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Enhancing Risk Management and Mitigation Strategies for the Infant Formula Milk Supply Chain through Hybrid AHP-TOPSIS Analysis

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Abstract

Infant formula milk (IFM) is critical in many babies' diets and must be high-quality. Unfortunately, IFM has been an adulteration target by those attempting to make illegal profits and has suffered from contamination-related issues. This study's main objective was to identify the most critical risks affecting IFM quality in the supply chain and determine mitigation strategies to improve IFM performance measurement. We developed a model to reduce adulteration and contamination rates in the infant formula milk supply chains (IFMSCs) and maximize safety. The steps to achieve the study's objectives included (1) identifying the importance of IFMs for infant nutrition and their risks, (2) establishing mitigation criteria for evaluating IFMSC's performance to maximize quality, and (3) analyzing each mitigation criterion to maximize IFM safety. Based on pairwise comparisons by professionals in the food supply chain (FSC) of decision-making, the hybrid Analytic Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to the Ideal Solution (TOPSIS) model were used to analyze and prioritize mitigation alternatives to develop a model that can prioritize and select the best criteria for maximizing IFM safety and achieving the study objective. According to the contamination quality risk agents, mitigation alternative (QR.M2) ranked highest in both tests. This study's findings illustrate how vital it is to avoid risk when dealing with public health, especially infants' health, and how IFM must undergo precise testing and quality checks at every supply chain stage to ensure quality.

Keywords
Infant formula milk; milk quality; supply chain risk; risk mitigation

1. Introduction

Infant milk is a component of a baby's diet that must be high-quality to ensure healthy growth and development. Of the two sources of infant milk, the main one is breast milk, which is recognized as the ideal form of infant feeding and provides multiple benefits for a child's health. The promotion, protection, and support of breastfeeding is therefore critical. For infants incapable of breastfeeding, who should not receive breast milk, or for whom breast milk is unavailable, high-quality infant formula milk (IFM) is the other preferred option (Kleczka and Shamir 2006). However, only 38% of infants worldwide are exclusively breastfed, and among Americans, only 13% initiate breastfeeding exclusively for a period not less than six months after birth (Martin et al. 2016). When the quality is high, IFM can be an effective breastfeeding substitute. For the first six months of a child's life, breastfeeding should be the sole source of nutrition.

With life demands increasing and women's need to work, many mothers rely on IFMs to feed their infants directly after delivery. Because IFM is such an essential product, no home that needs it should be without it, especially when infants require food to meet their nutritional needs. Even though a product identical to breast milk cannot be produced, every effort has been made to mimic and replicate the nutrition profile of breast milk to fulfill infants' needs.

IFM is available in three main formula types: (1) cow milk protein-base, the most common type, widely available, digestible, and modified to mimic breast milk; (2) soy-based version, which is suitable for infants who are allergic to cow milk, lactose, and carbohydrate that is naturally found in cow milk, or for parents who would like to eliminate animal proteins from their child's diet; and (3) a protein hydrolysate formula used for infants with severe allergies to protein-based formulas and formulas based on soy, in which the protein is partially or entirely hydrolyzed and broken down into smaller pieces to facilitate digestion (Mayo Clinic 2023). Different preparation forms for IFMs exist: (1) Powder, the most common and economical form of infant formula that must be mixed with water before feeding (2) Liquid, a concentrated liquid must be mixed with equal water; and (3) Ready-to-feed, the most expensive form of infant formula that, does not require mixing (Martin et al. 2016).

IFM has faced many issues throughout its history and has been a target for smugglers and those seeking to make illegal high profits due to its critical nature. In October 2008, the world witnessed the worst case of a Chinese scandal involving IFM trading. A substance known as melamine was illegally added to milk to increase its purported protein concentration deceptively. The fraud adversely affected approximately 294,000 children. Around 52,000 infants were hospitalized due to melamine-related urinary stones (MUS), and at least six died (Wen et al. 2016). In February 2022, Abbott Laboratories issued a massive recall because some versions of Similac, Alimentum, and EleCare baby formula contained Salmonella Newport and Cronobacter Sakazakii bacteria. Laboratory reports confirmed that IFMs were contaminated, and the U.S. Food and Drug Administration (FDA) found Abbott failed to maintain sanitary conditions procedures at the Michigan production plant (Jackson 2022). Reckitt, the manufacturer of Enfamil, recalled approximately 145,000 cans of ProSobee Simply Plant-Based Infant Formula in February 2023. The recall was due to the potential cross-contamination of Cronobacter sakazakii, which can cause severe newborn infections. Infant nutrition quality standards and product safety standards are in alignment with this action (Treisman, 2023).

Infant formula milk supply chain (IFMSC) actors are crucial to ensuring IFM quality and safety, particularly raw material suppliers, manufacturers, and distributors. They must continue improving their performance to meet the community's demands per the agreed-upon standards. The specific guidelines outlined in the US FDA's current Good Manufacturing Practices rules require that formulas must satisfy the quality factors of normal physical growth and adequate biological quality of protein components.

To evaluate the performance measurement of IFM in the supply chain, this study aimed to identify the most critical risks that can affect IFM quality, focus on the essential criteria and mitigate them appropriately. This research identified a literature gap on overcoming the concerns and challenges in the IFMSC to ensure its quality, which has never been addressed. The current study aimed to develop a model that maximizes IFM safety and eliminates adulteration and contamination rates. Using the hybrid analytic hierarchy process (AHP) and Technique for Order of Preference by Similarity to the Ideal Solution (TOPSIS) model, mitigation strategies were ranked and prioritized based on expert feedback.

The steps that will help in achieving the aim of this study include the following:

- Identifying the importance of IFMs for infant nutrition and the risks they pose;
- Determining the mitigation criteria for evaluating the IFMSC's performance to maximize its quality; and
- Analyzing the priorities and importance of each mitigation criterion to maximize IFM safety.

There are five sections in this study. Section 1 presents the articles, the background, the problem statement, and the aim and objectives of the current study. Section 2 has a review of the literature. Section 3 describes the methods used to collect the data for the study. The findings of the research are presented in Section 4. Section 5 is the last part of the study, presenting the research's conclusion, implications, and recommendations.

2. Literature Review

This section presents the facts about IFMs, the well-known issues that IFMs suffer, including adulteration and microbial contamination, and the importance of regular quality control of infant milk. The second sub-section discusses risk factors affecting the safety and quality of IFMs and their important classification from the literature. Finally, the section presents a framework with key points to facilitate assessing and managing IFM risks, listing the mitigation criteria.

2.1. Literature Identification and Collection

The literature identification and collection phase comprised three steps, as illustrated in Figure 1.

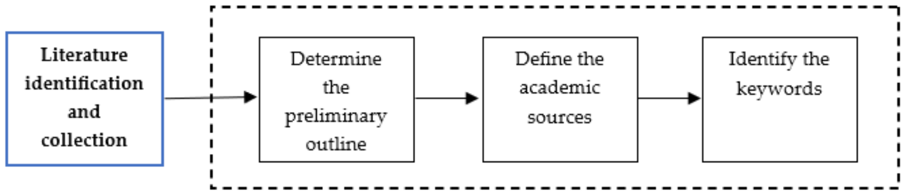

Figure 1. Literature identification and collection

Step 1: Define the preliminary outline.
An outline for the paper was created by exploring the issues associated with IFM, identifying the associated risk factors, and identifying areas to be discussed to ensure that IFM is safe for consumption. The dimensions of IFMSC risk factors were determined by reviewing various sources and articles and adequately using the recurrent concepts and phases of the IFM in different research papers. The risk factors were categorized into environmental, operational, and quality.

Step 2: Define the academic sources.
The literature search used Google Scholar, Researchgate, Science Direct, Scopus, and Springer Link. Using these search engines, we were able to access a diversified knowledge base containing a range of relevant concepts and gain a better understanding of risk factors and mitigation strategies.

Step 3: Identify the keywords.
We focused our search on secondary sources published in English only because primary sources were insufficient. Different keywords covering the objectives of the review were identified. The keywords were categorized into two areas. The first area investigated the issues with IFM and the risk factors, while the other focused on risk mitigation criteria for ensuring safe infant formula milk. Different search strings were used with different combinations of keywords, such as "infant formula milk AND milk quality AND infant formula milk supply chain," "supply chain risk (OR risks) AND risk mitigation."

