RISK ANALYSIS OF EMERGENCY SUPPLY CHAINS

A thesis submitted in partial fulfilment of the requirements of Liverpool John Moores University for the degree of Doctor of Philosophy

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To my daughter Kosi Khanyile and my parents, Morsimdi and Uche

ABSTRACT

Unknowns and uncertainties are integral to any disaster relief operation. Activities of the emergency supply chain are usually performed in highly volatile environments and are prone to risks. Due to the complexity of the operating relief environment, relief organizations can only anticipate some supply chain disruptions. As such, they must take a comprehensive and proactive approach to uncertainties to manage multiple unexpected events. Therefore, this research aims to develop a comprehensive framework for risk management in emergency supply chains. This study adopts a comprehensive and rigorous procedure to explore the risk factors and mitigation strategies for emergency supply chains. The research design is divided into three phases; first, the risk factors and mitigation strategies are collected through an extensive literature review; next, the risk factors and risk mitigation strategies are verified with experts through high-level surveys and semi-structured interviews. Finally, based on the weight of risk factors estimated using the fuzzy analytic hierarchy process, risk factors mitigation strategies to overcome the risk factors are prioritized using the fuzzy technique for order performance by similarity to ideal solution that considers uncertainty and impreciseness rather than a crisp value. This study found and verified 28 emergency supply chain risk factors, which are categorised into two main categories: internal and external risks; four sub-categories: demand, supply, infrastructural, and environmental risks; and 11 risk types: forecast, inventory, procurement, supplier, quality, transportation, warehousing, systems, disruption, social, and political risks. War and terrorism, the impact of follow-up disasters, poor relief supplies, and sanctions and constraints that hinder stakeholder cooperation and coordination are the most significant risks. Finally, eight risk factor mitigation strategies; strategic stock, prepositioning of resources, collaboration and coordination, flexible transportation, flexible supply bases, logistics outsourcing, flexible supply contracts, and risk awareness/knowledge management were proposed and prioritised to overcome the risk factors so decision-makers can focus on these mitigation strategies. This study provides a more efficient, effective, robust, and systematic way to overcome risk factors and improve the effectiveness of emergency supply chains in disaster relief operations. This study is the first to objectively identify, categorise, and analyse emergency supply chains' risk nature and frequency. Practitioners and policymakers can use the research findings to spot significant risk factors and appropriate mitigation strategies to reduce their effects. The risk profile will be a new database of risk factors affecting the emergency supply chain and allow stakeholders to immediately identify the disrupted emergency supply chain component.

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ABBREVIATIONS

AHP – Analytical Hierarchy Process

ANP – Analytical Network Process

CILT – Chartered Institute of Logistics and Transport

CRED – Centre for Research on the Epidemiology of Disasters

CSCs - Commercial Supply Chains

CSCMP – Council of Supply Chain Management Professionals

DEA – Data Envelopment Analysis

DEMATEL – Decision-Making Trial and Evaluation Laboratory

DROs – Disaster Relief Operations

ECHO – European Civil Protection and Humanitarian Aid Operations

EM-DAT – Emergency Event Database

ER – Emergency Relief

ESUPS – Emergency Supply Pre-positioning Strategy

ESCM – Emergency Supply Chain Management

ESCR – Emergency Supply Chain Risk

ESCRM – Emergency Supply Chain Risk Management

FMEA – Failure Modes and Effects Analysis

FNIS – Fuzzy Negative Ideal Solution

FPIS – Fuzzy Positive Ideal Solution

FST – Fuzzy Set Theory

FTA – Fault Tree Analysis

F-AHP – Fuzzy Analytical Hierarchy Process

F-TOPSIS – Fuzzy Technique for Order of Preference by Similarity to Ideal Solution

ISM – Interpretive Structural Modelling

MICMAC - Matriced' Impacts Croise's Multiplication Appliquée a UN Classement

IFRC – International Federation of Red Cross and Red Crescent Societies

MCDM – Multi-Criteria Decision Making

NGO – Non-Governmental Organisation

OCHA – Office for the Coordination of Humanitarian Affairs

QFD – Quality Function Deployment

RFID – Radio Frequency and Identification

SCM – Supply Chain Management

SCRM – Supply Chain Risk Management

SCs – Supply Chains

TFN – Triangular Fuzzy Number

TOPSIS – Technique for Order of Preference by Similarity to Ideal Solution

UN – United Nations

USA – United States of America

WHO – World Health Organisation

CHAPTER 1 - INTRODUCTION

1.1 Introduction

Research involves exploring, discovering, studying, and extending knowledge limitations for an appropriate and practical understanding of theories, ideas, and objectives. This chapter serves as an introductory phase of this research by presenting the background study and the rationale of the research. Subsequently, the research aims, objectives, and methodology are introduced. The chapter concludes with a description of the research structure.

1.2 Background and Motivations

During the early stages of this research, the COVID-19 pandemic struck the globe and caused unprecedented crises. This disaster is considered the most severe pandemic of this century (Kumar *et al.*, 2022). Similarly, the experience of the 7.7 magnitude earthquake that hit Turkey and Syria in February 2023 shows that disasters continue to cause loss of human life, environment damage, infrastructure disruption, and economic loss (IFRC, 2023). These occurrences reiterate that disasters are unpredictable, and they can occur in any place, at any time, with severe consequences (Kovács and Spens, 2007; Carroll and Neu, 2009; Tomasini and Van Wassenhove, 2009; Day *et al.*, 2012). The term "disaster" is usually applied to a breakdown in a community's normal functioning that significantly impacts people, their work and their environment, overwhelming local capacity (Van Wassenhove, 2006). This situation may result from a natural event –a hurricane or earthquake – or human activity. Several distinctions have been made between "disasters" – the result of natural phenomena- and "complex emergencies" that result from armed conflicts or large-scale violence and often lead to massive displacements of people, famine, and outflows of refugees. Some examples include the Balkan crisis, the Afghanistan crisis, the Ethiopian, Somali, and Sudanese famines, the genocide in Rwanda, and the violence in East Timor.

The Emergency Event Database (EM-DAT) documented 432 natural disasters worldwide in 2021. These were responsible for 10,492 fatalities, affecting an estimated 101.8 million people, and resulted in about 252.1 billion US$ in economic losses. Throughout all continents, Asia bore the brunt of the disasters, experiencing 40% of them and being responsible for 49% of the deaths and 66% of the affected population. Even though fatalities and impacted populations were lower in 2021 than in previous years, more disasters occurred that year, causing extensive economic losses. The United States of America (USA) was hit by five of the top ten most economically costly disasters in 2021, totalling 112.5 billion US$ in damages (CRED, 2022). Natural disasters have been responsible for an average of 45,000 deaths yearly over the past decade, or 0.1% of all deaths globally (Ritchie *et al.,* 2022). The magnitude of loss and disruption caused by any disaster depends on the nature of the calamity itself and the area's pre-existing financial, health, and social conditions(Agarwal *et al.,* 2021). As a result, disasters will continue to bring serious adverse effects (see Table 1.1) and raise awareness that calls for swift measures to alleviate human suffering and speed up reaction and recovery efforts. In the immediate aftermath of a disaster, the effects on the population and its surroundings generate different needs and require different approaches to meet those needs. Thus, disaster relief operations (DROs) become crucial and urgent, as they are essential for the safety and survival of those affected by the impacts of the disaster (Adem *et al.*, 2018). As the number of natural and man-made disasters is projected to increase by a factor of five over the next 50 years, disaster relief is and will remain a dynamic industry (Thomas and Kopczak, 2005). Aiding those in need during times of crisis has become a multibillion-dollar industry spanning borders and cultures (Carroll and Neu, 2009). The increasing number and effects of disasters (Seifert *et al.,* 2018) put a focus on the need for relief organisations (ROs) to develop and deploy well-functioning emergency supply chains (ESCs), which are charged with transforming resources into tangible products and services and delivering them appropriately and cost-effectively (Polater, 2021).

It has been clear that supply chain management (SCM) is applicable in the business world, but this is not necessarily the case for disaster relief (Fawcett and Waller, 2013). This is because commercial supply chains (CSCs) are driven by reasonably predictable demand, data that can be relied upon, verifiable results, and enough capacity. Conversely, the demand for emergency relief is erratic, urgent, and frequently confined by supply, negating any desire for financial gain (Tomasini and Van Wassenhove, 2009). Moreover, funding is often only available for a few periods, and the results of relief efforts are difficult to measure and assess precisely (Adem *et al.,* 2018).

Emergency supply chain management (ESCM) has emerged as a worldwide theme. It has been described as “the process of planning, managing, implementing and controlling the efficient, cost-effective flow and storage of relief items as well as related information and funds, from the point of origin (suppliers and donors) to the point of consumption to meet the end beneficiary’s requirements” (Maghsoudi and Moshtari, 2021).

