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Development of Risk Management Mitigation Plans for the Infant Formula Milk Supply Chain Using an AHP Model

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Abstract: Infant formula milk (IFM) is critical in the diet of many babies and must be of high-quality. Unfortunately, IFM has been a target of adulteration 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 Analytic Hierarchy Process (AHP) model was used to analyze and prioritize mitigation alternatives. According to the contamination quality risk agent, mitigation alternative (QR.M2) ranked highest. This study's findings illustrate how vital avoiding risk is 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

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1. Introduction

Infant milk is the first product in a baby's diet that must be of high-quality to ensure healthy growth and development. Of the two sources of infant milk, the main one is breast milk, recognized as the ideal form of infant feeding, and providing multiple benefits for a child's health. The promotion, protection, and support of breastfeeding is therefore critical. All organizations worldwide strongly recommend breastfeeding because of its numerous benefits, but it might not always be appropriate, feasible, or adequate for all children [1]. 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 [2]. When the quality of IFM is high, it can be an effective substitute for breastfeeding. For the first six months of a child's life, breastfeeding should be the sole source of nutrition. 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 [1].

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 [3]. There are also different types of preparation forms for IFMs: (1) Powder. The most common and economical form of infant formula that must be mixed with water before feeding; (2) Liquid. A concentrated liquid that must be mixed with an equal amount of water; and (3) Ready-to-feed. The most expensive form of infant formula that does not require mixing [1].

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 deceptively increase its purported protein concentration, as assessed by nitrogen measurement, and appears to meet the national standard for milk protein. 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 [4]. 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 [5].

Infant formula milk supply chain (IFMSC) actors are crucial to ensure IFM quality and safety, particularly raw material suppliers and manufacturers. 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 has identified a gap in the literature on overcoming the concerns and challenges in the IFMSC to ensure its quality that has never been addressed. The current study aimed to develop a model that maximizes IFM safety and eliminates adulteration and contamination rates. Using the analytic hierarchy process (AHP) 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;
- 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. In Section 2, we review the literature. In Section 3, we describe the methods used to collect the data for the study. This description includes the research approach, design, data collection method, research philosophy, and data analysis method. The findings of the research are presented in Section 4. A triangulation process is also used to ensure that findings and results are aligned with the literature from relevant studies. Section 5 is the last part of the study, which presents 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.

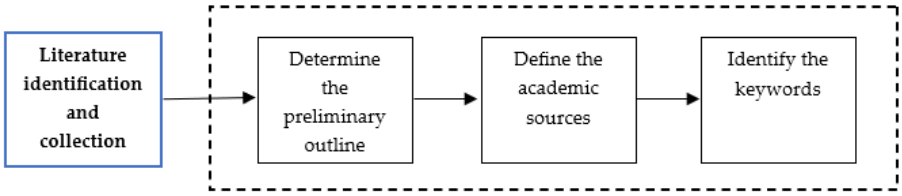

Figure 1. Literature identification and collection.

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 three categories: environmental, operational, and quality.

Step 2: Define the academic sources.

Library search engines such as Google Scholar, Researchgate, Science Direct, Scopus, and Springer Link were used to conduct the literature search. Book chapters were also used to enhance the search results and add more value to the review. The use of all these search engines provided a diversified knowledge base with a range of relevant concepts, as well as enhanced recognition of risk factors and mitigation strategies.

Step 3: Identify the keywords.

We focused our search on secondary sources published in English only, since primary sources were insufficient. Different keywords covering the objectives of the review were identified.

The keywords were categorized into two areas. The first area looked into the issues with infant formula milk 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 is one pillar of public health that ensures 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 [6]. Adulteration, contamination, and other IFM issues are certainly not limited to low-income countries; they are common, and cases were discovered in high-income countries too. A recent example is Abbott Laboratories' massive 2022 recall of IFMs due to Salmonella Newport and *Cronobacter sakazakii* bacteria, also known as *Enterobacter sakazakii* (E.S.).

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 [7]. In addition, Bacillus cereus contamination in IFMs has been well-documented in past literature [8,9]. IFM, whether in liquid or powder form, is an ideal medium for bacterial growth that poses a potential risk of foodborne illness [10]. 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 [11]. 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 [12].

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 [13]. Melamine is a component of flame retardants, glues, and plastics but is prohibited for human or animal consumption [14]. Nevertheless, it has been used illegally as an additive to food such as rice [15] and IFMs [16]. As a legal ingredient in packaging materials and feeds for poultry and livestock, melamine can be present but at low levels.

It could also be a metabolite of the cyromazine pesticide [17]. 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 [18]. Therefore, milk safety regulators should focus their monitoring resources on supervising milk sold in reputedly trustworthy stores and not allow exemptions from inspections [19].

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 [6]. 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 [20]. 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 [21].

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 [22]. 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 [23]. For the risks to be sufficient to generate a crisis, they, if left unattended, can become a catastrophe [24].

Various scholars have defined supply chain risk (SCR) differently, and no consensus exists on what it means [25,26]. According to Kumar et al., an SCR is any deviation from the primary goal that may lead to an overall reduction in the value-added process [27]. As Zsidisin [28] 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 categorized by Kern et al. [29]. An example of operational risk is a failure that can cause supply demand inconsistency [30].

Operational risks include malfunctioning equipment, failures of supplies, and strategy failures. Disruptive risks, however, are caused by human-made or natural catastrophes, such as terrorist attacks and natural disasters [31]. Unlike operational risks, disruptive risks are harder to control. According to Jüttner et al. [32], 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 [33]. Risks imposed by crucial products are higher 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. [34], 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) [35].

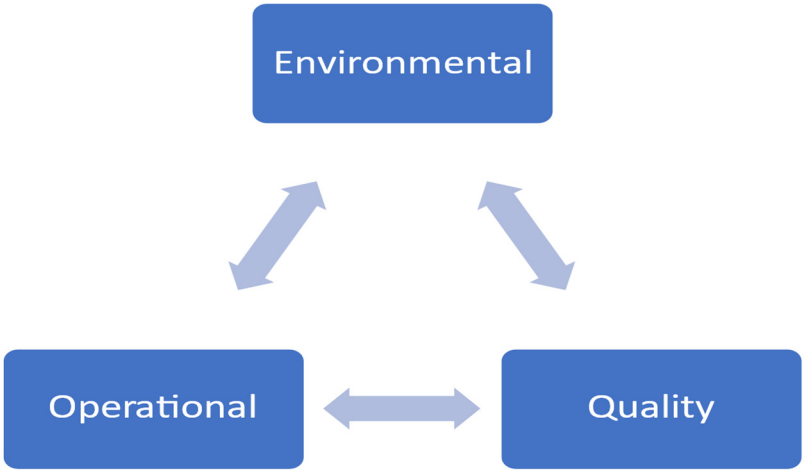

Figure 2. Dimensions of IFMSC risk factors.

