the country. Despite this growing demand, Figure 1 indicates that the number of consumable ice manufacturers significantly decreased after 2015. Therefore, it can be inferred that the consumable ice manufacturing industry faces certain risk factors. This study aims to assess, identify, and provide suggestions and recommendations, as well as develop a new assessment model for the consumable ice manufacturing industry. By applying Failure Mode and Effects Analysis (FMEA) and Multiple-Criteria Decision Making (MCDM), this study focuses on seven out of 14 consumable ice manufacturing companies in 18 districts of Chiang Rai Province, as shown in Figure 4.

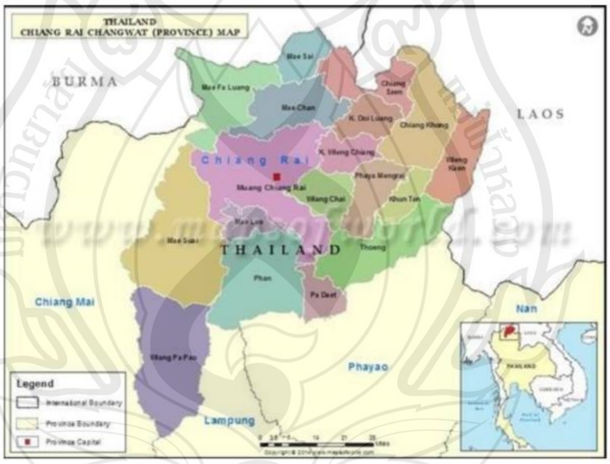


**Figure 4** 18 districts of Chiang Rai province Map (Source: Maps of World, 2024)

**Objective of the Study**

1. To identify and assess the risk factors faced by the consumable ice manufacturing industry.

2 . To provide suggestions, recommendations, and a new assessment model for the consumable ice manufacturing industry.

This study aims to identify risks in the consumable ice manufacturing industry. The population for the study consists of seven out of 14 consumable ice manufacturers in Chiang Rai, selected based on their daily production capacity of over 150 tons. Risk identification is conducted through observations and interviews with experts, including factory owners, production managers, and experienced engineers. FMEA is employed to analyze, identify, and rank risks based on the gathered information. Subsequently, the identified risk factors are assessed and evaluated using MCDM. Ultimately, a risk assessment framework for consumable ice manufacturing will be developed.

**Literature Review**

**The risk of consumable ice Manufacturing industry**

Operational risk identification can be categorized into two main approaches: internal and external methods. This identification process is crucial for effective risk management as it enables the detection of risk sources, which can be classified into three main categories: human factors, procedural elements, and technological aspects. These sources of risk can originate either from within the organization (internal) or from outside factors (external). (Eaton, 2005)

The consumable ice manufacturing industry is facing with sanitation problem. Some people avoid drinking beverage which adding ice in less-developed countries or developing countries. Hence ,ice may and does cause illnesses caused by food in developed nations like the United States. Many difficulties may be avoided by managing ice carefully. However, the ice must be safe to begin with. Most commercial ice is produced using ice machines or ice makers that are permanently linked to a water supply. The ice machine operator is responsible for ensuring the safety of the water supply (Powitz, 2013).

**Risk Management**

According to ISO 31000, risk Management is a coordinated use of resources to minimize, manage, and control the probability and/or effect of unfavorable occurrences or to maximize the implementation of possibilities. Risk management is the method and process to prepare, manage and deal with the uncertainty situation which is the case of loss in the organization. It is an integrated system that includes the study of actions and behaviors, the design of safety and emergency procedures, and different financial, legal, and insurance concerns. Operations are evaluated on their benefits to the company in relation to the risk of loss of human, financial, property, or reputation resources. The review requires extensive engagement with the organization's programs, property, employees, and legal departments. (Herman, Head, Jackson, & Fogarty, 2004)

Risk management enables management to accomplish its responsibilities with confidence, knowing that the business is aware of and effectively managing risks that can influence goal. which requires greater scrutiny than ever before on how risk is actively addressed and managed, enterprise risk management facilitates the development of stakeholder trust and confidence (Committee of Sponsoring Organizations of the Treadway Commission, 2017).

The objective of risk management is to establish a framework that enables businesses to deal with risk and uncertainty. Risks exist in nearly all financial and economic activities of businesses. The process of risk identification, assessment, and management is an integral part of a company's strategic development; it must be designed and planned by the board of directors. An integrated approach to risk management must evaluate, control, and monitor all risks and their inter dependencies to which the organization is exposed. (Dionne, 2013).

**FMEA method**

In the late 1940s, the U.S. military made the first well- known application of FMEA. The military developed this technique to eliminate sources of variance and corresponding potential problems in the manufacturing of weapons, and it proved to be a highly successful technique Further, the automobile sector was an early adopter of FMEA. Ford Motor Company led the way in the mid-1970s as an internal response to their safety and public relations concerns with the Ford Pinto. Other manufacturers in the United States, Europe, and the United Kingdom followed immediately Ford's lead. AIAG was formed in 1982 to get fierce U.S. auto industry competitors to collaborate and agree on standardized use of quality improvement tools and practices such as FMEA, statistical process control (SPC), measurement system analysis (MSA) and related practices.