Table 1.1 Short-term effects of major disasters

Effect	Earthquakes	Windstorms (without flooding)	Tsunamis and sudden floods	Slow-onset floods	Landslides	Volcanoes and mudslides
Deaths[a]	Many	Few	Many	Few	Many	Many
Severe injuries requiring extensive treatment	Many	Moderate	Few	Few	Few	Few
Increased risk of communicable diseases	This is a potential hazard after any significant natural disaster. The potential increases in close correlation with overcrowding and the degradation of the sanitation situation.					
Damage to health facilities	Severe (structure and equipment)	Severe	Severe, but localized	Severe (equipment only)	Severe, but localized	Severe (structure and equipment)
Damage to water supply systems	Severe	Minor	Severe	Minor	Severe but localized	Severe
Lack of food	Infrequent (generally caused by economic or logistical factors)		Common	Common	Infrequent	Infrequent
Large population displacements	Infrequent (tend to occur in urban areas that have suffered severe damage)		Common (generally limited)			

Source: (Pan American Health Organisation and World Health Organisation, 2001)

Activities of the ESC include determining what is needed, procuring it, getting people to move it, storing it, and finally distributing it (Gustavsson, 2003). The ESC strives to mitigate the suffering of vulnerable people to the greatest possible extent (Vaillancourt, 2016), deliver relief items to beneficiaries during the disaster (Singh *et al.,* 2018), and provide aid to victims (Zhou *et al.,* 2011). The critical success criteria of ESCs are providing "the right services and goods, at the right place, in the right amount, and at the right time" to the appropriate consumers under optimal conditions, all while maintaining a "non-profit purpose" (Dubey *et al.*, 2020). As soon as stakeholders hear cries for help, they begin the operations of ESCs to bring relief to the afflicted areas as quickly as possible. Organisational and synergistic efforts amongst relief aides, emergency relief coordinators, the ESCM team, and emergency relief logistics are crucial to disaster supply chain operations and management success. When the ESC fails to deliver aid effectively and efficiently, it can lead to massive loss of lives (Adem *et al.,* 2018). For example, the 2004 Asian tsunami revealed that issues relating to poor quality and inappropriate aid, capacity shortcomings, such as flight and warehousing capacity, and poor coordination among the relief organizations involved led to the poor outcome of the relief operation (Telford and Cosgrave, 2007). The functions of the ESC are frequently carried out in precarious settings, and relief groups face various risks and uncertainties when transporting, storing, and delivering the things intended to assist the vulnerable population. This includes the demand that is difficult to predict (when, where, and in what quantities the relief supplies will be needed), delays in supply, non-existent or damaged infrastructure, inadequate logistical resources, volatile political situations, and security concerns, as well as a lack of information (L'hermitte *et al.,* 2016). The organisations that provide aid must be able to react quickly to the unpredictable and shifting conditions that they face, and they must be able to swiftly and effectively change their operations to meet the requirements of the field environment (Charles *et al.,* 2010; L'hermitte *et al.*, 2015).

All supply chains face risks and uncertainty (Giunipero and Aly Eltantawy, 2004). Still, the nature of that risk and the extent to which it might affect an organization can vary widely depending on the type of business being conducted (Rao and Goldsby, 2009; Sodhi *et al.,* 2012). There has been a growing body of research on supply chain risk management (SCRM) since the turn of the millennium, and the risks and uncertainties that businesses face have been more clearly defined (Tang, 2006b; Rao and Goldsby, 2009). Some risks and uncertainties that can cause disruptions in CSCs include the failure of a critical supplier, shorter product life cycles, the need for more product variety, and fluctuating customer demands (Swafford *et al.,* 2006; L'hermitte *et al.*, 2015). The importance of risk management in disaster relief is often overlooked. Risk management is crucial but challenging in a fast-paced, uncertain setting like an emergency supply chain, where decisions must be made quickly with little information (Aqlan and Lam, 2015). Risk management is vital in ESCs due to the high uncertainty of their operating environment and the wide range of dangers to which they are vulnerable. An already dire situation might worsen if the ESC were interrupted (McLachlin *et al.,* 2009). Without well-executed ESC activities, it is impossible to mount a proper response to any disaster.

Moreover, no matter how good the preparation of emergency supply chain activities is, the execution of these activities may still fail since there are many risks inherent in disaster relief. Many potential difficulties can arise during an emergency response, so it is essential to be aware of the circumstances that could compromise the ESCs (Thévenaz and Resodihardjo, 2010). L'hermitte *et al.,* (2015) suggest investigating the ESC to learn more about the dangers and unknowns involved. In addition, more research is required to ascertain the nature and frequency of the risks encountered and to correctly identify, categorize, and analyze the severity of their consequences on the operations of the emergency supply chain. It has been suggested by L'hermitte *et al.,* (2014) that studies of ESC risks and uncertainties relevant to different types of disasters and operating settings are needed. Adaptable solutions to risks and uncertainties in demand, supply, and procedures are essential for relief organisations to operate effectively in disaster environments (Balcik and Beamon, 2008). This necessitates forethought, the ready deployment of appropriate resources, and efficient on-the-ground adaptation to a wide range of local conditions to ensure optimal operations. L'hermitte *et al.,* (2015) argue that an emergency supply chain's efficiency and effectiveness are directly tied to its agility and responsiveness in the face of external disturbances. This can only be achieved effectively by flexible (Blecken *et al.,* 2009; Oloruntoba and Gray, 2009; Merminod *et al.,* 2009) and economical supply networks (McLachlin *et al.*, 2009; Pettit and Beresford, 2009; Jahre *et al.,* 2016). Hence, considering the complexities and unique features of the ESC and the high impact of disasters in recent times, this study addresses these calls for more investigations to link the ESC and risk management to ensure effective disaster relief operations.

Accordingly, this first chapter introduces the thesis by explaining the reasoning behind the study and outlining its ultimate goals. The final methodological approach is briefly described. Before wrapping up this chapter, a quick overview of the thesis's organizational framework is provided.

1.3 Rationale of Study

The distinctive characteristics and phases of disaster relief operations bring on novel challenges, particularly regarding ESCs (Kovács and Spens, 2007; Sheu, 2007; Holguín-Veras *et al.*, 2012; Pedraza-Martinez and Van Wassenhove, 2012). Kovács and Spens, (2009) underline that the current approaches in ESCs are inadequate and that something must be done to improve the design, deployment, and management of ESCs (Day *et al.*, 2012). Moreover, in a guest editorial, Kovacs *et al.*, (2019) discuss that research in ESCs is maturing, and numerous calls have been made for empirical research and mixed methods in ESC research. Currently, mixed methods are not used, and empirical evidence in publications is scant, undermining ESC research's rigour and relevance. Therefore, the mixed methods approach is needed to improve the quality of research output.

Immediate disaster relief operations crucially rely on the ESCs primarily responsible for the rapid flow of relief (emergency food, water, medicine, shelter, and supplies) to areas impacted by large-scale, sudden-onset emergencies to minimize loss of lives. Thus, every new disaster leads to the configuration of a new ESC (Ertem *et al.*, 2010; Merminod *et al.*, 2014; L'hermitte *et al.*, 2016). The design and operations of the ESC play essential roles in achieving effective and efficient responses (Balcik and Beamon, 2008). Supply chain risks fundamentally result from uncertain events that prevent the network from achieving its goal. In contrast to the demand-driven and steady-state supply chains typical of commercial enterprises, the disaster relief setting presents more significant levels of uncertainty and dynamism that characterize ESC's function. Demand is not the primary factor contributing to uncertainty (Kovács and Spens, 2007; Sheu, 2007), and the environments in which disaster assistance occurs are far frosteady (Perry, 2007; Pettit and Beresford, 2005). The uncertainty over how much of an organisation's required relief capacity may be overshadowed by many other unknown factors emerging as the principal motivators of action. These factors may include logistical, authority, policy, socioeconomic, and financial concerns (Thevenaz and Resodihardjo, 2010). Disaster relief organisations face a unique set of challenges, including the need to align with supply chain partners that can collaborate to produce products in response to ever-changing market demands, as well as the need to manage complex networks of ever-changing supplier and customer relationships to adapt to very dynamic shifts across nearly every metric, including resource availability, information sharing, funding, and media attention. While there is a growing awareness among academicians and practitioners about the nature and presence of risks in the response contexts, current approaches to risk management remain inconsistent and fragmented. Many of the current frameworks from the commercial sector have proved inadequate in the disaster context. Even where proven SCM practices are used in these contexts (Balcik *et al.*, 2010; Day, 2014), acceptable response and recovery performance have remained. No comprehensive risk management framework is currently dedicated to the emergency supply chain. The ability of relief organisations to organize rapid responses transcends the emergency logistics and supply chain function and requires a business-wide approach and deep-rooted capabilities (L'hermitte *et al.*, 2016).