2.3.1. Environmental Risks

Environmental risks connect the environment to human health. 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 [36]. 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 [37]. Therefore, identifying environmental risk factors is crucial to public health decision-making [38–43].

2.3.2. Operational Risks

Operational risk is the risk of losses resulting 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 [44]. It is crucial to understand and monitor the underlying issues that can affect the performance of any process in the supply chain 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 [45]. Operational risks can also impede the monitoring of flawed product recalls due to quality standards breaches [46]. Azizsafaei et al. [37] 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 [47,48].

2.3.3. Quality Risks

Identifying and analyzing quality information is important 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 [35]. Information on quality involves time series conditions and dynamic risk analysis, which can cumulatively affect the entire supply chain [47].

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 Economic factors and market dynamic Epidemic diseases Exploitation Lack of an assessment of environmental and natural disasters Political instability Product life cycle risk Regulation changes Sanctions Transportation issues–unavailability of fuel, congestion, weather, illness	Breen [49]; Jaberidoost et al. [50]; Kumar et al. [22]; Haji et al. [48]; Azizsafaei et al. [47]; Haji et al. [51]
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	Breen [49]; Jaberidoost et al. [50]; Kumar et al. [22]; Ayyildiz & Taskin Gumus [52]; Permana et al. [53]; Haji et al. [48]; Azizsafaei et al. [47]; Haji et al. [51]

Table 1. *Cont.*

Risk Sources	Risk Variables	Author, Year
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	Breen [49]; Jaberidoost et al. [50]; Liu et al. [35]; Kumar et al., 2019; Permana et al. [53]; Haji et al. [48]; Azizsafaei et al. [47]; Haji et al. [51]

2.4. SCRM Process

Properly understanding SCRM begins with understanding the different processes that must be followed. Even though different studies propose different frameworks for the processes [54–58], most agree with the steps illustrated in Figure 3.

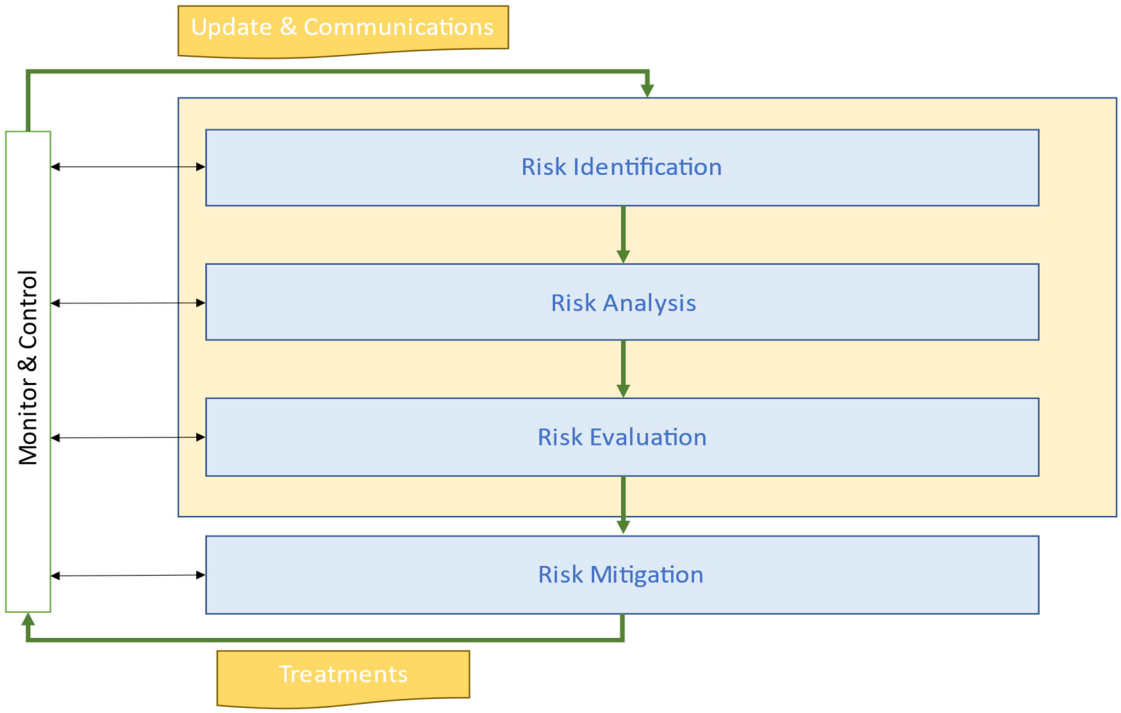

Figure 3. SCRM processes.

2.4.1. Risk Identification

For SCRM, identifying risks is the first and most critical step to understanding and addressing the threat level appropriately. The process involves identifying risk types, factors, or combinations [26].

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 [59].

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 investigate each activity related to a specific risk thoroughly, check out the activities' efficiency, and discover the flaws in their implementation [60]. 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 [61]. Risk mitigation involves reducing risks to a level the supply chain organization can tolerate or accept [62]. 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 [63]. 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 [64]. 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 [65]. Having gained a better understanding of how other supply chain elements affect risk susceptibility, organizations have begun to focus on managing supply chain risk [62]. 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 [66] five mitigation strategies. Figure 4 depicts the key strategies for risk mitigation.

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: This 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.