2.2. Facts and Issues of IFM

Food safety and high quality are pillars of public health that ensure a healthy community. In 1939, Cicely Williams raised the issue of low-income countries using IFMs as a health risk when she spoke on Milk and Murder, and concerns over IFMs increased in 1974 after the publication of The Baby Killer Report (Kent 2015). The prevalence of adulteration, contamination, and other IFM issues is not restricted to low-income countries; they are widespread, even in high-income countries. As an example, Abbott Laboratories recalled millions of IFMs in February 2022 due to Salmonella Newport and Cronobacter sakazakii bacteria, commonly known as Enterobacter sakazakii (ES), and Reckitt recalled approximately 145,000 cans of ProSobee Simply Plant-Based Infant Formula in February 2023.

It can be argued that IFMs are more associated with biological food safety issues, such as parasites, pathogenic bacteria such as Salmonella or pathogenic Escherichia coli, also known as E. coli, and foodborne viruses such as Norovirus that cause vomiting and diarrhea (Jacxsens et al. 2017). In addition, Bacillus cereus contamination in IFMs has been well-documented in past literature (Haughton 2010; Di Pinto et al. 2013). Whether in liquid or powder form, IFM is an ideal medium for bacterial growth that poses a potential risk of foodborne illness (Sadek et al. 2018). Consequently, such pathogens are more likely to infect babies and infants than adults because their immune systems are less developed, and their intestinal flora is less competitive (Townsend and Forsythe 2007). Several factors determine the microflora of dried milk powders, including raw milk or milk by-products, preheating temperature, operating conditions, evaporator and/or dryer, and plant hygiene (Deeb et al. 2010).

Food adulteration poses several food safety concerns. These issues affect IFM, including incidents such as the 2008 China milk scandal, where melamine was added to milk to appear more protein-rich. Melamine is a triazine compound with the formula $C_3H_6N_6$ used to manufacture household utensils and ornaments (Singh and Kumar 2009). Melamine is a component of flame retardants, glues, and plastics but is prohibited for human or animal consumption (Field and Field 2010). It has harmful effects on infants; melamine can retard their growth, cause urinary stones, and damage

their kidneys. Children exposed to this kind of toxicity at an early age may suffer uncertain long-term effects (Yasui et al. 2014). Therefore, milk safety regulators should focus their monitoring resources on supervising milk sold in reputedly trustworthy stores and not allow exemptions from inspections (Pei et al. 2011).
There is limited potential for regulating the IFM industry globally, but improvements can be made. Global regulation must be based on a negotiated consensus among nations. These regulations are not intended to set forth detailed, binding requirements for these nations but to define fundamental principles that national governments will follow and implement through their national laws. Therefore, a global governance system exists even sans a global government (Kent 2015). In addition, IFM producers and distributors must adhere to a high level of microbiological quality control while producing, distributing, and using IFM for newborn infants. Several extrinsic indicators can be used to determine a product's safety, including venue, brand, and company names or certifications concerning safety. Producers, processors, retailers, or safety supervisors often attach indicators like these during food production and supply processes rather than integrating them into physical structures. A consumer's confidence in extrinsic indicators heavily depends on their credibility as safety indicators (Zhang et al. 2010). IFM must be prepared with good hygienic procedures, quickly cooled, and consumed as soon as possible to minimize the risk of these adulterations and microbial contamination (Forsythe 2005).

2.3. Risk Factors of IFM

Risk is the possibility of something disrupting normal operations or activities, representing the uncertainties associated with a given activity (Kumar 2019). William Kannel, one of the pioneers of the Framingham Heart Study, coined the term "risk factor" despite the concept being widely discussed and applied. It was first used in medical literature in 1961 (Kannel 1961). For the risks to be sufficient to generate a crisis, they, if left unattended, can become a catastrophe (Davies and Walters 1998).

Various scholars have defined supply chain risk (SCR) differently, and no consensus exists on what it means (Ho 2015; Gurtu and Johny 2021). According to Kumar et al. (2019), an SCR is any deviation from the primary goal that may lead to an overall reduction in the value-added process. As Zsidisin (2003) defined it, risk in supply chains occurs when an incident in inbound supply occurs due to supplier or supply market failures, which results in the purchasing firm being unable to meet customer demands or poses an extreme threat to customer safety. Disruptive and operational risks are the two main types of risk that Kern et al. (2012) categorized. An example of operational risk is a failure that can cause supply-demand inconsistency (Wang 2016). Operational risks include malfunctioning equipment, failures of supplies, and strategy failures. In contrast, human-made or natural catastrophes, such as terrorist attacks and natural disasters, cause disruptive risks (Nakandala et al. 2017). Unlike operational risks, disruptive risks are more challenging to control. According to Jüttner et al. (2003), there are two types of risks: internal ones within a firm's supply chain and external ones in its environment.

Regarding safety and quality, IFM is an essential product for infants. Hence, it is linked to public health safety and community well-being (Haji et al. 2022). Crucial products impose higher risks and must be assessed and managed more meticulously. The dimensions of IFMSC risk factors were identified from the literature and classified into three main points: environmental, operational, and quality, based on the model proposed by Liu et al. (2018), as illustrated in Figure 2. Explicit and legible correlations between environmental, operational, and product quality information can be used to achieve supply chain risk management (SCRM) (Murray et al. 2009).

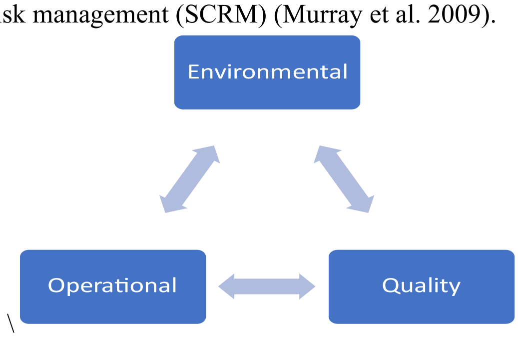

Figure 2. Dimensions of IFMSC risk factors

2.3.1. Environmental Risks

Environmental risks are connected to human health, both physically and mentally, as well as the surrounding environment in general. These risks comprise those impacting the whole supply chain network or those affecting a specific supply chain stage. In addition to pollution, radiation, noise, land use patterns, and uncontrollable external factors, climate change also falls under this category (Rojas-Rueda et al. 2021). Geopolitical factors contribute significantly to this type of risk. Political instability, trade relations, regulations, and international tensions are among these risks (Qin et al. 2023). Supply chain disruptions can be caused by these factors, including tariffs, embargoes, and regulatory changes that can affect sourcing, production, and distribution. Ultimately, the environmental efficiency of any food in the supply chain is influenced dramatically by the downstream processes, including the distribution of products by various channels. Choosing efficient environmental strategies and adopting appropriate approaches are critical to improving food quality systems (Azizsafaei et al.). Therefore, identifying environmental risk factors is crucial to public health decision-making (Mund et al., 2013; Luo et al. 2014; Dendup et al. 2018; Malak-Rawlikowska et al. 2019; Haji et al. 2020, Chandrasiri et al. 2022).

2.3.2. Operational Risks

Operational risk is the risk of losses from flawed processes, policies, systems, or events that disrupt business operations. Several factors can trigger operational risk, including employee errors, criminal activity, and physical events (Berger et al. 2022). Digital routes also introduce new risks and opportunities to supply chains. Among these risks are cloud technology risks, cybersecurity attacks, data leaks, non-compliance with standards, compatibility issues with process automation, resilience risks that encompass disruptions that affect business service availability, and data privacy concerns that pose a threat to the protection of sensitive information. There are a number of third-party risks, such as vulnerabilities in third-party ecosystems, non-compliance, breaches, and intellectual property theft. Additionally, talent gaps that affect workforce capability challenge achieving business objectives within these digital landscapes (Kost, 2023). Understanding supply chain dynamics is enhanced when these factors are taken into consideration. In addition, analyzing these aspects allows for the identification of potential weaknesses as well as the implementation of robust cybersecurity measures to protect against data breaches and cyber threats. Additionally, understanding and monitoring the underlying issues that can affect the performance of any process in the supply chain is crucial, as they affect the continuity of a business process. This vital performance indicator contributes to the perceived quality of service delivery. Thus, identifying and reducing operational risks in a supply chain can ensure business success, improving the product's operational efficiency (Jallow et al. 2007). Operational risks can also impede the monitoring of flawed product recalls due to quality standards breaches (Aung and Chang 2014). Azizsafaei et al. (2021) stated that operational risks arise from day-to-day activities, systems, processes, and people, resulting in damaged products or delivery delays. It is even more dangerous if no traceability technology tracks the product (Azizsafaei et al., 2022; Haji et al., 2021).