ESC systems are typically used in highly volatile and ambiguous settings. There is a lack of control and an increase in malfunctions due to the lack of reliable information, the short lead periods, and the distributed nature of the resources. There is also no centralized governance structure because the aid-providing institutions are all different and have their distinct capacities and goals (Kovács and Spens, 2007; Day, 2014). This fact severely weakens the possibility of regaining command. Nevertheless, the demands are pressing, and the repercussions of failure are tragic. Hence, the success of emergency relief efforts depends heavily on effective systems design, which is the process of setting shared goals and matching structure and capabilities to the environment to accomplish the intended results (Fawcett and Fawcett, 2013). Emergency relief operations are susceptible to numerous risks, and the information about the risks that the emergency supply chain is likely to confront is dispersed across a multitude of literature. This leaves researchers and practitioners in a state of confusion (Thévenaz and Resodihardjo, 2010). Notably, studies focused on the nature and frequency of risk factors prevalent in the emergency supply chain are missing, and studies that accurately identify, categorize, and analyze the severity of their impacts. Relief actors adopt diverse supply chain strategies to manage the situation. The existing literature addresses strategies that are currently in use, albeit implicitly. However, several studies are conceptual or theoretical, offering only anecdotal evidence. Moreover, the scholarly inquiry about ESCs fails to address the extent of the significance of these supply chain strategies and their potential application in mitigating distinct types of risks. Hence, the justification for conducting research grounded on primary data utilizing data collection tools such as surveys and interviews, among others, is evident.

This research draws its motivation and foundation from the abovementioned discussions and limitations. As a result, this study defines its research questions, aim, and objectives that must be met to achieve the research purpose.

These research questions include:

1. What constitutes an emergency supply chain risk management framework?
2. What risk factors often disrupt the emergency supply chain, and how to prioritize and categorize those risk factors?
3. What is the relative importance of these risk factors?
4. What supply chain strategies are currently implemented for risk mitigation in disaster relief operations?
5. What are the priorities of these supply chain strategies implemented in emergency supply chains?

1.4 Aim and Objectives

This research aims to develop a novel conceptual framework for risk management in emergency supply chains. In addition, a dynamic decision-support methodology that will aid emergency managers in risk management during disaster relief operations will be built to support the framework. Completion of the following objectives will help achieve the overall goal of this research:

- To conduct a literature review about the current practices of emergency supply management, supply chain risk management, risk assessment techniques, and the existing and current status of implementation of risk management technology in emergency supply chains.
- To develop a framework to identify, evaluate the risk level, and mitigate the interrelated hazards in the emergency supply chain.
- To develop models to examine the possibility and feasibility of using novel risk management technology in emergency supply chain operations, explicitly focusing on intermodal transport.
- To examine the applicability of the proposed framework and analytical models through empirical study to find the best solution to manage the risk in emergency supply chain operations.
- To conduct case studies to justify and demonstrate the applicability of the proposed framework and analytical models.

1.5 Research Methodology

The field of research on ESCs is evolving, and several recommendations have been made not just for empirical study but also for mixed methodologies in operations research and ESCs.

The rigour and usefulness of ESC research are being undermined because of the current lack of utilization of mixed-method research designs and the paucity of empirical evidence presented in published studies (Kovacs *et al.*, 2019). Conducting empirical studies widens the field's understanding and provides insights into real-world situations, enhancing the performance of academics, practitioners, and policymakers. Therefore, this thesis adopts a mixed-method research design to achieve its overall aim, which concerns how relief organizations can effectively manage the risk factors encountered during the operations of the ESCs.

In this research, the empirical study is directed at no region or country, and the necessary data will be retrieved through several methods, including reviewing pertinent articles, official documentation, topic-related websites, and reports. In addition, several rounds of high-level surveys and semi-structured interviews will also be utilized. Before the deployment of the questionnaire survey, each survey went through a pilot test, where various experts in the field, ranging from middle to senior level, were urged to examine the survey and make relevant comments concerning its appropriateness and clarity. The comments were utilized to modify the questionnaire to ensure its effectiveness before deployment.

A pertinent literature review serves as the foundation for identifying risk sources and solutions for risk mitigation. To verify the discovered risk factors and applicable risk mitigation strategies that were extracted from the existing resources and to investigate new risk factors and mitigation strategies that have not been addressed in the literature or other material, high-level questionnaire surveys and semi-structured interviews were conducted with participant experts from both academic and industry domains. In addition, in-person interviews were conducted to investigate further the appropriateness of the constructed hierarchy model and risk mitigation strategies currently implemented in the industry. The constructed hierarchy provides a summary of the validated risk factors.

It is vital to quantify the risks by identifying their priority weighting to achieve the goal of conducting risk factors assessment. Further high-level questionnaire surveys, or risk assessment surveys, were designed and deployed. This research utilised the Fuzzy Analytic Hierarchy Process (F-AHP) to analyze the feedback from this survey to determine the relative importance of each risk factor. Another high-level survey was utilized to collect the primary data pertinent to achieving a deeper level of comprehension regarding the significance of the selected risk mitigation solutions with the various risk factors. At the end of the survey, the

Fuzzy Technique for Order Preference by Similarity to Ideal Solution (F-TOPSIS) was applied to analyse the data and rank the relative importance of the risk mitigation strategies with the performance in various risk contexts.

1.6 Structure of the Thesis

This thesis consists of eight chapters, and they are summarized below.

Chapter 1 – Introduction: The purpose of the first chapter is to provide the reader with background information and specifics regarding the research's rationale, aim and objectives, research scope, methodological considerations, and organizational structure. Moreover, it provides a concise summary of the prerequisites for this research and an overview of the procedures that will be followed to carry out the research. See Figure 1.1 for a visual representation of the overall framework of the thesis.

Chapter 2 – Literature review: For research to be helpful, there must be a void in our understanding of a phenomenon. A comprehensive review of current literature is necessary to identify the necessary knowledge gaps. The second chapter of this thesis covers the completion of this task. In this section, the two main focuses of this research, which are ESCM and SCRM, will be discussed critically. This contributes to accomplishing the first research objective. The necessary research gaps are revealed, specifically the need to develop a comprehensive risk management framework for emergency supply chains and a decision methodology to assist relief actors during emergency relief operations.

Chapter 3 - Research methodology: In this chapter, the steps taken to arrive at a particular approach are detailed. This section provides an overview of the research philosophy, methodology, approach, and design. In addition, the purpose of this chapter is to outline the procedures for data collection and analysis to justify the methodological decisions made to accomplish the research aims.

Chapter 4 – Emergency supply chain risk management framework: The novel risk management conceptual framework is introduced in this chapter as a platform that aims to incorporate the five main components, including risk sources, relief actors, supply chain strategies, the supply chain risk management process, and performance outcomes, to meet the practical decision support needs of the industrial sector. The proposed framework serves as the basis for developing the integrated risk management model, which is then implemented by organizing and improving the various risk management approaches that have come before.

Chapter 5 – Risk factors identification in emergency supply chains: In this section, the research will go through the first phase of the risk management process: identifying the elements that pose a risk. This chapter summarises the relevant literature and other available materials to broaden the scope of risk factor identification and categorise the unstructured risk factors. Here, the first high-level survey is designed, pilot-tested and deployed to retrieve the perspectives of the disciplines' academics and industrial professionals. Experts' feedback is used to refine and validate the built hierarchical structure of identified risk variables through email exchanges and in-person meetings.

Chapter 6: Risk factors assessment in emergency supply chains: The research will weigh the prevalent risk factors in ESCs in this section. Here, the fuzzy analytical hierarchy process is used to analyze data gathered in the second round of in-depth questionnaires used in empirical research. This is done to identify the relative importance of each risk factor that could disrupt the supply chain.

Chapter 7: Risk factors mitigation in emergency supply chains: This study relies on a literature review to determine whether risk mitigation strategies are effective, and it also employs empirical research to identify those measures already being put into place in the context of real-time events. In the end, a comprehensive survey is conducted to assess the significant levels of risk mitigation strategies. The questionnaire survey uses a five-point Likert scale. The fuzzy technique for order preference by similarity of an ideal solution methodology is used to prioritise the risk mitigation strategies. This chapter concludes with a discussion and managerial implications.

Chapter 8 – Conclusions: The results of the previous chapters' efforts to identify risk factors, evaluate those factors, and develop strategies for mitigating those risks are summed up here. In addition to laying out the scope and limitations of this thesis, the conclusion offers suggestions for further research.

1.7 Publications Generated From the Research

During this research, three publications were produced. These are outlined as follows:

1. O. J. Chukwuka, J. Ren, and D. Paraskevadakis, "A research on purchasing relief supplies in disaster relief operations," 2021 6th International Conference on Transportation Information and Safety (ICTIS), Wuhan, China, 2021, pp. 642-647, Doi: 10.1109/ICTIS54573.2021.9798653.

2. Chukwuka, O.J., Ren, J., Wang, J. and Paraskevadakis, D. (2023), 'A comprehensive research on analyzing risk factors in emergency supply chains', *Journal of Humanitarian Logistics and Supply Chain Management*, 13(3), pp. 249-292. doi.org/10.1108/JHLSCM-10-2022-0108.
3. Chukwuka, O.J., Ren, J., Wang, J. and Paraskevadakis, D. (2023), "Managing risk in emergency supply chains - An empirical study" (under review).