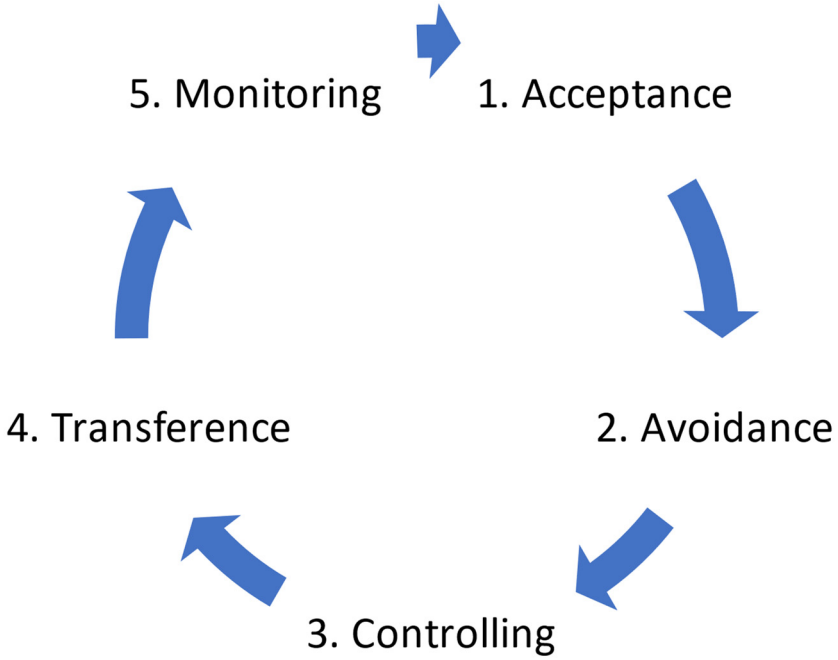

Figure 4. Classification of risk mitigation strategy factors.

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 [67]. Combining literature analysis, surveys, and interviews improved data collection reliability and verification. See Figure 5.

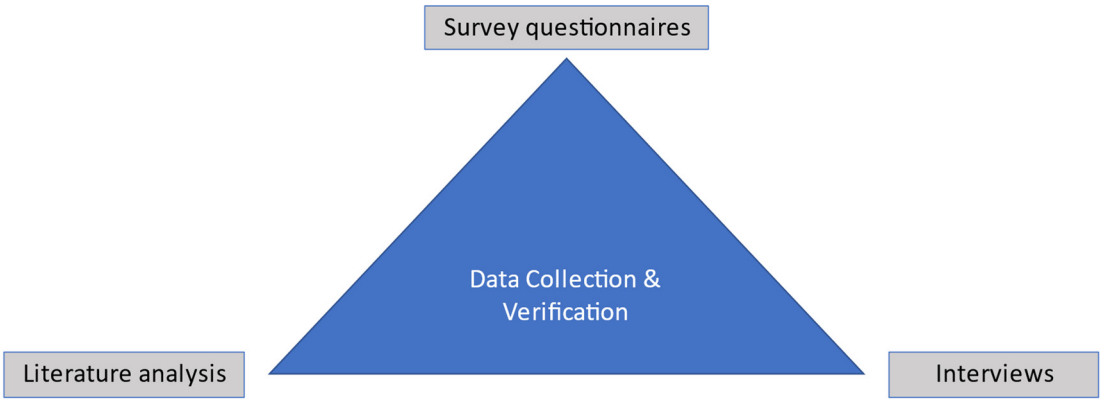

Figure 5. Triangulation paradigm for data collection and verification.

3.1. Research Methodology

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 calculation and identifying the ones that require more attention to achieve the research objective.

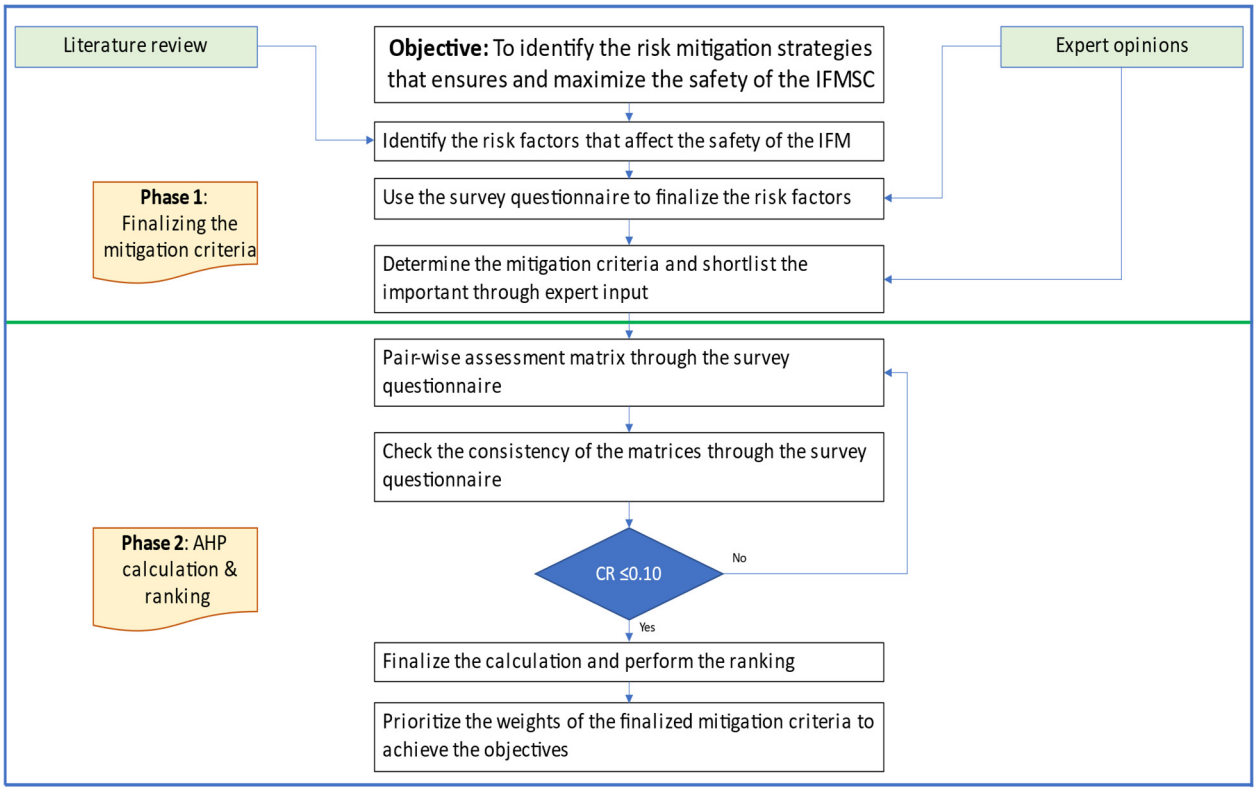

Figure 6. Research methodology.