2.3.3. Quality Risks

Identifying and analyzing quality information is essential for certifying a product's compliance with its quality conditions. Furthermore, all products have quality information that can be used directly to identify and assess risks (Liu et al. 2018). Information on quality involves time series conditions and dynamic risk analysis, which can cumulatively affect the entire supply chain (Azizsafaei et al. 2022).

As shown in Table 1, 160 risks were identified from the literature, repeated risks were removed, risks with the same meaning were merged, and then categorized into predefined dimensions. For the final analysis, 50 risks were selected.

Table 1. Risk factors impact the quality of IFM

Risk Sources	Risk Variables	Author, Year
Environmental	Climate changes	Azizsafaei et al. 2022
	Economic factors and market dynamic	Breen 2008
	Epidemic diseases	Haji et al. 2021
	Exploitation	Haji et al. 2022
	Lack of an assessment of environmental and natural disasters	Jaberidoost et al. 2013
		Kumar et al. 2019
	Political instability	
	Product life cycle risk	
	Regulation changes	

	Sanctions Transportation issues–unavailability of fuel, congestion, weather, illness	
Operational	Delivery reliability– Consumers are delayed in receiving products. Distributors are delayed in receiving/delivering products. Discrepancy in information on defective products and successful return process Disruptions in capacity and inventory The emergence of new technologies Failure of a machine or facility Financial and cost issues Improper packaging Improper storage Lack of accessibility Lack of communication and transparency in effective information sharing Lack of industry response to shortages Lack of knowledge regarding the manufacturing process Lack of security Lack of visibility and potential traceability of products Lack of stock visibility Long order cycle time Poor logistics and distributions Poor management knowledge Scarcity of skilled labor Short-term supply chain planning and forecasting Supply chain complexity and fragmentation Supply and supplier issue Unbalanced demand–supply Unexpected changes to the delivery schedule	Ayyildiz and Gumus 2021 Azizsafaei et al. 2022 Breen 2008 Haji et al. 2021 Haji et al. 2022 Jaberidoost et al. 2013 Kumar et al. 2019 Permana et al. 2019
Quality	Adulteration/counterfeiting Contamination (biochemical/microbial) Deterioration during shipping Excessive genetic modification Holding large stocks Insufficient regulations Lack of consumer awareness Lack of time–temperature traceability Lack of quality evaluation Lack of stock monitoring Rise in online purchases Risk of new competitors Supplier quality issue Packaging damage during shipment Poor quality inspection and assessment Poor quality of raw materials	Azizsafaei et al. 2022 Breen 2008 Haji et al. 2021 Haji et al. 2022 Jaberidoost et al. 2013 Kumar et al. 2019 Liu et al. 2018 Permana et al. 2019

2.4. SCRM Process

Correctly understanding SCRM begins with understanding the different processes that must be followed, even though different studies propose different frameworks for the processes (de Oliveira et al. 2017; Ferreira et al. 2018; Mvubu and Naude 2020; Senna et al. 2020; Qazi and Akhtar 2020), most agree with the steps illustrated in Figure 3.

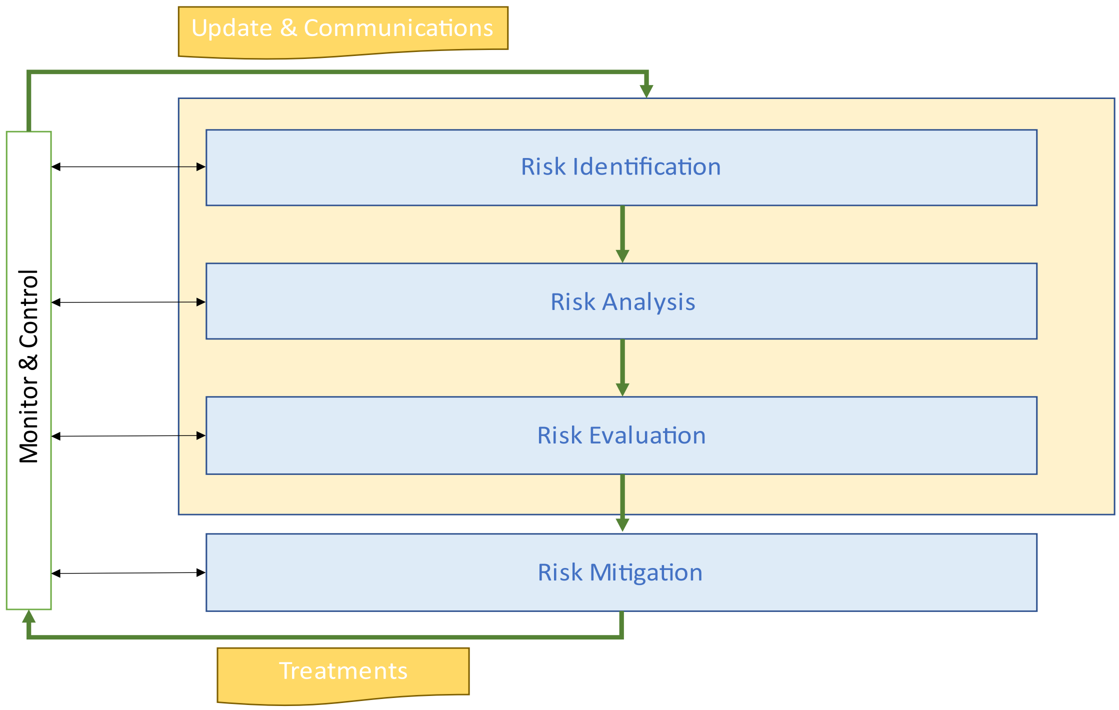

Figure 3. SCRM processes

2.4.1. Risk Identification

For SCRM, identifying risks is the first and most critical step to appropriately understanding and addressing the threat level. The process involves identifying risk types, factors, or combinations (Gossner et al. 2009)

2.4.2. Risk Analysis

A risk analysis is one aspect of the overall risk management plan, built on risk assessment. The probability that an event will occur and the significance of the consequences are related to this process. In this step, the likelihood and importance of each risk are to be determined, and then a score is assigned to each risk (CRI Group, 2021).

2.4.3. Risk Evaluation

An evaluation of risk determines how serious a risk is. There are qualitative and quantitative ways to assess risks. The best way to evaluate risk is to thoroughly investigate each activity related to a specific risk, check out the activities' efficiency, and discover the flaws in their implementation (Vrijling et al. 1995). This process allows a systematic analysis of the whole SCR to be conducted. Risk assessment and analysis are prerequisites to evaluating risk.

2.4.4. Risk Mitigation

An essential goal of risk mitigation is to minimize the impact of potential risks by implementing a plan to manage, eliminate, or limit setbacks (Grabowski and Roberts 1999). Risk mitigation involves reducing risks to a level the supply chain organization can tolerate or accept (Faisal et al. 2006). In addition, the risk can also undergo treatment by implementing risk modification measures.

2.5. Mitigation Criteria for IFM

A supply chain risk management tool focuses on managing products, services, and their lifecycles effectively (Ghosh and Jintanapakanont 2004). A major part of this act entails assessing and mitigating risks to ensure that users are safe. Risk mitigation or optimization aims to reduce the severity or likelihood of a loss (Hubbard 2009). It is nevertheless essential to implement comprehensive risk management, including identifying, assessing, treating, and monitoring supply chain risks. The objectives are to reduce vulnerability, ensure continuity, and provide profitability, resulting in competitive advantage, by implementing internal tools, techniques, and strategies and coordinating and collaborating externally with supply chain members (Fan and Stevenson 2018). Having gained a better understanding of how other supply chain elements affect risk susceptibility, organizations have begun to focus on managing supply chain risk (Faisal et al. 2006). Various uncertainties make risk reduction critical for ensuring effective supply chain operations. The risk must exist and be identified first to implement mitigation strategies effectively. From the literature, a framework of key mitigation strategy factors was identified. The framework was formulated based on Brown's (2022) five mitigation strategies. Figure 4 depicts the key strategies for risk mitigation.