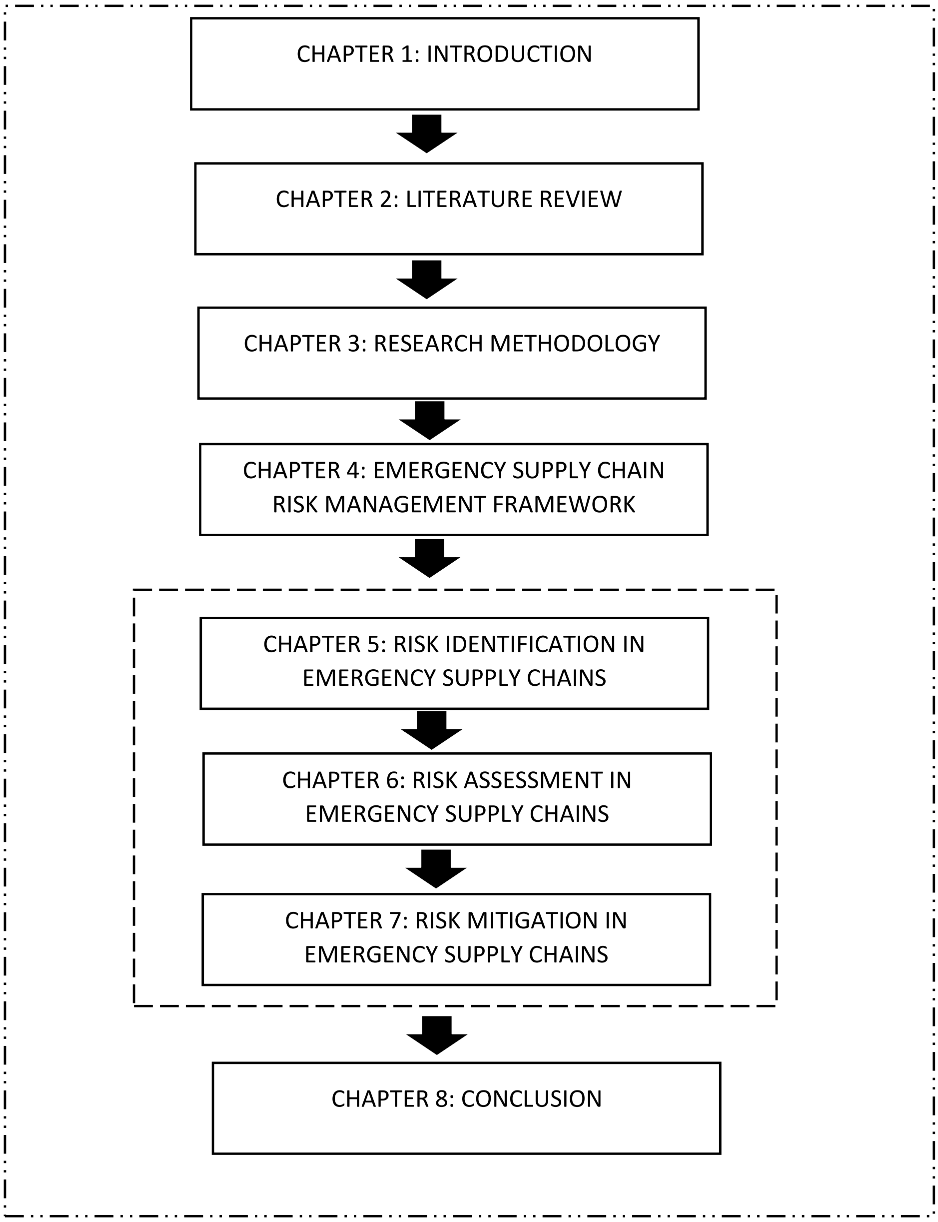

Figure 1.1 Structure of thesis

CHAPTER 2 - LITERATURE REVIEW

2.1 Introduction

In this chapter, the literature influencing this current study is reviewed. This literature review aims to provide a foundation for and support the study's definitive research questions. A structure map serving as a schematic of the review's organizational framework is presented in Figure 2.1.

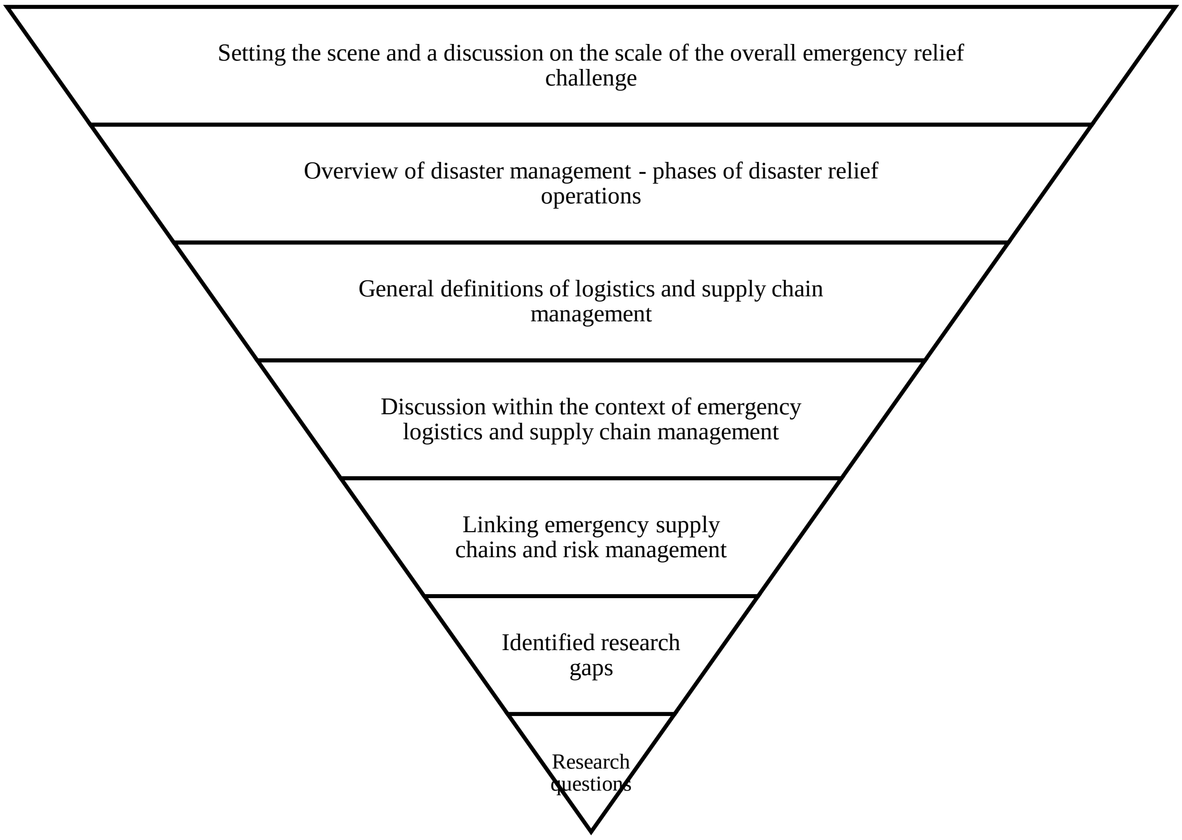

Figure 2.1 Literature Framework

The first stage of the literature review is the discussion on the magnitude of the problem faced by the community working in disaster relief. The following stage is the introduction to disaster management and its' various phases. Before examining the emergency logistics and supply chain scenario, the disciplines and concepts of supply chain and logistics management will be explored from a general perspective. The characteristics that set the ESCM apart from general CSCs will be defined in this setting. Through this comparison, the research will identify the players in the ESC and describe the conditions under which the ESC functions. This explanation will lay the groundwork for connecting ESCs and risk management. Definitions of supply chain risk (SCR) and SCRM, different types and classification models of supply chain risks, and the process of SCRM will all be discussed after a brief introduction to the field. Since it was mentioned at the beginning of this research that the ESC is a one-of-a-kind system, this section will focus on identifying the various risks associated with ESCs and providing an overview of how these risks are managed. The penultimate section of this review will utilize the preceding discussion in this chapter to highlight a considerable number of research gaps that will serve as the foundation for this research and the doctoral dissertation.

2.2 Setting the Scene

"The international humanitarian system must also ensure it is as effective as possible to meet the challenges resulting from a changing humanitarian landscape. While there is no agreed definition of humanitarian effectiveness, there is strong consensus that the fundamental goal of humanitarian action is to save lives and alleviate suffering. Humanitarian effectiveness is often discussed in terms of transparency, relevance, readiness, performance, speed of response, value for money and accountability to affected countries, people, and donors. However, what constitutes "effectiveness" will often depend on the context of the crisis — natural disasters compared to conflicts or situations of chronic vulnerability — and the perspective of the stakeholder (affected people, affected States, donors, humanitarian organizations, and other key actors) (United Nations, 2013)*".*

Every year, the frequency and intensity of disasters continue to increase. Looking at the recent events following the Indian Ocean Tsunami, one can conclude that an immense scale of relief effort is needed for one case in isolation, let alone other natural or human-inflicted disasters. Considering the COVID-19 pandemic, for example, the World Health Organization (WHO) reported the deaths of more than 6 million people, and a total of 456.8 million have been impacted, with this number still increasing (WHO 2022). In this sense, the importance of relief actions for the vulnerable population in crisis response continues to be emphasised (Lau *et al.*, 2020; Queiroz *et al.*, 2020). In 2015, the third UN World Conference on Disaster Risk Reduction held in Sendai, Miyagi, Japan, adopted a framework for 2015-2030 that encompasses four priorities for action. Priority 4 aims to enhance disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation, and reconstruction.