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.

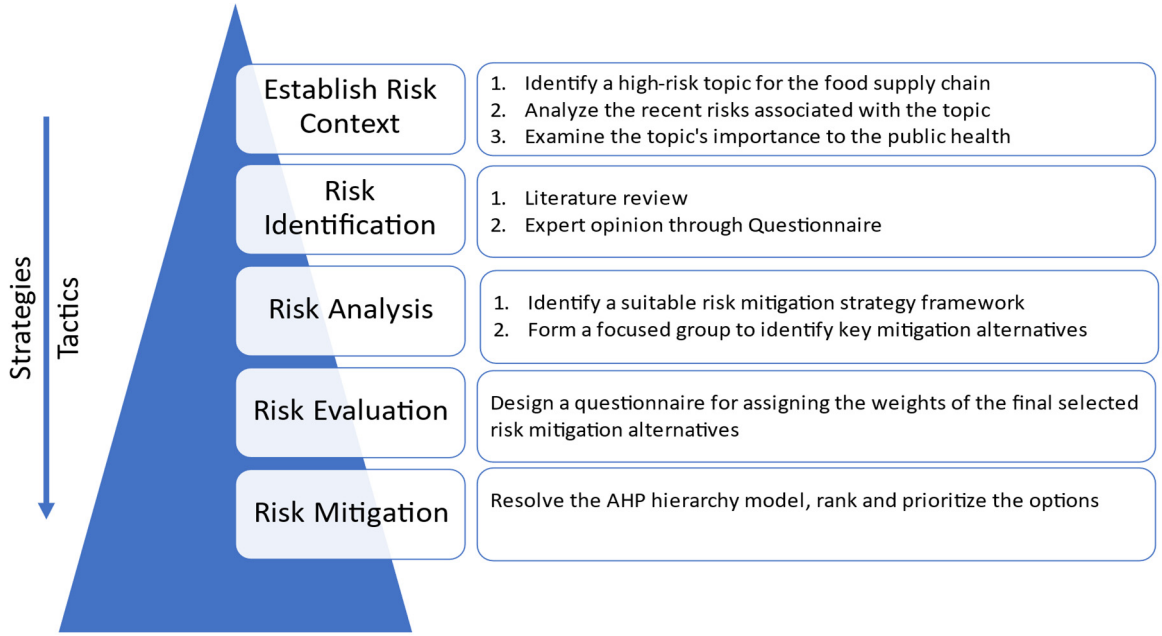

Figure 7. SCRM process mapped with strategies for mitigating IFMSC risks.

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 designed to simplify the AHP rating process.

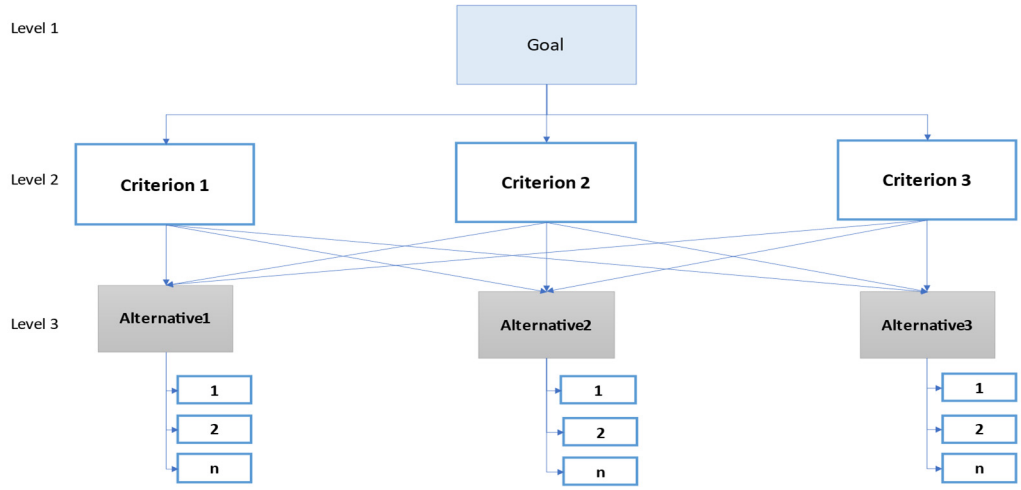

Figure 8. AHP Hierarchy model for IFMSC.

Saaty developed AHP in the 1970s as a multi-criteria decision-making method (MCDM) [68]. 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. Although AHP is the most commonly used MCDM method, it 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 [69,70]. 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 [51,71].

Table 2. The measurement scale 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 [72].

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

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. Last, the results based on the AHP model used for ranking the mitigation strategies for IFM are presented.

4.1. Risks Associated with the Safety of IFM

In this section, the results of the risk verification survey questionnaire are presented. We identified 160 risks that will affect the safety of the IFM from the literature, 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

Table 5. *Cont.*

	Frequency	Percentage (%)
Professional Experience		
Experienced in supply chains 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.

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.

In the first step of running the model, the decision matrix is constructed by comparing the mitigation attributes pairwise as it is 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

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.

