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.

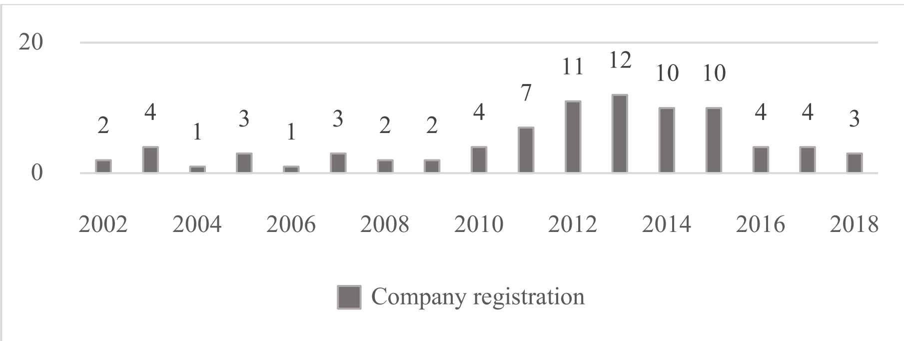

Figure 1 Amount of new ice manufacturing registration in northern Thailand between 2008-2018

(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.

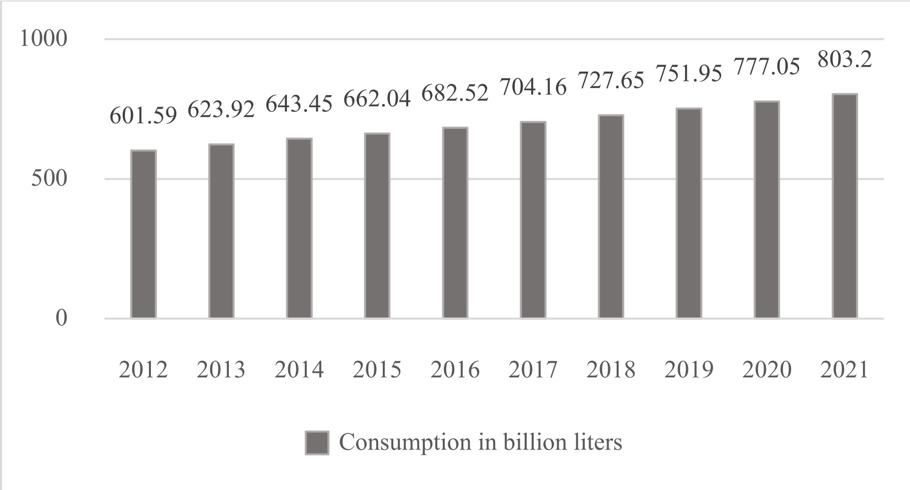

Figure 2 Worldwide Consumption of Non-alcoholic beverage between 2012- 2021

(Source: Statista, 2024)

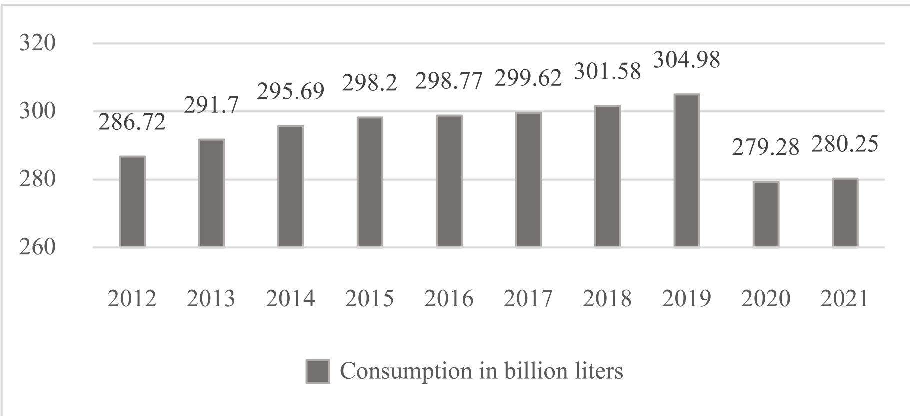

Figure 3 Worldwide Consumption of Alcoholic beverage from 2012-2021

(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.