Moreover, relief organizations that receive millions in financial aid and relief supplies from donors are under intense pressure to ensure that the vulnerable population in need is swiftly accessed. Relief organisations monitor the whole disaster response operations to ensure the practical impact of aid. Thus, being goal-oriented is fundamental to these organizations as donors continue to hold them accountable. Meanwhile, logistics accounts for around 80% of disaster relief operations; in this case, this primarily means achieving a successful operation through slick, efficient, and effective logistics operations and, more precisely, critical emergency supply chain management (Van Wassenhove, 2006).

Fritz, (1961) defined disasters as "Uncontrollable events that are coordinated in time or space, in which society undergoes severe danger and incurs such losses that the social structure is disrupted, and the fulfilment of all essential functions is prevented". Altay and Green, (2006) viewed disasters as "large, intractable problems that test the ability of communities, nations and regions to effectively protect their populations and infrastructure, to reduce both human and property loss and to recover rapidly". Guha-Sapir *et al.*, (2011) described the disaster as "a situation or event, which overwhelms local capacity, necessitating a request to a national or international level for external assistance; an unforeseen and often sudden event that causes great damage, destruction and human suffering". The Centre for Research on Epidemiology of Disaster (CRED) agrees with this definition. Underlining that a disaster is any disruption that physically affects a system and threatens its priorities and goals, Van Wassenhove, (2006) noted that a disaster can either be natural or man-made and developed a simple grid to help explain disaster (see Fig 2.2).

	Natural	**Man-made**
Sudden-onset	Earthquake Hurricane Tornadoes	Terrorist Attack Coup d'Etat Chemical leak
Slow-onset	Famine Drought Poverty	Political Crisis Refugee Crisis

Figure 2.2 Explaining disasters.

Source: Van Wassenhove (2006)

Getting the right aid and relief supplies at the right time and place and distributing them to the right people are common elements of any supply chain. This is also the case in the disaster relief context. Trunick, (2005) underlined that most of the activities in disaster relief operations could be attributed to logistics and supply chain management, which can mean the difference between a successful and failed operation. However, Van Wassenhove, (2006) highlights that developing and deploying an effective and efficient supply chain for disaster relief operations is complex. Logisticians and supply chain managers are often unaware of the basics for setting up the relief supply chain. They do not know when, where, what, how much, and how many times. Thus, they are confronted with several unknowns. The challenges faced in responding to disasters are often compounded by logistics and supply chain difficulties such as long lead times, dependence on sole suppliers for specialist items, multiple handling, and over-reliance on poor infrastructure (Oloruntoba, 2010). Likewise, each disaster relief operation has distinct political and cultural realities (Chandes and Paché, 2010). The 2004 Indian Ocean Tsunami remains a notable example, highlighting the fundamental role of adequate logistics and supply chain management in disaster relief operations. Following the impact of the disaster, loads of solicited and unsolicited relief supplies arrived and overwhelmed airports and warehouses in the affected regions. Relief managers faced the challenge of sorting, storage, and the last-mile distribution of supplies. Several infrastructures were damaged or destroyed in countries like India and Sri Lanka. Thomas and Kopczak, (2005) termed the situation a "logistical nightmare".

Research suggests that the subject has been locked into a vicious circle (see Figure 2.3), where a lack of understanding and its importance has resulted in its absence, in decision-making regarding planning and budgetary processes amongst stakeholders.

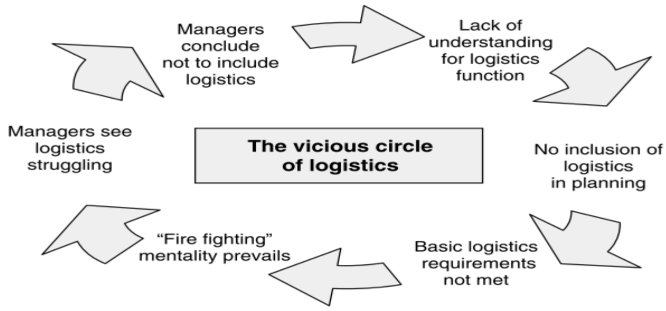

Figure 2.3 The vicious circle of logistics

Source: (Van Wassenhove, 2006)

Following Hurricane Mitch in 1998, the Government of Honduras requested the assistance of the IFRC. "However, they failed to coordinate the relief contributions of the donating National Societies; its technical staff had arrived on the disaster scene far too late; its specialized equipment was only deployed at the eleventh hour, and basic supplies took two weeks to mobilize and distribute to the vulnerable population" (Chomilier *et al.*, 2003). In response to the poor performance, the IFRC now understands the role of supply chain management. In addition, other organizations, including the World Food Programme, are waking up to the reality that logistics in this context is crucial to the adequate performance of relief operations and serves as a connection between activities conducted before and after the disaster impact (Thomas and Mizushima, 2005).

2.3 Disaster Management

Disaster management has often been viewed as a process with a sequence of phases (Pettit and Beresford, 2005; Kovács and Spens, 2007; Tomasini and Van Wassenhove, 2009). Disaster management is the comprehensive process of planning, organizing, coordinating, and putting into action the necessary steps to deal with the effects of a disaster on people effectively. No consensus exists on the number of phases in disaster management. Some studies have suggested a three-phased disaster management cycle (Kovács and Spens, 2007; Listou, 2008; Jahre and Jensen, 2010; Chakravarty, 2014; Dubey and Gunasekaran, 2016; Heaslip and Barber, 2016). Conversely, other studies have suggested a four-phased management cycle for disasters (Altay and Green, 2006; Van Wassenhove, 2006; Natarajarathinam *et al.,* 2009; Cozzolino *et al.,* 2012; Holguín-Veras *et al.,* 2012; John *et al.,* 2012; Leiras *et al.,* 2014; Scholten *et al.,* 2014). Varied phase title exists amongst studies with a similar number of phases. However, the fundamental difference between a three-phased and four-phased management cycle is the omission of the mitigation phase in the three-phased school of thought. Adopting from risk management, Cotrill, (2002) discussed the planning, mitigation, detection, response, and recovery phases in managing disasters. Considering different times, Lee and Zbinden, (2003) mentioned three stages of disaster relief operations: preparedness, during operations, and post-operations. Preparedness concerns relief activities conducted before the disaster strikes. Activities carried out immediately after the disaster strikes relate to the operations phase and can be seen as the immediate response phase. Post-operation steps relate to the activities carried out in the aftermath of the disaster. Long, (1997) suggests that the preparedness and immediate response phases are like strategic planning. Generally, the four-phased disaster management cycle is the most cited by researchers in the field. The National Governor's Association Centre for Policy Research 1979 proposed the four-phased disaster management cycle, including the mitigation, preparedness, response, and recovery phases (see Fig. 2.4, (Dowty and Wallace, 2010)). The disaster management cycle depicts the continuous process by which different groups work together to prepare for and mitigate the effects of disasters, respond to them in the immediate aftermath, and then rebuild their communities (Clerveaux *et al.,* 2010). Table 2.1 summarizes the activities conducted in each phase of disaster management.

The mitigation phase is concerned with identifying and evaluating the possible source of disasters and recognizing the set of activities to reduce and eliminate those sources to prevent the occurrence of the disaster or reduce its impact (Natarajarathinam *et al.,* 2009). The application of measures for the prevention of disaster onset and impact reduction is carried out in the mitigation phase (Altay and Green, 2006). Decker *et al.,* (2013) postulated that the activities in the mitigation phase involve gathering information on lessons learnt from previous

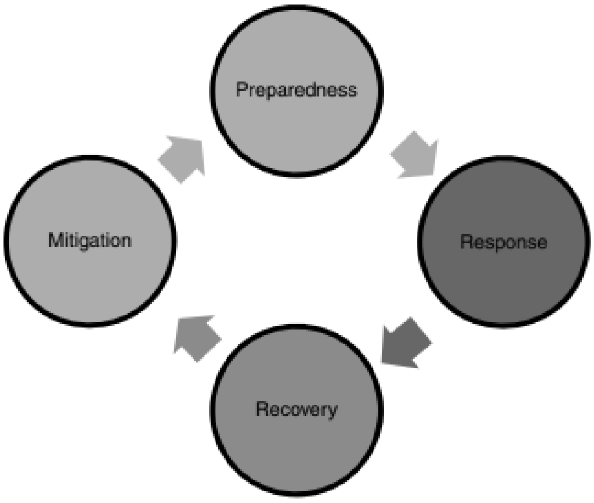

Figure 2.4 Disaster management life cycle

experiences to enable risk management and provide guidance for subsequent phases of the disaster management cycle. Preparedness is the next phase in the cycle. This phase is analogous to strategic planning in commercial supply chains. John *et al.*, (2012) discussed that activities in this phase concern several issues, including locating facilities, prepositioning assets, allocating resources, and planning modes and routes of transportation and critical supplies to those affected. Effective preparedness translates to the success of a disaster relief operation (Tomasini and Van Wassenhove, 2009).