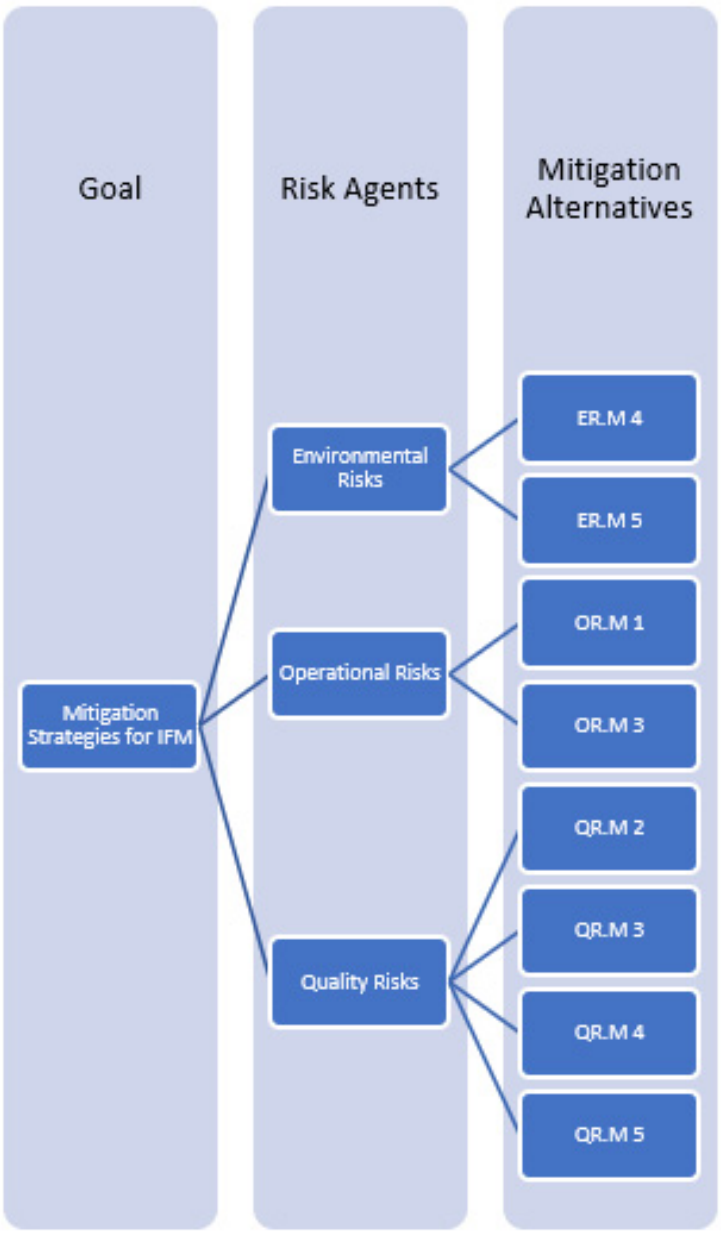

Figure 10. Finalized AHP mitigation alternatives hierarchy.

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, which is 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 8. 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. [73] 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 [53]. 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. 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. The details of ten test cases are presented in Table 9 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 9 presents the results of the sensitivity analysis.

Table 9. 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 > QR.M3 > OR.M1 > 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 > OR.M3 > QR.M4 > QR.M3 > QR.M5	QR.M2 > ER.M4 > OR.M1 > OR.M3 > QR.M4 > QR.M3 > OR.M3 > 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.

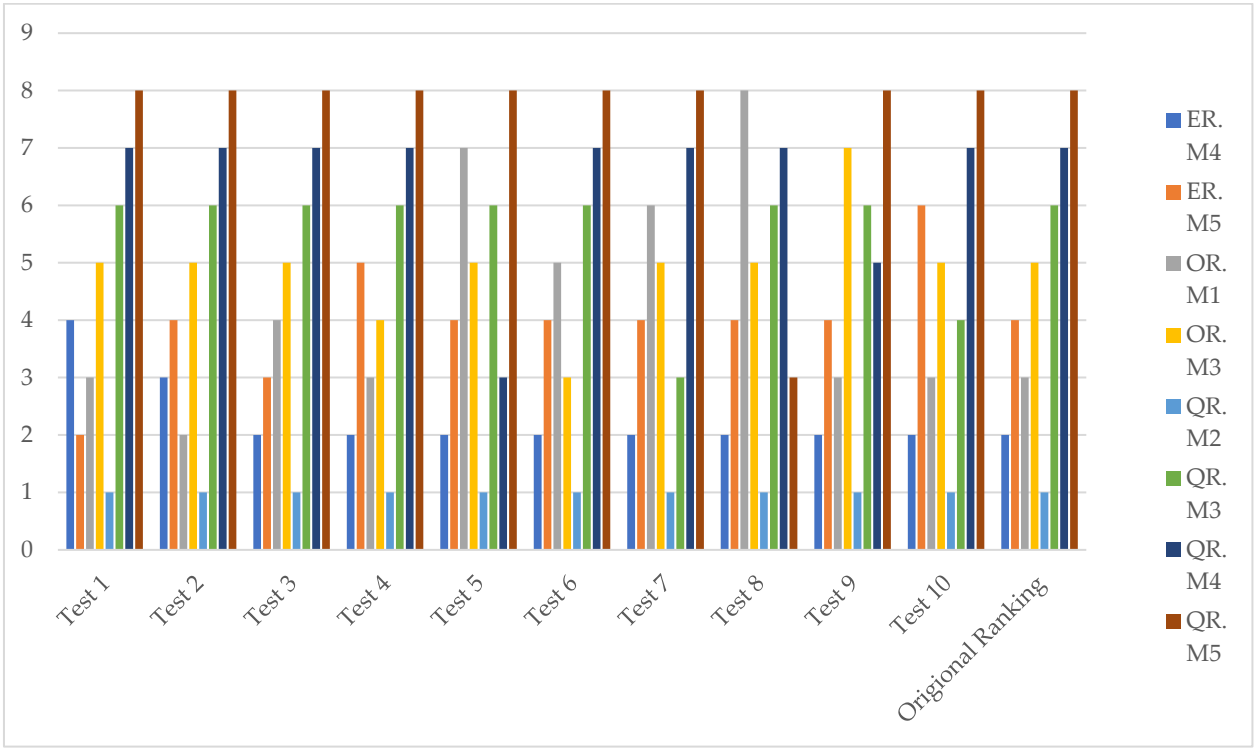

Figure 11. Sensitivity analysis correlation graph.

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 [74]. 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. 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. It 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 [48,51].