FMEA defines as an analytical method that ensures potential issues are considered, which is addressed throughout the product development and production process. FMEA could also be applied to sectors from outside manufacturing. For example, FMEA might be used to evaluate the risk of an administration process or a safety system. FMEA is typically used to product design and production processes when the potential advantages are clearly and possibly considerable. (AIAG, 2008).

**MCDM method**

MCDM and VIKOR method: MCDM relates to methods and the solution of planning and decision- making issues with multiple criteria. The purpose of these methods is to select alternatives, classify them into groups, and rank them according to priority or preference. A considerable number of studies have examined the literature review related to MCDA/MCDM (Behzadian, Kazemzadeh, Albadvi, & Aghdasi, 2010)

MCDM methods have been applied and used to prioritize choices through weighing conflicting criteria. However, these methods have continued facing scrutiny regarding reliability (Asadabadi, Chang, & Saberi, 2019). MCDM methods have been implemented in various applications and identify the optimal solution in order to select the most effective choice.

FMEA using combination weighting and fuzzy MCDM method to address uncertainty in risk evaluation. The approach is applied to general anesthesia risk analysis, and sensitivity analysis and comparison analysis are conducted to validate its robustness. The proposed approach effectively assesses potential failure modes in fuzzy FMEA, aiding hospitals in identifying high-risk failure modes during general anesthesia. Sensitivity analysis and comparison with comparable methods confirm its robustness, including priority ranking of failure modes (Liu, You, Lin, & Li, 2015)

**Research Methodology**

The study focuses on seven consumable ice factories in Chiang Rai. Data collection involves observations and interviews with experts and business owners from these factories, covering common problems, operational risks, external factors, frequency, and severity levels. By using snowball sampling method, the population of 14 consumable ice manufacturers was narrowed down to a sample size of seven.

Risk factors are identified using FMEA method, which detects, evaluates, and classifies potential failures based on their impact on secondary and major failures. Information from the business owners of the seven selected factories is utilized in the FMEA to estimate and report failures across the entire design and/or process. The results aim to identify major failures, prioritize corrective actions, and categorize risks into internal and external factors and using the MCDM method to weight and provide recommendations.

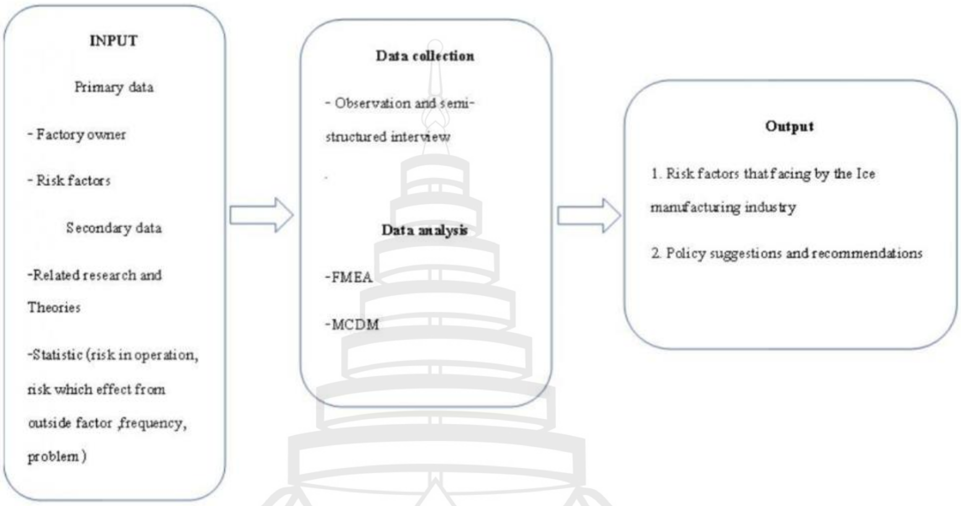


**Figure 5** Analysis Framework (Source: Researcher, 2024)

The ice manufacturing industry faces two types of risks: internal and external. Internal risks include human resources challenges like employee issues and skill gaps, along with operational problems that affect daily production. External risks consist of natural disasters, market competition, and rising costs from economic conditions.

Applying FMEA, major failures were identified and ranked. Nine criteria were then weighted using MCDM, and actions were prioritized with the MCDM method. Business owners from seven out of the 14 ice manufacturers were surveyed to evaluate the importance of three main criteria and nine sub factors. The main criteria categorized into 3 criteria which is Risk priority number , Action feasibility, Operational impacts.

**Risk priority number** are number that describes the severity of the risk, the frequency of occurrence, and the ability to detect the failure which is Severity (S) , Occurrence (O), Detectability (D).

**Action feasibilities** are feasibility of implementation, such as cost, ease of implementation, and implementation time. which is Cost (C), Easiness (E) , Duration (D).