In addition, Çelik *et al.,* (2012) underlined that "one dollar invested in preparedness saves seven dollars in disaster-related economic losses". Development of the response plan defines the role of relief actors in the immediate response; organisational and community development are other activities carried out in preparing for disaster impact (Decker *et al.*, 2013). Primarily, the onus falls on individual countries and local communities to conduct the activities in this phase. However, the presence of international parties taking part is becoming a norm (Goldschmidt and Kumar, 2016). The next phase is the response. A good disaster management plan encompasses a clear and defined plan for responding to disasters. The response phase constitutes actions and activities taken after the impact of a disaster. Natarajarathinam *et al.*, (2009) mention that the plan developed in the preparedness phase is deployed in the response phase. The response plan employs the available resources and emergency procedures to ensure the safety of lives, properties, the environment, and the social, economic, and political structure (Altay and Green, 2006). Goldschmidt and Kumar, (2016) mention that the immediate response efforts following disaster impact is around the first 72 hours, which is crucial to saving and evacuating the vulnerable population from the hot zone. Subsequently, a sustained response period emerges and lasts for the first 90-100 days after the immediate response. An effective response operation is influenced by coordination between diverse stakeholders, including the government, international relief organizations, non-governmental organisations and the military. Although achieving coordination, cooperation and information sharing is challenging due to competition among stakeholders for donations, resources, and relevant attention from the media.

The Recovery phase contains the final set of activities in the management cycle (Natarajarathinam *et al.,* 2009), long-term actions after the immediate response activities to aid the restoration and stabilization of the impacted community. The vulnerable population are assisted with recovery, and those evacuated are assisted to return home (Goldschmidt and Kumar, 2016). Moreover, the opportunity to rebuild better properties and infrastructure, address disaster's long-term effects, and improve community resilience arises. Recovery is crucial since it ensures continuity planning. However, the literature suggests stakeholders invest limited funding and pay less attention to the recovery phase (Kovács and Spens, 2007; Goldschmidt and Kumar, 2016).

Examining the different perspectives on disaster relief operations provides a basis for examining what differentiates emergency and supply chains from commercial and supply chains. The first issue concerns the definition of the concept. Discussion must now turn to the background of the definitions of SCM and logistics in the generic sense and those more relevant to the disaster relief setting.

Table 2.1 Typical activities of disaster operations management

Phase of disaster relief operations	Typical activities
Mitigation	Zoning and land use controls to prevent occupation of high hazards.
	Barrier construction to deflect disaster forces.
	Active preventive measures to control developing situations.
	Building codes to improve disaster resistance of structures.
	Tax incentives or disincentives.
	Controls on rebuilding after events.
	Risk analysis to measure the potential for extreme hazards.
	Insurance to reduce the financial impact of disasters.
Preparedness	Recruiting personnel for emergency services and community volunteer groups
	Emergency planning
	Development of mutual aid agreements and memorandums of understanding
	Training for both response personnel and concerned citizens
	Threat-based public education
	Budgeting for and acquiring vehicles and equipment
	Maintaining emergency supplies
	Construction of an emergency operations centre
	Development of communications systems
	Conducting disaster exercises to train personnel and test capabilities
Response	Activating the emergency operations plan
	Activating the emergency operations centre
	Evacuation of threatened populations
	Opening of shelters and provision of mass care
	Emergency rescue and medical care
	Fire fighting
	Urban search and rescue
	Emergency infrastructure protection and recovery of lifeline services
	Fatality management
Recovery	Disaster debris clean-up
	Financial assistance to individuals and governments
	Rebuilding of roads and bridges and critical facilities
	Sustained mass care for displaced human and animal populations
	Reburial of displaced human remains
	Complete restoration of lifeline services
	Mental health and pastoral care

Source: (Altay and Green, 2006)

2.4 Logistics and Supply Chain Management

Logistics and supply chain management are not novel notions. From building Diving into the history of mankind, the success or failure of wars has been defined by the effectiveness and efficiency of logistics activities. Logistics is essentially a planning orientation and framework that seeks to create a single plan for the flow of products and information through a business. The academic perspective (Mangan *et al.*, 2012; Slack *et al.*, 2010) leans towards an organisation's conventional transformational process view, where attention is placed on internal operations alone. However, organisations do not work in isolation (Waters, 2011); they are linked with other entities, including their suppliers, distributors and customers, to form a supply chain. Sweeney, (2005) explained that organisations must be aware of their supply chain and the critical role logistics plays in it. Since the 1980s, the term ‘supply chain management’ has been adopted increasingly by people who argue that ‘logistics’ does not give the subject a broad feel. Larson and Halldorsson, (2004) discussed that logistics is a narrower subject concerned with flows within a particular entity. SCM takes a broader view of the movement through all the related supply chain organisations.

The opinion of the Council of Supply Chain Management Professionals suggests that logistics is a broad function within an organisation, and SCM is responsible for integrating demand and supply management within and across an organisation. Waters, (2011) explains that logistics is essentially a planning orientation and framework that seeks to create a single plan for the flow of products and information through an organisation, while SCM builds on the logistics framework to link and coordinate the processes and activities of other entities in the network, i.e. suppliers and customers and the organisation itself. Thus, for example, the objective of supply chain management might be centred around reducing or eliminating inventory buffers between organisations in a supply chain through necessary information flow on demand and current stock levels. Simchi-Levi *et al.*, (2004) defined SCM “as a set of approaches used to efficiently integrate suppliers, manufacturers, warehouses, and stores so that merchandise is produced and distributed in the right quantities, to the right locations, and at the right time in order to minimise system-wide costs while satisfying service-level requirements”. Similarly, The Council of Supply Chain Management Professionals underlined that “Supply chain management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. It also includes coordination and collaboration with channel partners, suppliers, intermediaries, third-party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies" (CSCMP, 2014). SCM entails a significant change from the traditional arm's length, even adversarial, relationships that so often defined the relationships of buyers and suppliers in the past. It promotes cooperation and trust between organisations and the recognition that, properly managed, the whole can be greater than the sum of its parts. In addition, the focus of SCM is on the management of relationships in order to achieve a more profitable outcome for all parties in the chain. As a result, critical issues arise. For instance, the interest of a particular entity will have to be subsumed for the benefit of the chain as a whole. Hence, the underlying philosophy behind the logistics and supply chain management concept is that of planning and coordinating the materials flow from source to user as an integrated system rather than, as was so often the case in the past, managing the goods flow as a series of independent activities.

2.5 Emergency Logistics and Supply Chain Management

Emergency supply chain management (ESCM) is a discipline closely bound to the broader context of disaster management, which has met contemporary acceptance. The discipline revolves around distributing rescue resources to facilitate search and rescue operations, provide food and shelter and enable locals to be self-sufficient. Thus, the emergency supply chain focuses on the response phase of disaster management. Accordingly, the smooth flow of relief supplies to vulnerable populations impacted by disasters is now viewed as a global and multinational industry, as disasters may occur at any time and place with overwhelming concerns (Carroll and Neu, 2009; Tomassini and van Wassenhove, 2009). The need for more effective and efficient logistics and supply chain management in the disaster relief context has gained the necessary recognition.

Nevertheless, ineffective relief efforts in response to disasters remain a critical concern. For example, Thomas, (2005), remarking on the SE Asian Tsunami, notes, "*Logistics is the most under-recognized and under-resourced part of relief organizations…the focus is on the frontline and not the backroom that facilitates the frontline*". In the same line, findings from the Fritz Institute Survey in 2005 underlined that "traditionally, infrastructure is not the focus of donations". Tomasini and van Wassenhove, (2004) underlined that "*A successful disaster relief operation mitigates the urgent needs of a population with a sustainable reduction of their vulnerability in the shortest amount of time and with the least number of resources*". The decisive, effective emergency supply chain management must encompass multiple global, dynamic, agile, and momentary characteristics, which implies the ability to respond to several relief operations, often on a global scale, within a short time frame (Van Wassenhove, 2006).

Thomas and Kopczak, (2005) explained why emergency logistics and supply chain management is at the core of disaster relief operations:

- It is decisive to the effectiveness and speed of all disaster relief operations.
- It serves as a connection between disaster preparedness and its immediate response, between purchasing relief supplies and their distribution and between personnel in the office and those in disaster-struck zones (field).
- Its provision of reliable information for analysis of post-event effectiveness and lessons learned.
- It can mean the difference between success and failure due to the cost implications.