The causes and impacts of each risk could be studied in future research systematically 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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References

1. Martin, C.R.; Ling, P.R.; Blackburn, G.L. Review of infant feeding: Key features of breast milk and infant formula. *Nutrients* **2016**, *8*, 279. [CrossRef]
2. Kleczka, B.; Shamir, R. Standards for infant formula milk. *BMJ* **2006**, *332*, 621–622. [CrossRef]
3. Mayo Clinic. Healthy Lifestyle Infant and Toddler Health—Infant Formula. Mayo Clinic. Available online: https://www.mayoclinic.org/healthy-lifestyle/infant-and-toddler-health/in-depth/infant-formula/art-20045782 (accessed on 22 December 2022).
4. Wen, J.G.; Liu, X.J.; Wang, Z.M.; Li, T.F.; Wahlqvist, M.L. Melamine-contaminated milk formula and its impact on children. *Asia Pac. J. Clin. Nutr.* **2016**, *25*, 697–705. Available online: https://search.informit.org/doi/10.3316/ielapa.369546163189477 (accessed on 22 December 2022).
5. Jackson, I. Similac Formula Contaminated at Plant Where FDA Found Abbott Failed to Maintain Sanitary Conditions, Procedures. AboutLawsuits.com. Available online: https://www.aboutlawsuits.com/similac-contaminated-inspection-reports (accessed on 10 November 2022).
6. Kent, G. Global infant formula: Monitoring and regulating the impacts to protect human health. *Int. Breastfeed. J.* **2015**, *10*, 6. [CrossRef] [PubMed]
7. Jacxsens, L.; Uyttendaele, M.; Luning, P.; Allende, A. Food safety management and risk assessment in the fresh produce supply chain. In *IOP Conference Series: Materials Science and Engineering*; IOP Publishing: Bristol, England; Philadelphia, PA, USA, 2017; Volume 193, p. 012020. [CrossRef]
8. Haughton, P.; Garvey, M.; Rowan, N.J. Emergence of Bacillus cereus as a dominant organism in Irish retailed powdered infant formulae (PIF) when reconstituted and stored under abuse conditions. *J. Food Saf.* **2010**, *30*, 814–831. [CrossRef]
9. Di Pinto, A.; Bonerba, E.; Bozzo, G.; Ceci, E.; Terio, V.; Tantillo, G. Occurrence of potentially enterotoxigenic Bacillus cereus in infant milk powder. *Eur. Food Res. Technol.* **2013**, *237*, 275–279. [CrossRef]
10. Sadek, Z.I.; Abdel-Rahman, M.A.; Azab, M.S.; Darwesh, O.M.; Hassan, M.S. Microbiological evaluation of infant foods quality and molecular detection of Bacillus cereus toxins relating genes. *Toxicol. Rep.* **2018**, *5*, 871–877. [CrossRef]
11. Townsend, S.; Forsythe, S.J. The neonatal intestinal microbial flora, immunity, and infections. In *Enterobacter Sakazakii*; John Wiley & Sons: Hoboken, NJ, USA, 2007; pp. 61–100. [CrossRef]
12. Deeb, A.M.; Al-Hawary, I.I.; Aman, I.M.; Shahine, D.M.H.A. Bacteriological investigation on milk powder in the Egyptian market with emphasis on its safety. *Glob. Vet.* **2010**, *4*, 424–433. Available online: http://www.idosi.org/gv/gv4(5)10/1.pdf (accessed on 10 November 2022).
13. Singh, M.; Kumar, V. Preparation and characterization of melamine–formaldehyde–polyvinylpyrrolidone polymer resin for better industrial uses over melamine resins. *J. Appl. Polym. Sci.* **2009**, *114*, 1870–1878. [CrossRef]
14. Field, A.; Field, J. Melamine and cyanuric acid do not interfere with Bradford and Ninhydrin assays for protein determination. *Food Chem.* **2010**, *121*, 912–917. [CrossRef] [PubMed]
15. Xinhua. Mills Investigated over Tainted Rice. Beijing Review. Available online: http://www.bjreview.com.cn/health/txt/2013-05/22/content_544103.htm (accessed on 27 December 2022).
16. Gossner, C.M.E.; Schlundt, J.; Ben Embarek, P.; Hird, S.; Lo-Fo-Wong, D.; Beltran, J.J.O.; Teoh, K.N.; Tritscher, A. The melamine incident: Implications for international food and feed safety. *Environ. Health Perspect.* **2009**, *117*, 1803–1808. [CrossRef]
17. Dorne, J.L.; Doerge, D.R.; Vandenbroeck, M.; Fink-Gremmels, J.; Mennes, W.; Knutsen, H.K.; Vernazza, F.; Castle, L.; Edler, L.; Benford, D. Recent advances in the risk assessment of melamine and cyanuric acid in animal feed. *Toxicol. Appl. Pharmacol.* **2013**, *270*, 218–229. [CrossRef]
18. Yasui, T.; Kobayashi, T.; Okada, A.; Hamamoto, S.; Hirose, M.; Mizuno, K.; Kubota, Y.; Umemoto, Y.; Kawai, N.; Tozawa, K.; et al. Long-term follow-up of nephrotoxicity in rats administered both melamine and cyanuric acid. *BMC Res. Notes* **2014**, *7*, 87. [CrossRef]
19. Pei, X.; Tandon, A.; Alldrick, A.; Giorgi, L.; Huang, W.; Yang, R. The China melamine milk scandal and its implications for food safety regulation. *Food Policy* **2011**, *36*, 412–420. [CrossRef]
20. Zhang, C.; Bai, J.; Lohmar, B.T.; Huang, J. How do consumers determine the safety of milk in Beijing, China? *China Econ. Rev.* **2010**, *21*, S45–S54. [CrossRef]
21. Forsythe, S.J. Enterobacter sakazakii and other bacteria in powdered infant milk formula. *Matern. Child Nutr.* **2005**, *1*, 44–50. [CrossRef]
22. Kumar, A.; Zavadskas, E.K.; Mangla, S.K.; Agrawal, V.; Sharma, K.; Gupta, D. When risks need attention: Adoption of green supply chain initiatives in the pharmaceutical industry. *Int. J. Prod. Res.* **2019**, *57*, 3554–3576. [CrossRef]
23. Kannel, W.B.; Dawber, T.R.; Kagan, A.; Revotskie, N.; Stokes, J., III. Factors of risk in the development of coronary heart disease—Six-year follow-up experience: The Framingham Study. *Ann. Intern. Med.* **1961**, *55*, 33–50. [CrossRef]