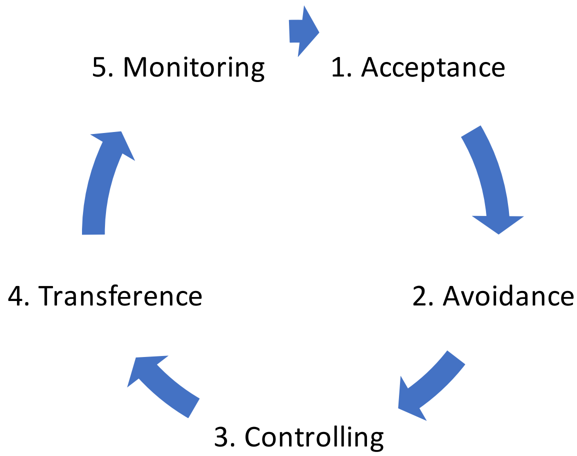

Figure 4. Classification of risk mitigation strategy factors

The following is a detailed explanation of each key mitigation strategy factor used in the framework.

- Accepting the risk: To accept the risk, supply chain members and stakeholders collaborate to analyze every risk so all members know the risks associated with the critical product in the supply chain and their implications beforehand. After that, each risk is defined in terms of its consequences so the members can determine which risks are acceptable. Cost, schedule, and performance risks are the major ones.
- Avoiding the risk: It is possible to apply this strategy to the accepted risk by taking preventative measures to prevent the risk from occurring in the first place.
- Controlling the risk: Whenever the accepted risks cannot be avoided, supply chain members can devise an action plan to minimize or remove their impact.
- Transferring the risk: Transfer involves sharing or handing over some of the responsibility for the risk and its consequences to another party to eliminate their effects.
- Monitoring the risk: The risks may have changed since they were identified, so observing them and keeping an eye out for any new risks that might come up is necessary to avoid unexpected consequences.

3. Methodology

The research employed the triangulation paradigm to ensure that qualitative and quantitative tools were combined effectively, as illustrated in Figure 4. Different data types are incorporated in triangulation to increase confidence in the conclusion results (Fielding and Schreier 2021). Combining literature analysis, surveys, and interviews improved data collection reliability and verification. See Figure 5.

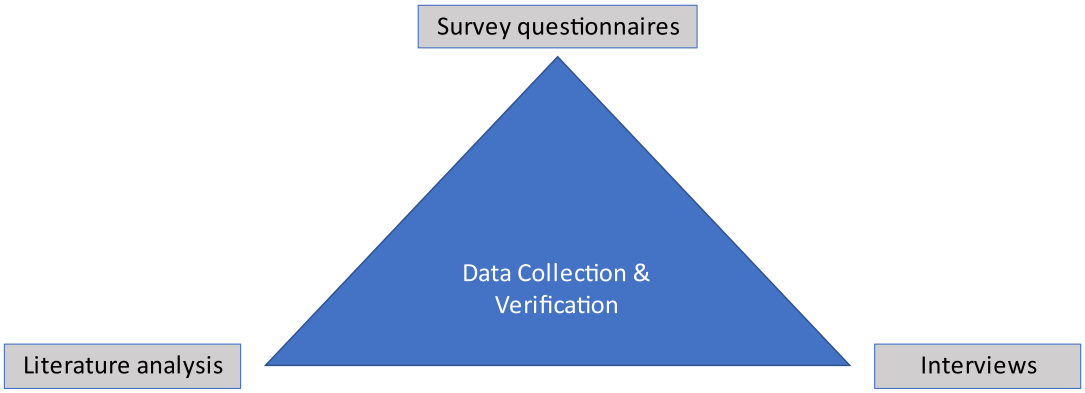

Figure 5. Triangulation paradigm for data collection and verification

3.1. Research Methodology

The methodology adopted for this study involves a two-step process of a Multi-Criteria Decision-Making (MCDM) model is utilized, which integrates the AHP and the TOPSIS. Initially, the AHP is employed to assign appropriate weights to the different risk mitigation alternatives. AHP is a systematic and structured approach that enables the decision-maker to evaluate and compare the importance of these alternatives concerning the predefined criteria. Subsequently, the TOPSIS assesses the risk mitigation criteria and compares the results. TOPSIS analyzes these criteria by contrasting their proximity to the Positive Ideal Solution (PIS) and the furthest distance from the Negative Ideal Solution (NIS). This comprehensive approach helps identify the most effective risk mitigation strategies, ensuring a robust evaluation and selection process. In addition, it aims to establish a prioritization framework for selecting the most suitable risk mitigation criteria to enhance the quality of IFM and fulfill the research objectives effectively.

Figure 6 shows the steps used for the research methodology to assess IFMSC risks and propose strategies to manage and mitigate them from future recurrence. The steps are divided into two main phases, first identifying risks that threaten the safety of IFM, then deciding the mitigation criteria based on feedback received from the expert, and categorizing them under the key criteria of the mitigation framework. The second phase is ranking and prioritizing the mitigation criteria based on AHP and TOPSIS calculations and identifying the ones that require more attention to achieve the research objective.

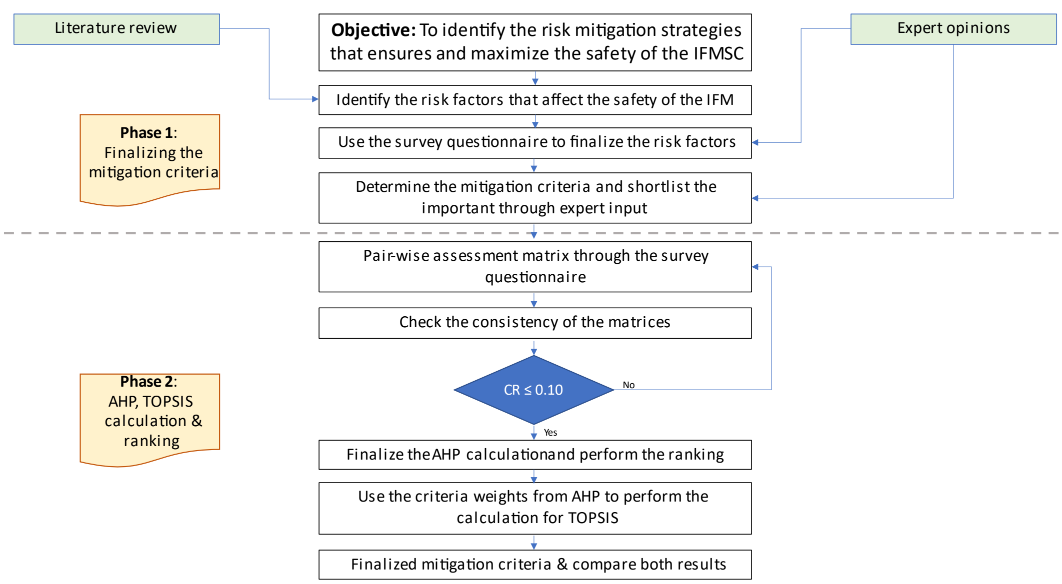

Figure 6. Research methodology

3.2. SCRM process for IFMSC Risk Mitigation

The following are detailed explanations of each step taken from the SCRM process to achieve ideal risk mitigation. Figure 7 shows each SCRM process mapped with the actions taken to achieve the required level of risk mitigation in a streamlined manner.

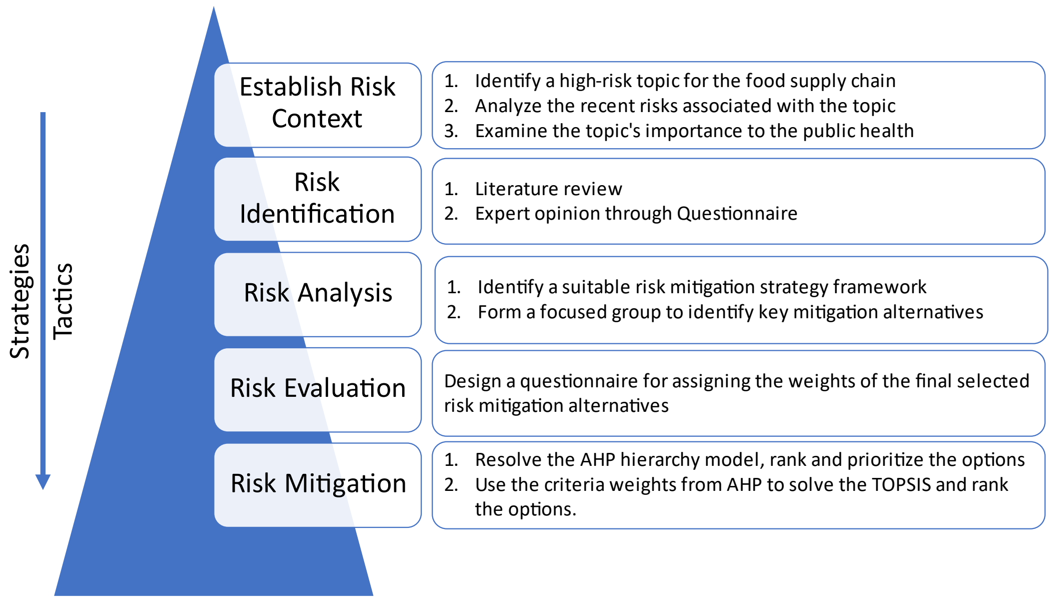

Figure 7. SCRM process mapped with strategies for mitigating IFMSC risks

3.2.1. Risk Context

There must be a threat and impact associated with any risk to mitigate it. Therefore, establishing a risk context is the first and most essential step in the thought process. This context means identifying a topic and defining its boundaries.