Oloruntoba and Gray, (2006) note that there is no typical form for the ESC, considering that disasters are distinctive in types and levels of intensity. Sheu, (2007) notes that several authors have defined logistics and supply chain management in the disaster relief context. Table 2.2 shows some definitions. However, the definition remains ambiguous. Ernst, (2003) described relief efforts as follows:

"A process of planning, managing and controlling the efficient flows of relief, information and services from the points of origin to the points of destination to meet the urgent needs of the affected people" (Ernst, 2003).

From the perspective of the Chartered Institute of Logistics and Transportation, emergency supply chain management is:

"*Right People, equipment, and material, in the right place, in the right sequence as soon as possible, to deliver maximum relief at the least cost -saved lives, reduced suffering and the best use of donated funds"* (CILT, 2011).

"Humanitarian logistics is the process of planning, implementing and controlling the efficient, cost-effective flow and storage of goods and materials, as well as related information, from point of origin to point of consumption for the purpose of meeting the end beneficiary's requirements" (Thomas and Mizushima, 2005).

Table 2.2 Definitions of Emergency Supply Chain Management

Definition	Author`	Context
The systematic use of policy instruments to deliver humanitarian assistance in a cohesive and effective manner. Such instruments include; • strategic planning, • Gathering data and managing information • Mobilising resources and assuring accountability • Orchestrating a functional division of labour in the field • Negotiating with host political authorities • Providing leadership and maintaining a serviceable theory	(Minear, 2002)	Coordination
The process of planning, implementing and controlling the efficient, cost-effective flow and storage and materials as well as related information from the point of origin to the point of destination for the purpose of alleviating the suffering of vulnerable people	(Thomas and Kopczak, 2005)	Emergency Logistics
The range of activities is designed to maintain control over disaster and emergency situations and to provide a framework for helping at-risk persons to avoid and recover from the impact of a disaster. Disaster management deals with a situation before, during and after a disaster.	(Schulz, 2008)	Disaster Relief
To design the transportation of first aid material, food, equipment and rescue personnel from supply points to a large number of destination nodes geographically scattered over the disaster region and the evacuation and transfer of people affected by disasters to healthcare centres safely and very rapidly.	(Kovacs and Spens, 2007)	Disaster Relief
A process of planning, managing and controlling the efficient flow of relief and services from the point of origin to the point of destination to meet the urgent needs of the affected people under emergency conditions.	(Sheu, 2007)	Emergency Logistics

Source: (John *et al.*, 2012)

However, when it comes to the most adopted definition of 'emergency supply chain management" in literature, it is based on traditional supply chain management. Thomas and Mizushima, (2005) adapt the Council of Supply Chain Management Professionals' (CSCMP) definition of logistics management to the disaster relief context. The difference in both definitions is a mere replacement of the terms 'end customer' to 'end beneficiary'. In addition, the concept of profit is absent. Thus, SCM forms the backbone of ESCM. Hereafter, for this study, the definition is accepted. Heaslip, (2013) highlights that amongst the disaster relief community, an argument is ongoing concerning re-labelling activities that stakeholders viewed as logistics to supply chain management. Disasters test the reactivity of our systems, especially the capacity of different actors to work together. They demand solutions from the collaboration of these diverse actors, including governments, the military, civil society, and humanitarian organizations. Sharing processes and distribution channels demand a vision beyond mere logistics (moving goods from point A to point B). Tomasini and van Wassenhove, (2009) underline that a management approach for effective performance coordination, eliminating redundancies, and improving efficiencies in terms of cost and speed is vital. The aim of this research aligns with the definition of Mangan and Lalwani, (2016), who explained that "the supply chain is a much wider, intercompany, boundary-spanning concept, than is the case with logistics".

Considering the definition of supply chain management and its significance in the disaster relief context, perspectives must now focus on the complex environment associated with the emergency supply chain to differentiate it from the commercial supply chain. Furthermore, an exploration into the actors involved in the inclusive emergency supply chain is also required.

2.5.1 Unique features of the emergency supply chain

Nature, frequency, and intensity contribute to the diversity of disasters. Irrespective of nature, the disaster response process remains relatively similar. According to Thomas, (2003), the speed of disaster relief operations is influenced by the ability of supply chain managers to effectively control the sourcing, purchase, transportation, and last-mile distribution of the supplies to those in need. Moreover, logisticians and supply chain managers face distinct difficulties due to the complex nature of their working environment. Thus, emergency supply chains possess specific characteristics that set them apart from their business counterparts (Kovacs and Spens, 2007). Commercial supply chains are often associated with a fixed set of stakeholders and, in any case, likely demand – all of which are unknown in the emergency supply chain (Cassidy, 2003). Beamon and Kotleba, (2006) underlined that those extensive activities, variations or irregularities in demand and rare challenges in large-scale emergencies characterize the emergency supply chain.

Contrary to the goal of effecting and maximizing profit in commercial supply chains, emergency supply chains are centred on alleviating the sufferings of the vulnerable population

(Thomas and Kopczak, 2005). Numerous actors constitute the supply network of the emergency supply chain without well-defined connections. Even though processes and relief actors are entangled, distinctions exist between the diverse groups of actors and different phases of disaster relief operations. Every disaster relief operation is focused on providing aid to vulnerable populations to ensure survival. The operation is often performed in complex environments with destabilized infrastructures extending from the absence of power supply to inadequate transportation and distribution infrastructure. Still, disasters can occur anywhere and anytime; hence, demand in this case is often unpredictable (Maon *et al.*, 2009). Operations conducted instantly after a disaster impact most often entail many relief supplies being pushed into the impacted region. The actual demand is absent. Table 2.3 summarises the differences between the commercial and emergency supply chains.

Table 2.3 Characteristics of emergency supply chains

Emergency supply chains	
The main aim	Alleviating the suffering of vulnerable people
Actor structure	Stakeholders focus on no apparent links to each other the dominance of NGOs and governmental actors.
3-phase set-up	Preparation, immediate response, reconstruction
Basic features	Variability in supplies and suppliers, large-scale activities, irregular demand, and unusual constraints in large-scale emergencies
Supply chain philosophy	Supplies are "pushed" to the disaster location in the immediate response phase. Pull philosophy applied in reconstruction
Transportation and Infrastructure	Infrastructure destabilized, and lack of possibilities to ensure the quality of food and medical supplies.
Time effects	Time delays may result in loss of lives.
Bounded knowledge actions	The nature of most disasters demands an immediate response; hence, supply chains need to be designed and deployed at once, even though the knowledge of the situation is minimal.
Supplier structure	Choice limited, sometimes even unwanted suppliers
Control aspects	Lack of control over operations due to an emergency

Source: (Kovács and Spens, 2007)

2.5.2 Actors in the Emergency Supply Chain

Following the impact of disasters, the need to promptly develop and deploy supply chains for the prompt and appropriate supply of relief to the vulnerable population is crucial (Thomas and Kopczak, 2005). The emergency supply network involves various actors (Fig. 2.5). Thus, the emergency supply chain is complex (Paciarotti *et al.*, 2021).

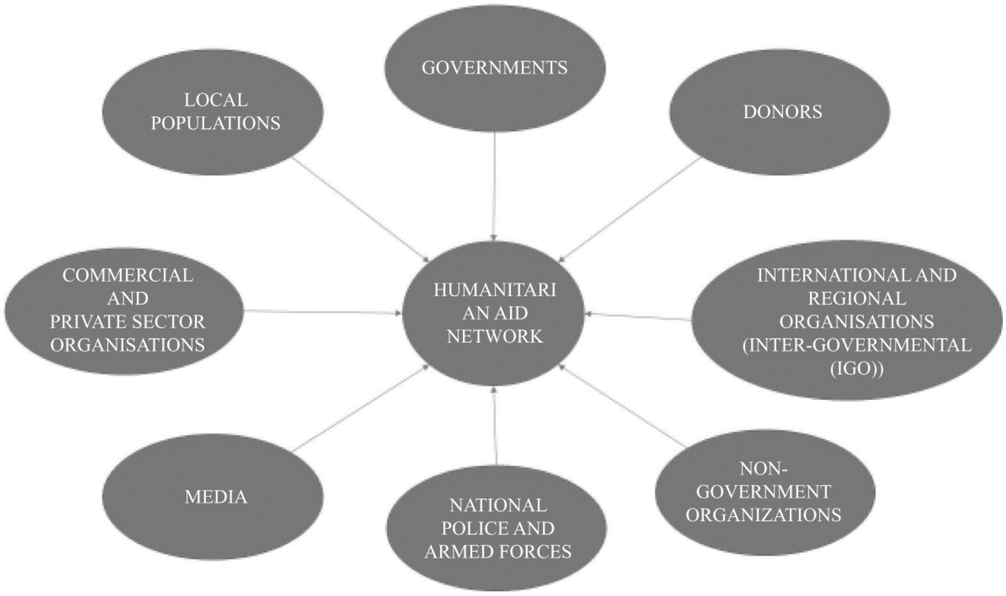

Figure 2.5 Actors in the Emergency Supply Chain

Source: (Paciarotti *et al.,* 2021)

Actors in emergency assistance are groups or individuals who participate in and contribute to procedures involving emergency logistics and supply chains. The actors participating in emergency supply chain activities can be categorized as assistance organisations, governments, non-governmental organisations (NGOs), businesses, the military, and donors, according to Kovacs and Spens, (2007). According to Balcik *et al.,* (2010), the actors are host governments, the military, domestic and international relief groups, and private sector companies, each of which has distinct interests, mandates, capacities, and logistical skills. Such actors react to a significant global disaster to supply the affected communities with food, water, and non-food essentials like shelter (Burkart *et al.,* 2016; Banomyong *et al.,* 2019a; Kim *et al.,* 2019; Oloruntoba *et al.,* 2019). Each actor has a crucial role to play for the logistics and supply chain plan to be successful and cost-effective. Emergency relief supply chain coordination among participants impacts the success or failure of a relief operation. As a result of the severity and complexity of the crisis and the limited resources available, participants in the ESCs must work together and have trust in one another to achieve shared objectives (Dubey *et al.*, 2019). A lack of coordination among those involved in the ESC could lead to significant losses and poor response in the impacted areas (Noori and Weber, 2016; Dubey *et al.,* 2018). The function of each actor in the ESC is summarized in Table 2.4.