**Operational impacts** are affects operations such as operational safety, operational reliability, and employee satisfaction, which is Operation safety, Operation reliable, Employee satisfaction.

Each criterion was categorized with a score ranking from 1 to 10, as shown in Table 1 These scores were provided by the business owners of the seven selected ice manufacturers for each suggestion.

**Table** 1 The Nine criteria and description of each score

| **Category** | **The linguistic descriptions of each score** | | | | |
|---|---|---|---|---|---|
| | **The descriptions of the scores** | | | | |
| | **1-2** | **3-4** | **5-6** | **7-8** | **9-10** |
| Severity (S) | Negligible | Minor | Moderate | Major | Catastrophic |
| Occurrence (O) | Rare | Unlikely | Possible | Likely | Almost certain |
| Detectability (D) | Very easy to detect | Easy | Moderate | Difficult | Almost impossible |
| Cost (C) | Very high | High | Moderate | Low | Very low |

| Category | The linguistic descriptions of each score | | | | |
|---|---|---|---|---|---|
| | The descriptions of the scores | | | | |
| | 1-2 | 3-4 | 5-6 | 7-8 | 9-10 |
| Easiness (E) | Almost impossible | Difficult | Moderate | Easy | Very easy to implement |
| Duration (D) | The time required very high | High | Moderate | Low | Very low |
| Operation safety | Very low | Low | Moderate | High | Very high |
| Operation reliable | Very low | Low | Moderate | High | Very high |
| Employee satisfaction | Very low | Low | Moderate | High | Very high |

This study's population includes seven out of 14 consumable ice manufacturers in Chiang Rai, selected based on a production capacity exceeding 150 tons per day. Risk identification was conducted through observations and interviews with experts and employees. The details of the selected manufacturers are shown in Table 2.

**Table 2** List of consumable ice manufacturing industry production capacity exceeds 150 tons per days

| No. | Name of manufacturers | Job Position |
|---|---|---|
| 1 | HongSawan LIMITED PARTNERSHIP | Business owner |

| No. | Name of manufacturers | Job Position |
|---|---|---|
| 2 | U.P.ICE(2003) LIMITED PARTNERSHIP | Business owner |
| 3 | SAKOL ICEBERG CO.,LTD. | Business owner |
| 4 | KO TI NAMKHEANG LIMITED PARTNERSHIP | Business owner |
| 5 | D.D DRINRK LTD., PARTNERSHIP | Business owner |
| 6 | SAKOL ICE-DRINKING WATER(1980) COMPANY LIMITED | Business owner |
| 7 | RATANASUWAN ICE FACTORY LIMITED PARTNERSHIP | Business owner |

**The Result of the Study**

Interviews with seven owners of consumable ice manufacturing facilities revealed that their operational processes are either identical or very similar. Observations and interviews conducted to identify risks faced by these manufacturers showed that the risk factors and their consequences are also similar with the literature. For internal factors, there are employees that do not follow the standard operation procedure and lack of responsibility causing the operation issues such as: water valve and ammonia pipe did not completely close or the leakage between pipeline connection. For external factor, the factory sometimes facing of electricity shortage. The major risks identified can be categorized into internal and external risks, as shown in Table 3.