3.2.2. Risk Identifications

An extensive literature review was conducted to identify the risks that affect IFMs' safety. A survey questionnaire was conducted to verify the identified risks with experts and evaluate the highest risks affecting the safety of IFM. The questionnaire was distributed to receive expert assistance in rating the importance of each risk variable regarding the severity of impact on the IFMSC. The survey used a 5-point Likert scale to determine whether a selected risk should be included or excluded from the list. Potential answers ranged from 1 = negligible, 2 = marginal, 3 = significant, 4 = critical, and 5 = crisis. A survey was administered to supply chain professionals and stakeholders of the food supply chain (FSC). Participants were recruited via e-mails, phone calls, and virtual and physical interviews. The surveys were created on a Word document and distributed via a link through e-mails; some people were handed a hard copy. Surveys were collected from 45 FSC experts or stakeholders from any supply chain phase from January to February 2023.

3.2.3. Risk Analysis

Based on the five main key mitigation strategy factors proposed in the literature (acceptance, avoidance, controlling, transference, and monitoring), a focus group was formed to gather expert feedback on the mitigation strategies for each factor. The group consisted of eight experts and professionals in FSC.

3.2.4. Risk Evaluation

A hierarchical decision tree was constructed to provide an overall view of the mitigation alternatives model for selecting the finalized ones. Figure 8 illustrates its decomposition into three levels. The first level identifies the objective of the decision, which is to maximize the safety and quality of IFM. The second level of the pyramid indicates the risk criteria that determine the goal decision behavior, while the third level contains the mitigation alternatives of the candidate set. Using the AHP model hierarchy index system, weights can be assigned to each criterion based on the pairwise comparison measurement conducted to evaluate the alternative performance rating through the questionnaire survey. Pairwise comparisons were made using a questionnaire to simplify the AHP rating process. Additionally, TOPSIS was used to assess risk mitigation criteria and compare the results with those obtained from the AHP.

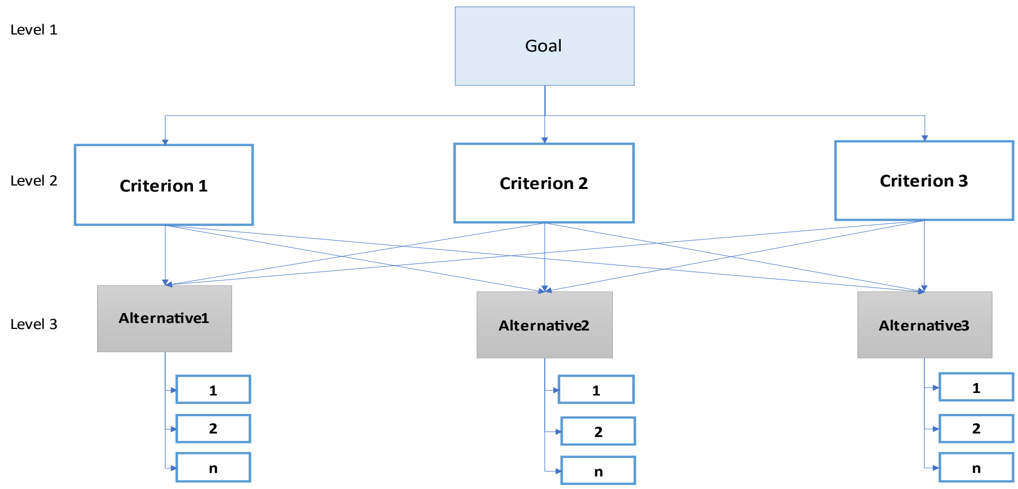

Figure 8. AHP Hierarchy model for IFMSC

Saaty developed AHP in the 1970s as a multi-criteria decision-making method (MCDM) (Saaty1980). AHP is used to calculate the subjective weights based on the decision maker's preference. It defines the weights of the criteria and alternatives through qualitative comparisons. When there is no clear best choice, the AHP is particularly useful. The method is based on developing a model to prioritize and select the best criteria to achieve the study objective. AHP is the most commonly used MCDM method and has a clear and mathematically sound structure compared to other methods. Using AHP, researchers can quantify the overall objective and numerically prioritize the analysis by breaking down complex decision problems into subproblems. Hierarchical levels assign appropriate metrics to the appropriate management levels (Saaty 1994; Reddy et al. 2019). In addition, Saaty developed a relative measurement scale for pairwise comparisons, as shown in Table 2, to determine which scale to use. Table 2 shows the measurement scale for the pairwise comparison (Haji et al. 2022; Saaty 1986).

Table 2. The measurement scale of importance for pairwise comparisons

Numerical Rating	Definition	Explanation	Reciprocal
1	Equal Importance	Two activities contribute equally to the objective	1
3	Moderate Importance	Experience and judgment slightly favor one activity over another	1/3
5	Strong Importance	Experience and judgment strongly favor one activity over another	1/5
7	Very Strong Importance	An activity is favored very strongly over another	1/7
9	Absolute Importance	Evidence favoring one activity over another is of the highest possible order of affirmation	1/9
2,4,6,8	Intermediate values	Used to represent a compromise between the priorities listed above	1/2, 1/4, 1/6, 1/8

3.2.5. Risk Mitigation

By resolving the AHP model and ranking the options, we better understood how to mitigate the risks regarding the IFM's quality. The steps used to achieve the results from the AHP were:

- Performing a pairwise comparison of elements.
- Normalizing the matrix.

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \quad (1)$$

$$w_j = \frac{1}{n}\sum_{i=1}^{n} x_{ij} \quad (2)$$

- Calculating the consistency index (CI)

$$\text{Consistency Index (CI)} = \frac{\lambda_{max} - \text{n}}{\text{n} - 1} \quad (3)$$

where λ_{max} is the largest eigenvalue, and n represents the number of mitigation attributes.

- Calculating consistency ratio (C.R.)

$$\text{Consistency Ratio (C.R.)} = \frac{\text{CI}}{\text{RCI}} \quad (4)$$

As a result of dividing the CI by the RCI, we obtain the C.R. The upper limit should not exceed 0.1 to ensure the C.R. condition is satisfied (Wang et al. 2018).

Random consistency index (RCI) = chosen following the order of the indicators (n) in the comparison matrix with the Saaty proposed table, as shown in Table 3, where for n = 3, it equals 0.58, and for n = 8, it equals 1.41.

Table 3. Random consistency index

n	1	2	3	4	5	6	7	8	9	10
RCI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

The TOPSIS) is another MCDM method that has gained popularity in various fields due to its simplicity and effectiveness in solving complex decision problems. TOPSIS was first introduced by Hwang and Yoon in 1981 as a method for solving MCDM problems. Since then, it has undergone several modifications and extensions to adapt to diverse decision contexts. The method's name is derived from its fundamental principle, which identifies the ideal and anti-ideal solutions among a set of alternatives based on the shortest and longest distances, respectively. TOPSIS has found applications in various domains, including finance, engineering, environmental management, healthcare, and business. The steps used to achieve the results from the TOPSIS were:

- Normalization: TOPSIS begins with the normalization of the decision matrix to ensure that criteria are on the same scale and that no criterion dominates due to its measurement unit. This step is crucial for fair comparisons (r_{ij}).
- Weighting: Depending on the context, criteria may be assigned weights to represent their relative importance. These weights influence the final ranking of alternatives (w_{ij}) & (v_{ij}). The AHP method was used for steps 1 & 2.

$$v_{ij} = w_{ij} r_{ij} \quad (5)$$

- Ideal and Anti-Ideal Solutions: TOPSIS identifies the ideal or positive ideal solution (maximizing all benefits and minimizing all costs) and the anti-ideal or negative ideal solution (minimizing all benefits and maximizing all costs) in the normalized decision matrix.

$$\text{A}^{+} = \{ v_1^{+}, v_2^{+}, \ldots, v_n^{+}\} \text{ where } v_j^{*} = max_i v_{ij} \text{ for benefit and } v_j^{*} = min_i v_{ij} \text{ for cost} \quad (6)$$

$$\text{A}^{-} = \{ v_1^{-}, v_2^{-}, \ldots, v_n^{-}\} \text{ where } v_j^{-} = min_i v_j^{-} \text{ for benefit and } v_j^{-} = max_i v_{ij} \text{ for cost} \quad (7)$$

- Proximity Measures: The method uses proximity measures, such as Euclidean distance or other distance metrics, to assess how closely each alternative approaches the ideal and anti-ideal solutions.