24. Davies, H.; Walters, M. Do all crises have to become disasters? Risk and risk mitigation. *Prop. Manag.* **1998**, *16*, 5–9. [CrossRef]
25. Ho, W.; Zheng, T.; Yildiz, H.; Talluri, S. Supply chain risk management: A literature review. *Int. J. Prod. Res.* **2015**, *53*, 5031–5069. [CrossRef]
26. Gurtu, A.; Johny, J. Supply chain risk management: Literature review. *Risks* **2021**, *9*, 16. [CrossRef]
27. Kumar, S.K.; Tiwari, M.K.; Babiceanu, R.F. Minimisation of supply chain cost with embedded risk using computational intelligence approaches. *Int. J. Prod. Res.* **2010**, *48*, 3717–3739. [CrossRef]
28. Zsidisin, G.A. A grounded definition of supply risk. *J. Purch. Supply Manag.* **2003**, *9*, 217–224. [CrossRef]
29. Kern, D.; Moser, R.; Hartmann, E.; Moder, M. Supply risk management: Model development and empirical analysis. *Int. J. Phys. Distrib. Logist. Manag.* **2012**, *42*, 60–82. [CrossRef]
30. Wang, X. Food supply chain safety risk evaluation based on AHP fuzzy integrated evaluation method. *Int. J. Secur. Its Appl.* **2016**, *10*, 233–244. Available online: https://www.earticle.net/Article/A271001 (accessed on 22 December 2022).
31. Nakandala, D.; Lau, H.; Zhao, L. Development of a hybrid fresh food supply chain risk assessment model. *Int. J. Prod. Res.* **2017**, *55*, 4180–4195. [CrossRef]
32. Jüttner, U.; Peck, H.; Christopher, M. Supply chain risk management: Outlining an agenda for future research. *Int. J. Logist. Res. Appl.* **2003**, *6*, 197–210. [CrossRef]
33. Haji, M.; Kerbache, L.; Al-Ansari, T. Food Quality, Drug Safety, and Increasing Public Health Measures in Supply Chain Management. *Processes* **2022**, *10*, 1715. [CrossRef]
34. Liu, L.; Liu, X.; Liu, G. The risk management of perishable supply chain based on coloured Petri Net modeling. *Inf. Process. Agric.* **2018**, *5*, 47–59. [CrossRef]
35. Murray, J.; Farrington, D.P.; Eisner, M.P. Drawing conclusions about causes from systematic reviews of risk factors: The Cambridge Quality Checklists. *J. Exp. Criminol.* **2009**, *5*, 1–23. [CrossRef]
36. Rojas-Rueda, D.; Morales-Zamora, E.; Alsufyani, W.A.; Herbst, C.H.; AlBalawi, S.M.; Alsukait, R.; Alomran, M. Environmental risk factors and health: An umbrella review of meta-analyses. *Int. J. Environ. Res. Public Health* **2021**, *18*, 704. [CrossRef] [PubMed]
37. Azizsafaei, M.; Sarwar, D.; Fassam, L.; Khandan, R.; Hosseinian-Far, A. A critical overview of food supply chain risk management. In *Cybersecurity, Privacy and Freedom Protection in the Connected World*; Springer: Cham, Switzerland, 2021; pp. 413–429. [CrossRef]
38. Mund, M.; Louwen, F.; Klingelhoefer, D.; Gerber, A. Smoking and pregnancy—A review on the first major environmental risk factor of the unborn. *Int. J. Environ. Res. Public Health* **2013**, *10*, 6485–6499. [CrossRef]
39. Luo, Y.; Kawashima, A.; Ishido, Y.; Yoshihara, A.; Oda, K.; Hiroi, N.; Ito, T.; Ishii, N.; Suzuki, K. Iodine excess as an environmental risk factor for autoimmune thyroid disease. *Int. J. Mol. Sci.* **2014**, *15*, 12895–12912. [CrossRef]
40. Dendup, T.; Feng, X.; Clingan, S.; Astell-Burt, T. Environmental risk factors for developing type 2 diabetes mellitus: A systematic review. *Int. J. Environ. Res. Public Health* **2018**, *15*, 78. [CrossRef] [PubMed]
41. Malak-Rawlikowska, A.; Majewski, E.; Wąs, A.; Borgen, S.O.; Csillag, P.; Donati, M.; Freeman, R.; Hoàng, V.; Lecoeur, J.; Mancini, M.C.; et al. Measuring the economic, environmental, and social sustainability of short food supply chains. *Sustainability* **2019**, *11*, 4004. [CrossRef]
42. Haji, M.; Kerbache, L.; Muhammad, M.; Al-Ansari, T. Roles of technology in improving perishable food supply chains. *Logistics* **2020**, *4*, 33. [CrossRef]
43. Chandrasiri, C.; Dharmapriya, S.; Jayawardana, J.; Kulatunga, A.K.; Weerasinghe, A.N.; Aluwihare, C.P.; Hettiarachchi, D. Mitigating Environmental Impact of Perishable Food Supply Chain by a Novel Configuration: Simulating Banana Supply Chain in Sri Lanka. *Sustainability* **2022**, *14*, 12060. [CrossRef]
44. Berger, A.N.; Curti, F.; Mihov, A.; Sedunov, J. Operational risk is more systemic than you think: Evidence from U.S. bank holding companies. *J. Bank. Financ.* **2022**, *143*, 106619. [CrossRef]
45. Jallow, A.K.; Majeed, B.; Vergidis, K.; Tiwari, A.; Roy, R. Operational risk analysis in business processes. *BT Technol. J.* **2007**, *25*, 168–177. [CrossRef]
46. Aung, M.M.; Chang, Y.S. Traceability in a food supply chain: Safety and quality perspectives. *Food Control* **2014**, *39*, 172–184. [CrossRef]
47. Azizsafaei, M.; Hosseinian-Far, A.; Khandan, R.; Sarwar, D.; Daneshkhah, A. Assessing risks in dairy supply chain systems: A system dynamics approach. *Systems* **2022**, *10*, 114. [CrossRef]
48. Haji, M.; Kerbache, L.; Sheriff, K.M.; Al-Ansari, T. Critical success factors and traceability technologies for establishing a safe pharmaceutical supply chain. *Methods Protoc.* **2021**, *4*, 85. [CrossRef] [PubMed]
49. Breen, L. A Preliminary Examination of Risk in the Pharmaceutical Supply Chain (PSC) in the National Health Service (NHS). *J. Serv. Sci. Manag.* **2008**, *1*, 193–199. [CrossRef]
50. Jaberidoost, M.; Nikfar, S.; Abdollahiasl, A.; Dinarvand, R. Pharmaceutical supply chain risks: A systematic review. *DARU J. Pharm. Sci.* **2013**, *21*, 69. [CrossRef]
51. Haji, M.; Kerbache, L.; Al-Ansari, T. Evaluating the Performance of a Safe Insulin Supply Chain Using the AHP-TOPSIS Approach. *Processes* **2022**, *10*, 2203. [CrossRef]
52. Ayyildiz, E.; Taskin Gumus, A. Interval-valued Pythagorean fuzzy AHP method-based supply chain performance evaluation by a new extension of SCOR model: SCOR 4.0. *Complex Intell. Syst.* **2021**, *7*, 559–576. [CrossRef]