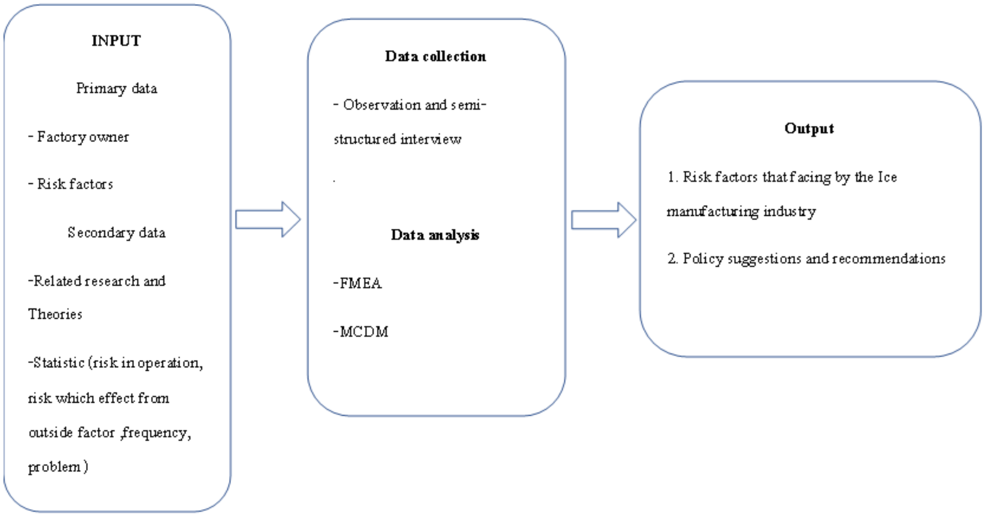

Figure 5 Analysis Framework (Source: Researcher, 2024)

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.

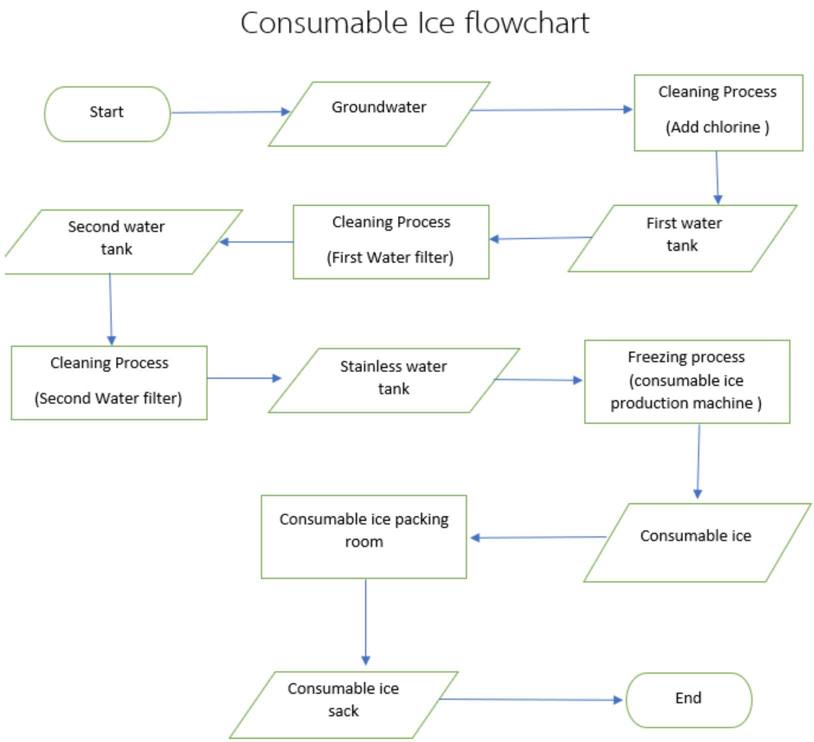

Figure 6 Flow Chart of consumable ice manufacturing industry (Source: Researcher, 2024)

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. R3. Set up Portable gas detector R4.Choose the correct seamless pipe and pressure resistant pipe (according to the standard) 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 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 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.

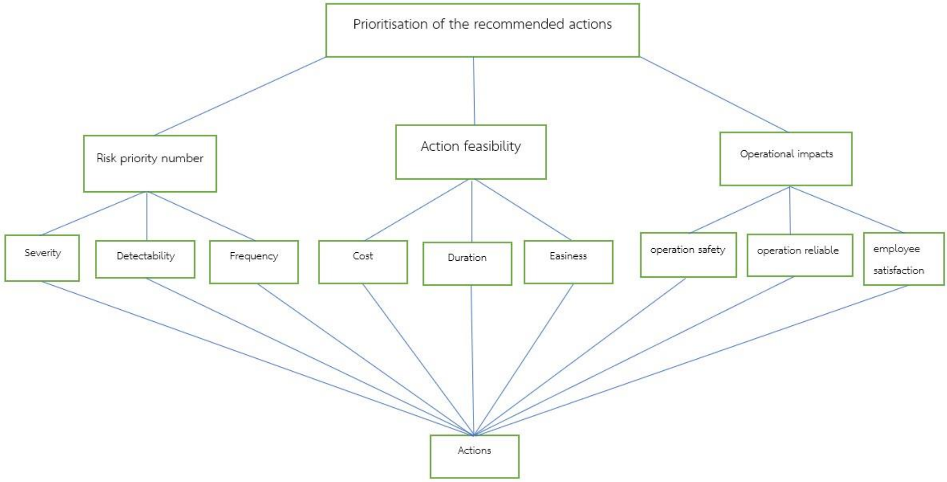

Figure 7 Prioritization the recommended actions (Source: researcher, 2024)

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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