Positive ideal separation formula:

$$S_i^{+} = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^{*}\right)^2} \quad (8)$$

Negative ideal separation formula:

$$S_i^- = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^-)^2} \quad (9)$$

- Relative Closeness: Alternatives are ranked based on their relative closeness to the ideal solution. The one with the shortest distance to the ideal solution and the longest distance from the anti-ideal solution is considered the best choice.

$C_i = \frac{S_i^-}{S_i^+ + S_i^-}$ $and\ 0 \leq C_i^+ \leq 1$; where Ci % is the TOPSIS performance score. (10)

4. Results and Discussion

This section presents the results achieved and discusses them in a structured manner. The results are presented in three sub-sections. The first section contains the results of the first questionnaire for risk identification. The focus group results are presented in the second section, and the more appropriate mitigation criteria are selected. In the final section, we present the AHP and TOPSIS models' results separately for comparison to rank mitigation strategies for IFM.

4.1. Risks Associated with the Safety of IFM

This section presents the results of the risk verification survey questionnaire. We identified 160 risks from the literature that will affect the safety of the IFM, and after filtering out duplicates, 100 were deemed valid. After that, we combined the ones with a similar meaning, resulting in 50 risks. A total of 10 risks were found under the environmental risk event, 24 under the operational risk event, and 16 under the quality risk event. Based on the survey questionnaire, we calculated the expert score opinion for each risk. The selection was focused mainly on risks, with the highest score being considered the most severe risks marked as '5 = crisis.' The geometric means (∏) for the reoccurrence were calculated based on all decision makers' weighted criteria, as shown in Table 4. Therefore, those risk agents were selected for further analysis.

Table 4. Score of the selected risk agents

Risk Event	Risk Agent	Total Risks	∏
Environmental Risk	Lack of an assessment of environmental and natural disasters	10	7
Operational Risk	Lack of visibility and potential traceability of products	24	11
Quality Risk	Contamination (microbial/biochemical)	16	9

Table 5 shows the demographics of participants from the survey questionnaire.

Table 5. Demographics of participants

	Frequency	Percentage (%)
Gender		
Male	23	51
Female	22	49
Total	45	100
Professional Experience		
Experienced in supply chain management	12	26.6
A professional in food supply chain management (sourcing, procurement, warehousing, distribution, retailing)	15	33.4
Food consumer	18	40
Total	45	100.0
Activity in Food Supply Chain		
Supplying raw materials	1	2.2
Manufacturing	4	8.9
Packaging	3	6.7
Distributing	5	11.1
Retailing	32	71.1

Total	45	100.0
Years of Experience		
>10 years	15	33.3
1–3 years	12	26.7
4–6 years	10	22.2
7–9 years	8	17.8
Total	45	100.0

4.2. List the Risk Mitigation Criteria for Evaluation

Based on the interview results and depending on the five key mitigation strategies proposed earlier, experts' comments were analyzed and arranged in the vertical bullet list diagram shown in Figure 9. Five mitigation strategies are available for each risk agent, with the finalized ones highlighted in red.

Environmental Risk
(ER) Lack of an assessment of environmental and natural disasters

- ER.M1 - Acceptance: Maintain a steady pace of production and deliveries so that the market demand can be met.
- ER.M2 - Avoidance: Plan and prepare hazard mapping to protect infant formula milk logistics and make sure deliveries are safe.
- ER.M3 - Controlling: Management to consider knowledgeable and dedicated team to measure and study the climate change, un expected natural calamities and safely mitigate their effects.
- ER.M4 - Transference: Authorities must invest in modern technologies to anticipate unavoidable natural disasters and mitigate their effects.
- ER.M5 - Monitoring: Monitor climate change closely.

Operational Risk
(OR) Lack of visibility and potential traceability of products

- OR.M1 - Acceptance: Communication and collaboration between stakeholders within the IFMSC, regardless of their trust level.
- OR.M2 - Avoidance: Develop an interactive team management system to promote transparency and effective communication.
- OR.M3 - Controlling: Implement advanced traceability technology to ensure IFM safety.
- OR.M4 - Transference: Establish a good relationship with infant formula milk raw material suppliers to build trust.
- OR.M5 - Monitoring: Get regular feedback from your stakeholders and customers.

Quality Risk
(QR) Contamination (microbial/biochemical)

- QR.M1 - Acceptance: Verify the time-temperature traceability of IFM throughout the supply chain to ensure its safety.
- QR.M2 - Avoidance: The IFM must undergo a precise test and quality check at each stage of the supply chain and before it is being delivered to consumers.
- QR.M3 - Controlling: Educate consumers concerning the risks associated with buying IFM online from unknown sources.
- QR.M4 - Transference: Recall defective batches in an effective and successful manner.
- QR.M5 - Monitoring: Assess the performance of the IFM manufacturers to decrease the risk of flawed products.

Figure 9. Focus group results on mitigation alternatives and their codes.

4.3. The AHP Model for Identifying the Best Mitigation Options

Figure 10 depicts the final AHP hierarchy model tree with the final mitigation options selected from the previous step to ensure the safety of IFMSC.

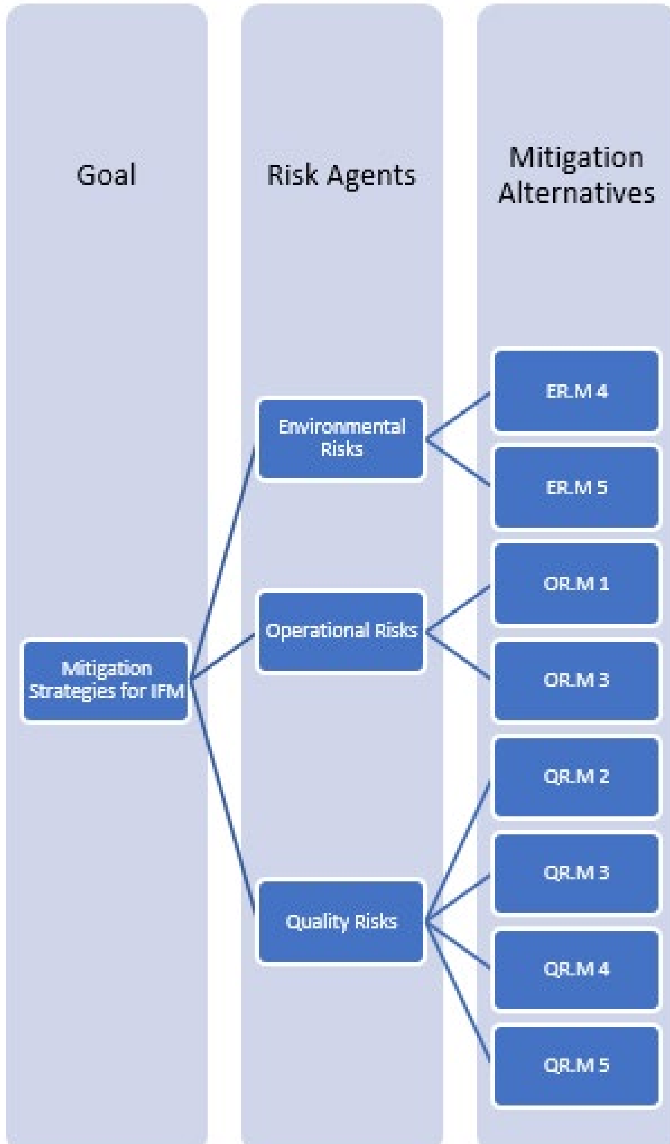

Figure 10. Finalized AHP mitigation alternatives hierarchy

In the first step of running the model, the decision matrix is constructed by comparing the mitigation attributes pairwise, as shown in Table 6, and the performance score is calculated by the decision-makers using Table 2.