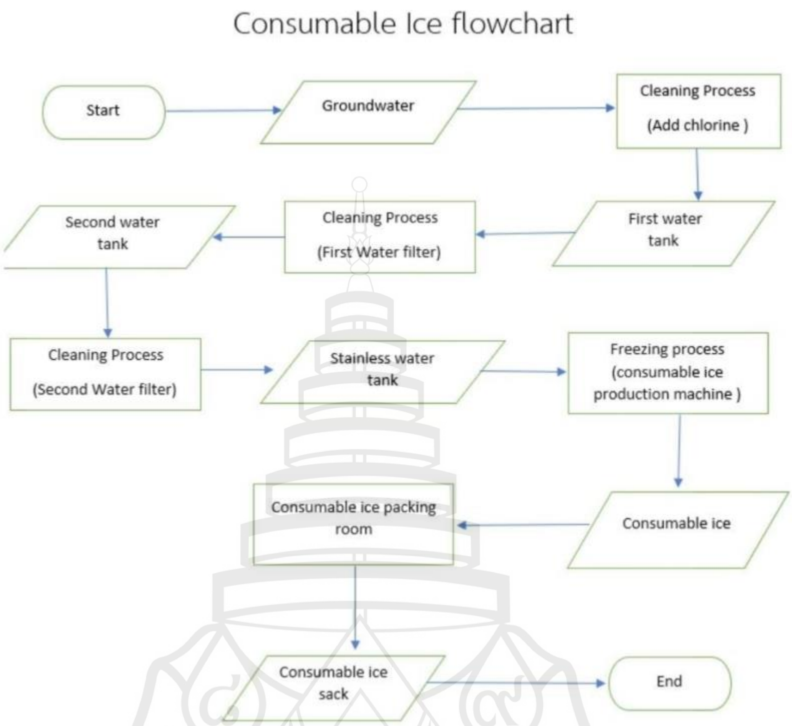


**Figure 6** Flow Chart of consumable ice manufacturing industry (Source: Researcher, 2024)

Human resource issues, such as a lack of employees, irresponsible behavior, and insufficient knowledge, pose significant threats to the ice manufacturing industry. Operational issues include equipment failures, accidents, and electrical short circuits. Natural disasters, which are uncontrollable factors like flooding, earthquakes, storms, and diseases, also present substantial risks. Additionally, competition for customers and rising costs, including fuel, labor, and electricity, are major external challenges. By interviewing with experts, we were able to learn about the severity, occurrence, and detectability of each risk and received the scoring results from experts by using Table 1. to describe as shown in Table 4-6 . However, severity, occurrence and detection of each ice manufacturer varies in terms of management, location, and strategy.

**Table 3** Major of risk for manufacturers of consumable ice

| Types of risk | No. | Source of risk |
|---|---|---|
| Internal risks | 1 | Human resources issues |
| | 2 | Operation issues |
| External risks | 1 | Natural disaster |
| | 2 | Competitor |
| | 3 | Higher cost |

**Table 4** Severity of each risk in ice manufacturers

| Types of risk | Risk | Severity (Score) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Internal risks | Human resources issues | 8 | 7 | 5 | 9 | 4 | 7 | 5 |
| | Operation issues | 6 | 5 | 6 | 5 | 7 | 5 | 5 |
| External risks | Natural disaster | 7 | 9 | 7 | 9 | 9 | 8 | 8 |
| | Competitor | 8 | 7 | 4 | 6 | 9 | 6 | 6 |
| | Higher cost | 10 | 8 | 8 | 9 | 9 | 7 | 9 |

**Table 5** Occurrence of each risk in ice manufacturers

| Types of risk | Risk | Occurrence (Score) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Internal risks | Human resources issues | 10 | 8 | 4 | 9 | 2 | 7 | 2 |
| | Operation issues | 3 | 4 | 3 | 5 | 3 | 3 | 2 |
| External risks | Natural disaster | 3 | 5 | 4 | 4 | 5 | 5 | 3 |
| | Competitor | 6 | 9 | 3 | 9 | 9 | 6 | 5 |
| | Higher cost | 10 | 9 | 8 | 9 | 9 | 8 | 7 |

**Table 6** Detection of each risk in ice manufacturers

| Types of risk | Risk | Detection(Score) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Internal risks | Human resources issues | 3 | 6 | 7 | 4 | 8 | 6 | 5 |
| | Operation issues | 3 | 3 | 5 | 5 | 7 | 5 | 4 |
| External risks | Natural disaster | 3 | 5 | 8 | 5 | 3 | 3 | 4 |
| | Competitor | 8 | 8 | 6 | 7 | 8 | 8 | 9 |
| | Higher cost | 8 | 9 | 8 | 7 | 9 | 9 | 8 |

The result from observations and interviews with experts of 7 factories displayed the same discussion results as literature review. Which are the operational risks being the major of risk for manufacturers of consumable ice. From interviews with expert the operational risks are the factor that can be easiest to planned, controlled, and prevented. While other factors are sensitive and uncontrollable. In the next section, we apply FMEA to assess operational risks, identifying potential product and process related failure modes and analyzing the effects of prospective failures on the process, product, and business. The lists of failures and problems identified in the ice manufacturing industry through observations and interviews are shown in Table 7.

**Table 7** List of operation risks and problem of ice manufacturing industry

| No. | List of operation risks and problem of ice manufacturing industry |
|---|---|
| 1 | Groundwater transport pipe leaks, clogged pipe |
| 2 | Ammonia pipe leak |
| 3 | The water valve cannot be completely closed |
| 4 | Failure of transformer electrical system |
| 5 | Failure of water pump |

The 5 potential failure modes as shown in Table 7 will be used in the FMEA. The result shows the severity, occurrence, and detection of each risk in the list, then we can obtain FMEA result by calculate Risk Priority Number (RPN) using formula:

**RPN** = Severity x Occurrence x Detection

as provide recommended actions The result is shown in Table 8-10.