53. Permana, R.A.; Ridwan, A.Y.; Yulianti, F.; Kusuma PG, A. Design of food security system monitoring and risk mitigation of rice distribution in Indonesia Bureau of Logistics. In Proceedings of the 2019 IEEE 13th International Conference on Telecommunication Systems, Services, and Applications (TSSA), Bali, Indonesia, 3–4 October 2019; IEEE: Piscataway, NJ, USA, 2019; pp. 249–254. [CrossRef]
54. de Oliveira, U.R.; Marins, F.A.S.; Rocha, H.M.; Salomon, V.A.P. The ISO 31000 standard in supply chain risk management. *J. Clean. Prod.* **2017**, *151*, 616–633. [CrossRef]
55. Ferreira FD, A.L.; Scavarda, L.F.; Ceryno, P.S.; Leiras, A. Supply chain risk analysis: A shipbuilding industry case. *Int. J. Logist. Res. Appl.* **2018**, *21*, 542–556. [CrossRef]
56. Mvubu, M.; Naude, M. Supply chain risk management strategies: A study of South African third-party logistics providers. *S. Afr. Bus. Rev.* **2020**, *24*, 1–24. Available online: https://hdl.handle.net/10520/EJC-1e3f37b049 (accessed on 30 December 2022). [CrossRef]
57. Senna, P.; Reis, A.; Santos, I.L.; Dias, A.C.; Coelho, O. A systematic literature review on supply chain risk management: Is healthcare management a forsaken research field? *Benchmarking Int. J.* **2020**, *28*, 926–956. [CrossRef]
58. Qazi, A.; Akhtar, P. Risk matrix driven supply chain risk management: Adapting risk matrix based tools to modelling interdependent risks and risk appetite. *Comput. Ind. Eng.* **2020**, *139*, 105351. [CrossRef]
59. Risk Assessment Breakdown: Identification, Analysis, Evaluation. (1 September 2021). Lexology. Available online: https://www.lexology.com/library/detail.aspx?g=892f0d15-7488-4506-9923-2399819078a0 (accessed on 30 December 2022).
60. Vrijling, J.K.; Van Hengel, W.; Houben, R.J. A framework for risk evaluation. *J. Hazard. Mater.* **1995**, *43*, 245–261. [CrossRef]
61. Grabowski, M.; Roberts, K.H. Risk mitigation in virtual organizations. *Organ. Sci.* **1999**, *10*, 704–721. [CrossRef]
62. Faisal, M.N.; Banwet, D.K.; Shankar, R. Supply chain risk mitigation: Modeling the enablers. *Bus. Process Manag. J.* **2006**, *12*, 535–552. [CrossRef]
63. Ghosh, S.; Jintanapakanont, J. Identifying and assessing the critical risk factors in an underground rail project in Thailand: A factor analysis approach. *Int. J. Proj. Manag.* **2004**, *22*, 633–643. [CrossRef]
64. Hubbard, D.W. *The Failure of Risk Management: Why It's Broken and How to Fix It*; John Wiley & Sons: Hoboken, NJ, USA, 2009; p. 46.
65. Fan, Y.; Stevenson, M. A review of supply chain risk management: Definition, theory, and research agenda. *Int. J. Phys. Distrib. Logist. Manag.* **2018**, *48*, 205–230. [CrossRef]
66. Brown, L. Risk Mitigation Strategies in Project Management, Invensis Learning Blog. Available online: https://www.invensislearning.com/blog/risk-mitigation-strategies-in-project-management/ (accessed on 10 November 2022).
67. Fielding, N.; Schreier, M. Introduction: On the compatibility between qualitative and quantitative research methods. In *Forum Qualitative Sozialforschung/Forum: Qualitative Social Research*; GESIS: Mannheim, Germany, 2001; Volume 2. [CrossRef]
68. Saaty, T.L. *The Analytic Hierarchy Process*; McGraw-Hill: New York, NY, USA, 1980.
69. Saaty, T.L. *Fundamentals of Decision Making and Priority Theory with the Analytic Hierarchy Process*; RWS Publications: Pittsburgh, PA, USA, 1994.
70. Reddy KJ, M.; Rao, A.N.; Krishnanand, L. A Survey on Application of a System Dynamic Approach in Supply Chain Performance Modeling. In *Mechanical Engineering for Sustainable Development*; Apple Academic Press: Palm Bay, FL, USA; Burlington, ON, Canada, 2019; pp. 283–295. [CrossRef]
71. Saaty, T.L. Axiomatic foundation of the analytic hierarchy process. *Manag. Sci.* **1986**, *32*, 841–855. [CrossRef]
72. Wang, C.N.; Huang, Y.F.; Cheng, I.F.; Nguyen, V.T. A multi-criteria decision-making (MCDM) approach using hybrid SCOR metrics, AHP, and TOPSIS for supplier evaluation and selection in the gas and oil industry. *Processes* **2018**, *6*, 252. [CrossRef]
73. Chen, C.; Zhang, J.; Delaurentis, T. Quality control in food supply chain management: An analytical model and case study of the adulterated milk incident in China. *Int. J. Prod. Econ.* **2014**, *152*, 188–199. [CrossRef]
74. Ji, Y.G.; Ko, W.H. Developing a Catering Quality Scale for University Canteens in China: From the Perspective of Food Safety. *Sustainability* **2022**, *14*, 1281. [CrossRef]

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