Table 6. Pairwise comparison of mitigation criteria factors

	ER.M4	ER.M5	OR.M1	OR.M3	QR.M2	QR.M3	QR.M4	QR.M5
ER.M4	1	2	2	4	0.5	4	5	3
ER.M5	0.5	1	0.5	2	0.33	2	4	3
OR.M1	0.5	2	1	2	0.5	2	3	4
OR.M3	0.25	0.5	0.5	1	0.33	3	2	2
QR.M2	2	3	2	3	1	5	5	7
QR.M3	0.25	0.5	0.5	0.33	0.2	1	2	3
QR.M4	0.2	0.25	0.33	0.5	0.2	0.5	1	2
QR.M5	0.33	0.33	0.25	0.5	0.14	0.33	0.5	1
Sum	5.03	9.58	7.08	13.33	3.20	17.83	22.5	25

Following this, the decision matrix is normalized by converting attributes to non-dimensional types using Equation (1). A weighted normalized decision matrix can be calculated using Equation (2). The C.R. is calculated before the ranking, as shown in Table 7, and is 0.039, less than 0.1, showing our matrix has a reasonable consistency.

Table 7. Results of the consistency test

Lambda Max.	CI	RCI	CR
8.39	0.056	1.41	0.039

Table 8 shows the final weighted normalized matrix and ranking. The topmost ranking goes to QR.M2. It refers to the mitigation alternative requiring a precise test and quality check along the supplier chain before the IFM is delivered. The QR.M2 alternative has been classified as avoiding the risk mitigation strategy illustrated in Figure 9. This classification makes sense, particularly when talking about a product that infants will consume, and it is inappropriate in this case to accept, control, transfer, or monitor our risks. Ensuring the IFM is of high quality at every stage of the FSC is critical to ensuring product safety. The quality control model that Chen et al. (2014) proposed with an emphasis on the Chinese dairy industry is not recommended because the decentralized supply chain structure may lead to distortions in product quality depending on the sampling technology. Stakeholders within the supply chain cannot benefit from a centralized and single authority system (Permana et al. 2019). Therefore, the best way to manage quality would be to find an equilibrium between both models without giving any part of the supply chain a single authority point. Even though the IFM undergoes extensive quality control throughout the supply chain and before it is delivered to consumers, this must occur at each supply chain phase, where all authorized stakeholders can view and provide status updates as the IFM moves through their supply chains.

Table 8. Weighted normalized matrix of mitigation criteria factors

	ER.M4	ER.M5	OR.M1	OR.M3	QR.M2	QR.M3	QR.M4	QR.M5	Weights	Ranks
ER.M4	0.20	0.21	0.28	0.30	0.16	0.22	0.22	0.12	0.21	2
ER.M5	0.10	0.10	0.07	0.15	0.10	0.11	0.18	0.12	0.12	4
OR.M1	0.10	0.21	0.14	0.15	0.16	0.11	0.13	0.16	0.14	3
OR.M3	0.05	0.05	0.07	0.07	0.10	0.17	0.09	0.08	0.08	5
QR.M2	0.40	0.31	0.28	0.22	0.31	0.28	0.22	0.28	0.29	1
QR.M3	0.05	0.05	0.07	0.02	0.06	0.06	0.09	0.12	0.07	6
QR.M4	0.04	0.07	0.08	0.04	0.06	0.03	0.04	0.08	0.04	7
QR.M5	0.07	0.03	0.03	0.04	0.04	0.02	0.02	0.04	0.04	8
Sum	1	1	1	1	1	1	1	1	1	

4.4. The TOPSIS Model for Identifying the Best Mitigation Options

The strengths and limitations of AHP and TOPSIS make them suitable for different decision-making contexts. In pairwise comparisons, AHP might be sensitive to the consistency of judgments made due to subjective preferences and hierarchical structures. AHP can also be complex and time-consuming to manage many criteria or alternatives. TOPSIS, on the other hand, is more straightforward and suitable for situations where criteria interdependencies are not crucial. According to TOPSIS, however, all criteria are equally important, and subjectivity in weighting is not explicitly addressed. In MCDM, the choice depends on the specific decision context and the problem being addressed. Using TOPSIS, we compared the AHP results and determined if the proposed model was valid. Because the matrix has proven consistent, the criteria weights can be used from the AHP step. A calculation of the ideal best A^+ and ideal worst A^- is shown in Table 9.

Table 9. Ideal beat and ideal worst of TOPSIS calculations

	ER.M4	ER.M5	OR.M1	OR.M3	QR.M2	QR.M3	QR.M4	QR.M5
ER.M4	0.20	0.21	0.28	0.30	0.16	0.22	0.22	0.12
ER.M5	0.10	0.10	0.07	0.15	0.10	0.11	0.18	0.12
OR.M1	0.10	0.21	0.14	0.15	0.16	0.11	0.13	0.16
OR.M3	0.05	0.05	0.07	0.07	0.10	0.17	0.09	0.08
QR.M2	0.40	0.31	0.28	0.22	0.31	0.28	0.22	0.28
QR.M3	0.05	0.05	0.07	0.02	0.06	0.06	0.09	0.12
QR.M4	0.04	0.07	0.08	0.04	0.06	0.03	0.04	0.08
QR.M5	0.07	0.03	0.03	0.04	0.04	0.02	0.02	0.04
(A^+)	0.43	0.35	0.30	0.34	0.29	0.33	0.23	0.26
(A^-)	0.04	0.03	0.04	0.03	0.04	0.02	0.02	0.04

Table 10 shows the calculation for the Euclidean distance and assesses how closely each alternative approaches the ideal best and ideal worst solutions. Following this, the alternatives are ranked according to how close they are to the ideal solution. The best choices are those with the shortest distances to the ideal solutions.

Table 10. TOPSIS calculations and ranking of mitigation criteria factors

Criteria	A^+	A^-	S_i^+	S_i^-	C_i	%	Ranks
ER.M4	0.43	0.04	0.33	0.63	0.66	65.79	2
ER.M5	0.35	0.03	0.58	0.60	0.51	51.08	4
OR.M1	0.29	0.04	0.50	0.58	0.54	53.62	3
OR.M3	0.34	0.03	0.67	0.66	0.50	49.78	5
QR.M2	0.29	0.04	0.09	0.68	0.89	88.80	1
QR.M3	0.33	0.02	0.73	0.71	0.49	49.11	6
QR.M4	0.23	0.02	0.78	0.75	0.49	48.88	7
QR.M5	0.26	0.04	0.79	0.76	0.49	48.81	8

In Table 11, the model shows that both AHP and TOPSIS calculations yield comparable criteria ranking results, highlighting the decision-making process's robustness. The convergence of these two distinct methodologies in determining similar criterion rankings highlights the reliability and consistency of the decision-making approach. Despite their unique methods, their alignment strengthens confidence in the identified priorities. This consistency bolsters the credibility of the identified criteria and reinforces their relative significance within the decision-making process. Moreover, this alignment affirms the consistency and validation of criteria rankings, irrespective of varying methodologies and computational approaches. Such coherence allows decision-makers to direct their focus and resources towards consistently critical factors in the decision process.

Table 11. Comparison results of AHP vs. TOPSIS for mitigation criteria factors

Criteria	ER.M4	ER.M5	OR.M1	OR.M3	QR.M2	QR.M3	QR.M4	QR.M5
AHP Ranks	2	4	3	5	1	6	7	8
TOPSIS Ranks	2	4	3	5	1	6	7	8

4.5. Sensitivity Analysis

Using MCDM requires a sensitivity analysis to examine the impact of using different weights for risk mitigation criteria when selecting risk mitigation measures that ensure the safety and quality of IFM. Table 12 presents the details of ten test cases for the sensitivity analysis. The overall results indicate that, despite slight changes in rank, QR.M2 generally appears to be the best mitigation alternative regardless of weight changes. As a result, it is unsurprising that the factors' weights tend to remain relatively stable during the decision-making process.