**Table 8** List of operation risks and problem of ice manufacturing industry

| FAILURE MODE AND EFFECTS ANALYSIS | | | | | |
|---|---|---|---|---|---|
| Potential Failure Mode | Potential Effect(s) of Failure | **S** | Potential Cause(s) | **O** | **D** |
| Groundwater transport pipe leaks, clogged pipe | Make the water unclean, wastewater | 5 | Lack of inspection and maintenance | 4 | 3 |
| Ammonia pipe leak | Causing chemical pollution in the surrounding area | 9 | Lack of inspection and maintenance | 3 | 5 |
| Failure of water pump | Can't pump water into pond or tank | 6 | water pump machine failure | 2 | 4 |
| The water valve cannot be completely closed | Can't retention clean water in tank and wasting water | 6 | expired of water valve | 6 | 3 |
| Failure of transformer electrical system | Can't use electrical devices | 8 | The machine is broken or a short circuit | 3 | 2 |

**Table 9** Ranked list of operation risks and problem of ice manufacturing industry

| No. | List of operation risks and problem of ice manufacturing industry | RPN |
|---|---|---|
| 1 | Ammonia pipe leak | 135 |
| 2 | The water valve cannot be completely closed | 108 |
| 3 | Groundwater transport pipe leaks, clogged pipe | 60 |
| 4 | Failure of water pump | 48 |
| 5 | Failure of transformer electrical system | 48 |

**Table 10** Selected risks and recommended actions in the ice manufacturers process

| Failure mode/ Risk | Recommended actions |
|---|---|
| F1.Groundwater transport pipe leaks, clogged pipe | R1. Set schedule a time to check condition and maintain |
| F2.Ammonia pipe leak | R2. Create a specialized team to oversee, prevent, and control risks.<br>R3. Set up Portable gas detector<br>R4.Choose the correct seamless pipe and pressure resistant pipe (according to the standard)<br>R.5.Control the construction process correctly according to engineering principles with certification from an engineer |
| F3.Faliure of water pump | R6.Prepare backup pump routes<br>R7.Prepare backup pump equipment |

| Failure mode/ Risk | Recommended actions |
|---|---|
| F4.The water valve cannot be completely closed | R8.Post a warning sign for employees |
| F5.Faliure of transformer electrical system | R9.Prepare a backup electrical generator<br>R10.Always follow the news from Provincial Electricity Authority |

A score from 1 to 5 was used to categorize each criterion, as represented by the linguistic descriptions in Figure 7. The ice manufacturers owner assigned scores for each recommendation. From the result of the study, we can obtain the new assessment model which consists of 3 aspects: Risk Priority Number, Action feasibility and Operation impacts.

This model introduces the simple step to evaluate risks faced by ice manufacturers, provide feasibility actions, and assess the impact of those actions in the ice manufacturing operation.

Additionally, the ice manufacturers used their expert judgment to prioritize the actions independently of other methods. This approach aimed to validate the findings from the RPN and MCDM methods. Subsequently, the results from the three approaches (expert judgment, RPN, and MCDM methods) were compared.

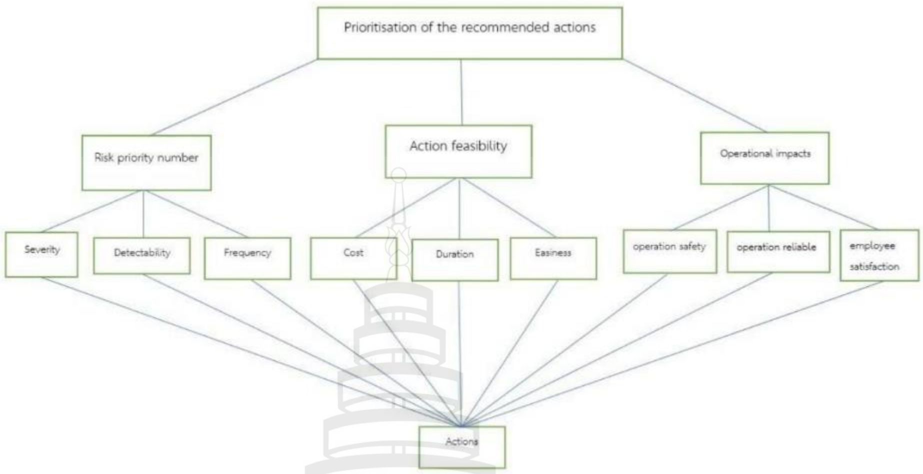


**Figure 7** Prioritization the recommended actions (Source: researcher, 2024)

The seven ice manufacturers provided the local weight for each main criteria and sub-criteria for conducting MCDM method as shown in Table 11-18. The local weight values come from an expert judgment approach from business owners. The calculation of the global weight using local weight of main criteria multiply by local weight of sub-criteria. Table 11-18 show the results from expert judgment to give weight to 3 main criteria and 9 sub-criteria.

**Global weight** = local weight of main criteria x local weight of sub-criteria

**Table 11** The local weight U.P.ICE (2003) LIMITED PARTNERSHIP

| U.P.ICE (2003) LIMITED PARTNERSHIP | | | | |
|---|---|---|---|---|
| **Main criteria** | **Local weight** | **Sub-criteria** | **Local weight** | **Global weight** |
| C1. Risk priority number | 0.4 | C1.1. Severity | 0.45 | 0.18 |
| | | C1.2. Occurrence | 0.20 | 0.08 |
| | | C1.3. Detectability | 0.35 | 0.14 |
| C2. Action feasibility | 0.5 | C2.1. Cost | 0.40 | 0.20 |
| | | C2.2. Duration | 0.35 | 0.18 |
| | | C2.3 Easiness | 0.25 | 0.13 |
| C3. Operational impacts | 0.1 | C3.1 Operation safety | 0.50 | 0.05 |
| | | C3.2 Operation reliable | 0.30 | 0.03 |
| | | C3.3 Employee satisfaction | 0.20 | 0.02 |