Table 12. Sensitivity analysis

Alternative Code	**Original Ranking**	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Test 6**	**Test 7**	**Test 8**	**Test 9**	**Test 10**
ER.M4	2	4	3	2	2	2	2	2	2	2	2
ER.M5	4	2	4	3	5	4	4	4	4	4	6
OR.M1	3	3	2	4	3	7	5	6	8	3	3
OR.M3	5	5	5	5	4	5	3	5	5	7	5
QR.M2	1	1	1	1	1	1	1	1	1	1	1
QR.M3	6	6	6	6	6	6	6	3	6	6	4
QR.M4	7	7	7	7	7	3	7	7	7	5	7
QR.M5	8	8	8	8	8	8	8	8	3	8	8
Ranking Order	QR.M2 > ER.M4 > OR.M1 > ER.M5 > OR.M3 > QR.M3 > QR.M4 > QR.M5 QR.M2 > ER.M5 > OR.M1 > ER.M4 > OR.M3 > QR.M3 > QR.M4 > QR.M6 QR.M2 > OR.M1 > ER.M4 > ER.M5 > OR.M3 > QR.M3 > QR.M4 > QR.M5 QR.M2 > ER.M4 > ER.M5 > OR.M1 > OR.M3 > QR.M3 > QR.M4 > QR.M5 QR.M2 > ER.M4 > OR.M1 > OR.M3 > ER.M5 > QR.M3 > QR.M4 > QR.M5 QR.M2 > ER.M4 > QR.M4 > ER.M5 > OR.M3 > QR.M3 > OR.M1 > QR.M5 QR.M2 > ER.M4 > OR.M3 > ER.M5 > OR.M1 > QR.M3 > QR.M4 > QR.M5 QR.M2 > ER.M4 > QR.M3 > ER.M5 > OR.M3 > OR.M1 > QR.M4 > QR.M5 QR.M2 > ER.M4 > QR.M5 > ER.M5 > OR.M3 > QR.M3 > QR.M4 > OR.M1 QR.M2 > ER.M4 > OR.M1 > ER.M5 > QR.M4 > QR.M3 > OR.M3 > QR.M5 QR.M2 > ER.M4 > OR.M1 > QR.M3 > OR.M3 > ER.M5 > QR.M4 > QR.M5										

According to the correlation between the original ranking and the ten tests conducted, they are highly correlated at 0.836. The outcome of a simple calculation of the frequency repetition of each mitigation alternative shows a stable ranking pattern, with QR.M2 and QR.M5 ranking 1st and 8th in all ten tests, respectively. Similarly, ER.M4, QR.M3, and QR.M4 have been ranked 2nd, 6th, and 7th eight times, respectively. The OR.M3 rank repeats seven times, while ER.M5 repeats six times. There was only one alternative that did not show a stable pattern, which was OR.M1, which duplicated the original ranking twice, as depicted in the graphical representation of the sensitivity analysis in Figure 11.

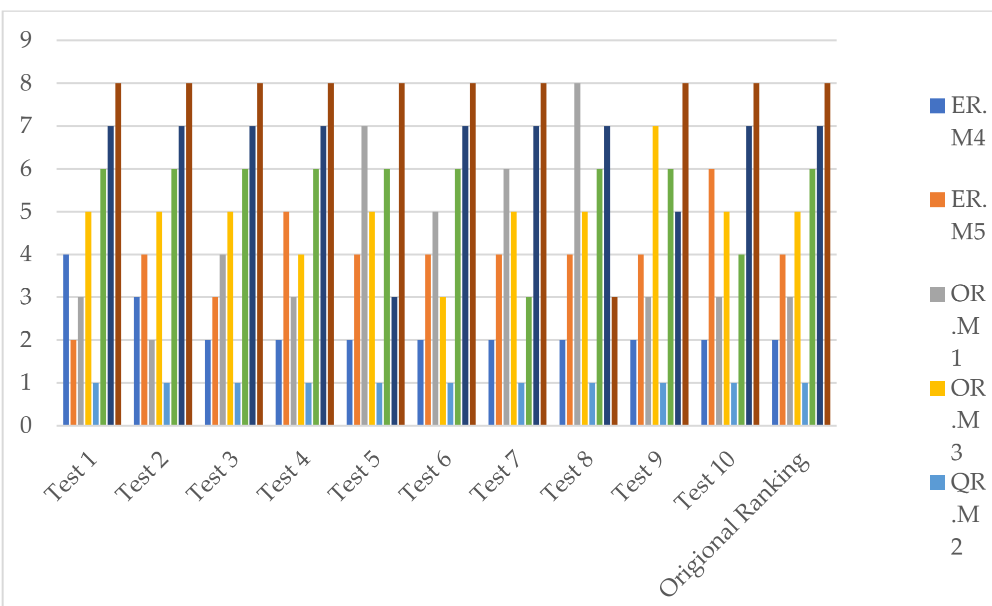

Figure 11. Sensitivity analysis correlation graph

5. Conclusions

Nowadays, food quality is increasingly a focus of our society due to the evolution of science and advancements in modern technology. Several food quality incidents have recently occurred, negatively impacting suppliers' reputations and consumers' interests and significantly impacting public health. Taking special care regarding infant formula milk (IFM) is crucial because we are dealing with newborns and babies. Infants are more likely to become infected with foodborne pathogenic bacteria due to their immature immune systems and the permeability of their digestive tracts.

The IFM has been a target of smugglers and those looking to make illegal high profits, like the Chinese scandal in 2008 when melamine was added to deceive consumers by increasing the white color to look like concentrated protein. In addition, Abbott Laboratories issued a massive recall in February of 2022 after acknowledging that some versions of Similac, Alimentum, and EleCare baby formula contained Salmonella Newport and Cronobacter Sakazakii bacteria. A lab report confirmed that IFMs were contaminated, and the production facility failed to maintain sanitary conditions.

Food safety involves several links between the actors of the infant formula milk supply chains (IFMSCs), including but not limited to the suppliers of raw materials, manufacturers, transporters and distributors, and standards of storage facilities to ensure adherence to quality (Ji and Ko 2022). The authors of the current research identified a gap in the literature on how to overcome the concerns and challenges in the IFMSCs to ensure the quality of IFM. Therefore, this study aimed to evaluate the performance measurement of IFM in the supply chain by identifying the most critical risks that can affect IFM quality, emphasizing the essential criteria, and mitigating them appropriately to eliminate the rate of adulteration and contamination. As part of mitigating risks, specific steps were taken to understand the different processes for supply chain risk mitigation (SCRM), starting with identifying the risk, analyzing it, evaluating it, and finally, eliminating or limiting setbacks. The research employed the triangulation paradigm (literature analysis, surveys, and interviews) to ensure that qualitative and quantitative tools were combined effectively, thus improving the reliability of data collection and verification. A predefined environmental, operational, and product quality information dimension was used to identify IFMSC risk factors. The predefined dimensions were also used to categorize 50 of 160 risks.

According to the survey questionnaire results, three risks were classified as crisis issues and selected, including "Lack of assessment of environmental and natural disasters," "Lack of visibility and potential traceability of products," and "Contamination (biochemical/microbial)." For risk analysis, expert feedback was required on the mitigation strategies for each of the five major mitigation strategy factors (acceptance, avoidance, controlling, transference, and monitoring).

An analytic hierarchy process (AHP) model was developed to prioritize mitigation strategies for the IFMSC based on expert feedback to maximize safety. A similar ranking based on the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method is then obtained, highlighting the robustness of the decision-making process. This convergence of two distinct methodologies in determining similar criterion rankings highlights the consistency and reliability of the decision-making process. To maximize the quality of the IFM, QR.M2 was ranked highest and most important, based on an avoidance strategy from the five key mitigation strategies. This makes sense, particularly when we are discussing a product for infants. Accepting, controlling, transferring, or monitoring our risks is inappropriate in this situation. Public health, especially infant health, depends on avoiding risks, and IFM must undergo precise testing and quality checks at every stage of the supply chain to ensure its quality. Although IFMs require extensive quality control throughout the food supply chain (FSC) before they are delivered to consumers, finding an equilibrium point between the centralized and the decentralized models without giving a single authority point to any part of the supply chain is imperative. The decentralized supply chain model distributes the supply chain's activities from a central authority and gives equal control to all stakeholders. As a result, a semi-decentralized model could be enhanced by using traceability technology as a decentralized control and avoiding giving one authority point to a specific stakeholder or part of the chain, thus, allowing them to collaborate and work effectively even in the absence of trust (Haji et al. 2021; Haji et al. 2022). The causes and impacts of each risk could be studied systematically in future research for each phase of the IFSC. Further analysis of the costs and benefits of implementing technologies in the IFMSC might provide insight into the importance of the support gained through their implementation. It is possible to apply other risk identification methods to see if the same results can be achieved and to compare the differences.

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Biography

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