**Table 12** The local weight SAKOL ICEBERG CO., LTD.

| SAKOL ICEBERG CO., LTD. | | | | |
|---|---|---|---|---|
| **Main criteria** | **Local weight** | **Sub-criteria** | **Local weight** | **Global weight** |
| C1. Risk priority number | 0.4 | C1.1. Severity | 0.40 | 0.16 |
| | | C1.2. Occurrence | 0.30 | 0.12 |

| SAKOL ICEBERG CO., LTD. | | | | |
|---|---|---|---|---|
| **Main criteria** | **Local weight** | **Sub-criteria** | **Local weight** | **Global weight** |
| | | C1.3. Detectability | 0.30 | 0.12 |
| C2. Action feasibility | 0.2 | C2.1. Cost | 0.20 | 0.04 |
| | | C2.2. Duration | 0.40 | 0.08 |
| | | C2.3 Easiness | 0.40 | 0.08 |
| C3. Operational impacts | 0.4 | C3.1 Operation safety | 0.50 | 0.20 |
| | | C3.2 Operation reliable | 0.30 | 0.12 |
| | | C3.3 Employee satisfaction | 0.20 | 0.08 |

**Table 13** The local weight KO TI NAMKHEANG LIMITED PARTNERSHIP

| KO TI NAMKHEANG LIMITED PARTNERSHIP | | | | |
|---|---|---|---|---|
| **Main criteria** | **Local weight** | **Sub-criteria** | **Local weight** | **Global weight** |
| C1. Risk priority number | 0.50 | C1.1. Severity | 0.30 | 0.15 |
| | | C1.2. Occurrence | 0.40 | 0.20 |
| | | C1.3. Detectability | 0.30 | 0.15 |

| KO TI NAMKHEANG LIMITED PARTNERSHIP | | | | |
|---|---|---|---|---|
| **Main criteria** | **Local weight** | **Sub-criteria** | **Local weight** | **Global weight** |
| C2. Action feasibility | 0.30 | C2.1. Cost | 0.40 | 0.12 |
| | | C2.2. Duration | 0.20 | 0.06 |
| | | C2.3 Easiness | 0.40 | 0.12 |
| C3. Operational impacts | 0.40 | C3.1 Operation safety | 0.40 | 0.16 |
| | | C3.2 Operation reliable | 0.40 | 0.16 |
| | | C3.3 Employee satisfaction | 0.20 | 0.08 |

**Table 14** The local weight D.D. DRINRK LTD., PARTNERSHIP

| D.D DRINRK LTD., PARTNERSHIP | | | | |
|---|---|---|---|---|
| **Main criteria** | **Local weight** | **Sub-criteria** | **Local weight** | **Global weight** |
| C1. Risk priority number | 0.35 | C1.1. Severity | 0.40 | 0.14 |
| | | C1.2. Occurrence | 0.20 | 0.07 |
| | | C1.3. Detectability | 0.40 | 0.14 |
| C2. Action feasibility | 0.35 | C2.1. Cost | 0.50 | 0.18 |
| | | C2.2. Duration | 0.10 | 0.04 |
| | | C2.3 Easiness | 0.40 | 0.14 |
| C3. Operational impacts | 0.30 | C3.1 Operation safety | 0.40 | 0.12 |
| | | C3.2 Operation reliable | 0.50 | 0.15 |
| | | C3.3 Employee satisfaction | 0.10 | 0.03 |

**Table 15** The local weight SAKOL ICE-DRINKING WATER (1980) COMPANY LIMITED

| SAKOL ICE-DRINKING WATER (1980) COMPANY LIMITED | | | | |
|---|---|---|---|---|
| **Main criteria** | **Local weight** | **Sub-criteria** | **Local weight** | **Global weight** |
| C1. Risk priority number | 0.40 | C1.1. Severity | 0.45 | 0.18 |
| | | C1.2. Occurrence | 0.20 | 0.08 |
| | | C1.3. Detectability | 0.35 | 0.14 |
| C2. Action feasibility | 0.35 | C2.1. Cost | 0.40 | 0.14 |
| | | C2.2. Duration | 0.35 | 0.12 |
| | | C2.3 Easiness | 0.25 | 0.09 |
| C3. Operational impacts | 0.25 | C3.1 Operation safety | 0.50 | 0.13 |
| | | C3.2 Operation reliable | 0.30 | 0.08 |
| | | C3.3 Employee satisfaction | 0.20 | 0.05 |

**Table 16** The local weight RATANASUWAN ICE FACTORY LIMITED PARTNERSHIP

| **RATANASUWAN ICE FACTORY LIMITED PARTNERSHIP** | | | | |
|---|---|---|---|---|
| **Main criteria** | **Local weight** | **Sub-criteria** | **Local weight** | **Global weight** |
| C1. Risk priority number | 0.40 | C1.1. Severity | 0.40 | 0.16 |
| | | C1.2. Occurrence | 0.30 | 0.12 |
| | | C1.3. Detectability | 0.30 | 0.12 |
| C2. Action feasibility | 0.20 | C2.1. Cost | 0.20 | 0.04 |
| | | C2.2. Duration | 0.40 | 0.08 |
| | | C2.3 Easiness | 0.40 | 0.08 |
| C3. Operational impacts | 0.40 | C3.1 Operation safety | 0.50 | 0.20 |
| | | C3.2 Operation reliable | 0.30 | 0.12 |
| | | C3.3 Employee satisfaction | 0.20 | 0.08 |

**Table 17** The local weight HongSawan LIMITED PARTNERSHIP

| HongSawan LIMITED PARTNERSHIP | | | | |
|---|---|---|---|---|
| **Main criteria** | **Local weight** | **Sub-criteria** | **Local weight** | **Global weight** |
| C1. Risk priority number | 0.30 | C1.1. Severity | 0.70 | 0.21 |
| | | C1.2. Occurrence | 0.10 | 0.03 |
| | | C1.3. Detectability | 0.20 | 0.06 |
| C2. Action feasibility | 0.30 | C2.1. Cost | 0.40 | 0.12 |
| | | C2.2. Duration | 0.10 | 0.03 |
| | | C2.3 Easiness | 0.50 | 0.15 |
| C3. Operational impacts | 0.40 | C3.1 Operation safety | 0.60 | 0.24 |
| | | C3.2 Operation reliable | 0.30 | 0.12 |
| | | C3.3 Employee satisfaction | 0.10 | 0.04 |

**Table 18** The global weights of all criteria

| The global weights of all criteria | | | | |
|---|---|---|---|---|
| **Main criteria** | **Local weight (average)** | **Sub-criteria** | **Local weight (average)** | **Global weight** |
| C1. Risk priority number | 0.39 | C1.1. Severity | 0.44 | 0.17 |
| | | C1.2. Occurrence | 0.24 | 0.10 |
| | | C1.3. Detectability | 0.31 | 0.12 |
| C2. Action feasibility | 0.31 | C2.1. Cost | 0.36 | 0.11 |
| | | C2.2. Duration | 0.27 | 0.09 |
| | | C2.3 Easiness | 0.37 | 0.12 |
| C3. Operational impacts | 0.32 | C3.1 Operation safety | 0.49 | 0.16 |
| | | C3.2 Operation reliable | 0.34 | 0.11 |
| | | C3.3 Employee satisfaction | 0.17 | 0.06 |

**Remark**: The local weight summary does not equal 1 because the average weight for all seven ice manufacturers has been rounded up.

The seven ice manufacturers assigned a numerical rating between 1 and 5 to each recommended action for all sub-criteria. The data collected, as shown in Table 19, were used to apply the MCDM method and calculate the RPN for comparisons.

**Table 19** The average scores and rankings provided by seven ice manufacturers

| The average scores and rankings provided by seven ice manufacturers | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Recommended actions | RPN | | | Action feasibility | | | Operational impacts | | | RPN | Multiply all ten criteria | Ranking |
| | S | O | D | C | E | D | OS | OR | ES | SxOxD | | |
| R1. | 2 | 3 | 4 | 2 | 5 | 4 | 5 | 4 | 2 | 24 | 38.40 | 2 |
| R2. | 5 | 1 | 1 | 4 | 2 | 4 | 3 | 4 | 3 | 5 | 5.76 | 10 |
| R3. | 5 | 1 | 1 | 4 | 4 | 3 | 5 | 5 | 5 | 5 | 30.00 | 4 |
| R4. | 5 | 1 | 1 | 4 | 4 | 3 | 5 | 5 | 4 | 5 | 24.00 | 5 |
| R5. | 5 | 1 | 1 | 4 | 3 | 3 | 5 | 4 | 5 | 5 | 18.00 | 6 |
| R6. | 3 | 2 | 1 | 3 | 4 | 2 | 5 | 5 | 3 | 6 | 10.80 | 8 |
| R7. | 4 | 2 | 1 | 3 | 4 | 2 | 5 | 5 | 3 | 8 | 14.40 | 7 |
| R8. | 3 | 3 | 2 | 1 | 5 | 5 | 5 | 5 | 3 | 18 | 33.75 | 3 |
| R.9 | 5 | 2 | 5 | 5 | 3 | 2 | 5 | 3 | 3 | 50 | 67.50 | 1 |
| R.10 | 5 | 2 | 5 | 1 | 1 | 5 | 5 | 4 | 2 | 50 | 10.00 | 9 |

**Discussion**

Seven out of the 14 consumable ice manufacturers in Chiang Rai were selected for the study, with the criterion that their production capacity exceeds 150 tons per day. The risk factor analysis, conducted through observations and interviews with industry experts, identified several key risks affecting the consumable ice manufacturing sector. These include groundwater transport pipe leaks, clogged pipes, ammonia pipe leaks, water pump failures, issues with water valves not closing properly, and transformer electrical system malfunctions.

To evaluate and prioritize these risks, FMEA was used. The results ranked the risks based on their RPN values. The analysis showed that ammonia pipe leaks had the highest RPN, marking it as the most critical risk, followed by issues with water valves not closing properly, groundwater transport pipe leaks, clogged pipes, water pump failures, and transformer electrical system failures. This ranking offers a comprehensive overview of the risks and their implications for the industry, and it also includes 10 recommended actions, as shown in Table 10.

After identifying and ranking the risks with the greatest impact on the consumable ice manufacturing business, MCDM methods were applied to provide recommendations. The study results include ten recommendations along with the weights for each recommendation, as detailed in Table 19.

This study's findings align with existing research on risk management in industrial settings, particularly in ammonia refrigeration systems. The use of FMEA to prioritize risks, such as ammonia pipe leaks, is supported by previous studies and also emphasize the importance of leak detection and safety measures (Hasson et al, 2019). Additionally, the focus on water system and electrical maintenance is consistent with findings and highlight the need for regular equipment checks and backup systems (Yang et al, 2017). The application of MCDM for prioritizing actions reflects broader trends in risk management (Zavadskas et al, 2012). Lastly, the recommendation for continuous monitoring and adapting to industry changes mirrors insights and stressing the importance of ongoing updates to risk strategies (Neumeyer et al, 2020). Overall, the study contributes to the academic discourse by advocating for proactive, data-driven, and adaptive risk management practices in consumable ice manufacturing.

**Conclusion**

In this study, FMEA was used to calculate and rank risks based on RPN values, identifying and prioritizing the risk factors faced by the consumable ice manufacturing industry. Additionally, 10 recommendations were provided. Nine criteria and the recommendations were weighted using the MCDM method, which was then applied to prioritize the actions. The results showed that ammonia pipe leaks are the most significant concern for consumable ice manufacturers. This risk is particularly challenging to detect, occurs frequently, and leads to increased production costs. Furthermore, ammonia pipe leaks pose the greatest severity risk to the production line, as ammonia is a highly dangerous chemical that can cause severe injury or even death.

To ensure safe and efficient ice production operations, several critical recommendations have been identified for various system components. For ammonia pipe leak prevention, it is crucial to establish a specialized risk management team, implement portable gas detectors, use standard-compliant seamless pressure-resistant pipes, and ensure proper construction oversight by certified engineers. Regarding water system issues, which directly impact both ice production costs and equipment longevity, the facility should address water valve closure problems and implement preventive measures for groundwater transport pipe leaks. This can be achieved by creating a dedicated maintenance team and ensuring correct pipe installation with appropriate water pressure monitoring. Although water pump and transformer electrical system failures present operational risks, their low RPN values indicate that these issues occur infrequently and are easily detected. Nevertheless, recommended actions include regular equipment maintenance, the installation of appropriate water pumps with backup systems, and preparation for power disruptions by installing backup electrical generators and maintaining communication with the Provincial Electricity Authority.

## Suggestion

### Suggestion for Further Study

Data collection in the consumable ice industry is challenging due to seasonal fluctuations in demand. Future research should segment data by season to better capture these variations and associated risks and This study relied on expert interviews, potentially overlooking some risks. Further study should involve a wider range of employees, such as factory workers, to improve risk identification and recommendations.

### Suggestion of This Study Results

To apply the study's findings in the consumable ice manufacturing industry, integrate FMEA into daily operations for risk assessment and prioritize risks like ammonia leaks, water system issues, and electrical failures. Establish a dedicated risk management team focused on ammonia safety, ensure ongoing training, and implement robust safety measures, such as portable gas detectors and high-quality pipes. Improve water system maintenance with regular inspections and pressure monitoring and maintain electrical systems with backup pumps and generators. Use MCDM to prioritize actions and continuously assess the effectiveness of risk mitigation strategies. Stay updated on industry trends and adapt your strategies to address emerging risks and regulatory changes.

**Research Limitations**

1. Gathering data in the consumable ice industry presents challenges due to seasonal variations in consumer demand. This research utilized data aggregated over the entire year to analyze risks. However, for a more nuanced understanding of industry problems, future research should examine data segmented by each season.

2. Future research should explore AIAG & VDA FMEA 1st edition version 2019 the techniques and procedures in greater detail to assess their applicability and potential benefits for the industry, AIAG & VDA FMEA introduced a new FMEA form that applies Action Priority (AP) in the framework. The techniques and procedures of AIAG & VDA FMEA 1st edition version 2019 should be examined in more detail in future research.

3. This research identified from observation and interview only with expert or business owner of ice manufacturers. This making some risks are unnoticed in in future studies, the researcher should observation and interview from other personnel worker to increase efficiency in finding risks, identify and recommendations for solving those risks.

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