Table 2.4 Functions of relief actors in the emergency supply chain

Relief actor	**Functions**	**Source**
Government	The emergency logistics activators that have the authority to approve the task and mobilise the assets	(Eng, 2006; Kovács and Spens, 2007; Altay and Pal, 2014; Leiras *et al.,* 2014; Bealt *et al.,* 2016; Burkart *et al.,* 2016; Ganguly and Rai, 2016; Banomyong *et al.,* 2019b; Oloruntoba *et al.,* 2019; Behl and Dutta, 2019; Dubey *et al.,* 2019; Kourula *et al.,* 2019; Quarshie and Leuschner, 2020; Zhang *et al.,* 2020)
The military	A vital player in the process as the soldiers deliver primary aid to the affected people and support the entire operation. The primary roles of the military in relief supply chains include security and protection, distribution, and engineering. Primary military aid also includes installing camps and hospitals, repairing routes and paths, and telecommunication services.	(Heaslip and Barber, no date; Kovács and Spens, 2007; Pettit and Beresford, 2009; Mclachlin and Larson, 2011; Bealt *et al.,* 2016; Burkart *et al.,* 2016; Ganguly and Rai, 2016; Banomyong *et al.,* 2019a; Behl and Dutta, 2019; Dubey *et al.*, 2019; Oloruntoba *et al.,* 2019; Quarshie and Leuschner, 2020)
The police	Establish safe rescue routes. Shifting of all vehicles to the parking yards; Traffic control. Assist in controlling and fighting disasters and salvage operations.	(Dubey *et al.,* 2019)
Aid agencies	The medical aid agencies provide emergency supplies, i.e., emergency relief efforts in response to natural disasters.	(Kovács and Spens, 2007; Bealt *et al.,* 2016; Ganguly and Rai, 2016; Behl and Dutta, 2019; Dubey *et al.*, 2019)
The logistics services providers	Effectively manage the physical distribution of products along the emergency supply chain in relief operations.	(Kovács and Spens, 2007; Bealt *et al.,* 2016; Behl and Dutta, 2019; Dubey *et al.,* 2019; Kim *et al.,* 2019)
The financial sectors	The role of the financial sector, prominently banks and insurance companies, in the event of a disaster and their fit in the emergency supply chain is significant in terms of providing funds during the response and rehabilitation process.	(Bealt *et al.,* 2016; Behl and Dutta, 2019; Zhang *et al.,* 2020)
Donors	The individuals who freely donate and give monetary intended to support the relief efforts.	(Kovács and Spens, 2007; Pettit and Beresford, 2009; Balcik *et al.*, 2010; Mclachlin and Larson, 2011; Cozzolino *et al.,* 2012; Altay and Pal, 2014; Bealt *et al.,* 2016; Behl and Dutta, 2019; Quarshie and Leuschner, 2020)
NGOs (local and international)	To offer the aid to an emergency relief process centred on its responsibility: donors and collectors/providers. Donor offers financial support in terms of cash to boost disaster relief activities. Collectors are the ones who collect the funds from the suppliers, employees, and customers to help with the activities. The provider is an organisation/agency offering free goods and services.	(Bealt *et al.,* 2016; Behl and Dutta, 2019; Zhang *et al.*, 2019; Quarshie and Leuschner, 2020)
Red Cross	A relief organisation that provides emergency assistance, disaster relief and disaster preparedness education globally.	(Dubey *et al.*, 2019)
OCHA	United Nations Office of Coordination for Humanitarian Assistance (OCHA) coordinates the global emergency response to save lives and protect people in disasters. It aims to strengthen the international response to complex emergencies and natural disasters	(Jahre and Jensen, 2010; Dubey *et al.*, 2019)

Source: (Negi and Negi, 2020)

2.5.3 Operational Environment of Emergency Supply Chains

Getting the right products to the right people at the right time, in the right location, and through the correct distribution method is the primary goal of every supply chain. It may appear to be a complicated process to establish and deploy a supply chain in the initial stages of a reaction to a natural or man-made disaster since the fundamentals of developing and deploying an efficient emergency supply are sometimes lacking. Also, stakeholders in relief efforts are frequently confronted with multiple and varied operations that span the entire world. The first three days of the emergency response operation are critical, and the goal during this phase is speed at any cost. This purpose includes the expeditious transportation and distribution of emergency relief supplies and resources to the affected population. Reduced response times are a direct result of an efficient emergency supply chain. The more lives that can be preserved by reducing unnecessary delays, the better. In this sense, efficiency guarantees cost savings; the greater the cost savings, the greater the number of preserved lives. After the first 90–100 days, the process becomes a balancing act between reducing time and money spent, providing meaningful assistance to clients, and doing so affordably. The emergency supply chain is unique and operates in highly volatile conditions that could prove immensely challenging for its commercial supply chain counterparts. For example, though the overall objective of a commercial supply chain is to make a profit for stakeholders and deliver value to the final customers, the strategic purpose of the emergency supply chain is to save lives, alleviate suffering and minimize damages and loss (Hashemi Petrudi *et al.,* 2020). Relief actors and stakeholders operate complexities that could result in multiple risks during logistics activities (procuring, transporting, and distributing), including unpredictable demand (when, where, and in what quantities the relief supplies will be needed), uncertainty in supply, non-existent and damaged infrastructure, inadequate logistics resources, volatile political situations, security issues, as well insufficient information (L'hermitte *et al.*, 2014).

Additionally, these relief actors and stakeholders arrive at the scene of disasters in large numbers with diverse ideologies, religious beliefs, objectives, and interests. Thus, presenting major coordination complications could lead to unexpected events (Balcik *et al.*, 2010). Besides, the unpredictability and uncertainties of disasters present more complexities for stakeholders. The challenges experienced in the global disaster response are compounded by supply chain difficulties, including long lead times, dependence on sole suppliers, multiple handling of supplies and reliance on poor transportation infrastructure. The mismatch of supply and demand is not the only risk in the emergency supply chain. Disruption is an increasing risk in global supply chains. Disaster relief operations encompass emergency supply chains with longer paths and shorter clock speeds. Thus, the increasing possibility for supply chain disruptions and small margins of error, poor purchasing and distribution strategies, modal choices, local taxes on foreign aid, unreliable or damaged infrastructures, and political influences can present unexpected events during the immediate response to a disaster. Time is not linked to money in the emergency supply chain but marks the difference between life and death (Van Wassenhove, 2006). Every disaster is a unique adverse event with distinctive characteristics demanding a different response and network.

2.6 Emergency Supply Chains and Risk Management

Global supply chains are often disrupted by predictable and unpredictable events that impede the network from achieving its overall objective. Moreover, there appears to be growing interest amongst academics and practitioners to identify the causes of these adverse events to proffer immediate solutions for these challenging problems. Baryannis *et al.*, (2019) discuss three factors influencing this growing interest. Firstly, organisations adopt contemporary methods such as lean management and just-in-time strategies to ensure efficiency in production and logistics, which leaves the supply chain more vulnerable to adverse events since the network can often accommodate zero room for errors (Synder, 2016). Secondly, organisations have more global presence and are less likely to integrate vertically. Thus, increasing the supply chain's complexity exposes it to more risks (Behzadi *et al.*, 2018). Thirdly, the world continues to experience several adverse events, such as natural disasters, that often impede the normal functioning of the supply chain. The occurrence of natural and man-made disasters is expected to increase another fivefold over the next 50 years (Thomas and Kopczak, 2005). Some examples of these disasters include the 2011 Thailand floods that disrupted the global hard disk drives supply chain Chopra and Sodhi, 2004; Baryannis *et al.*, (2019); the 9/11 terrorist attacks and the Covid-19 pandemic that brought the entire globe to a standstill. Several countries worldwide enforced a national lockdown that prevented the free movement of people and hampered several activities. In a supply chain context, They can exist in several forms, including supplier shutdowns, production stoppages at manufacturing firms, or even intentional acts (Ponomarov and Holcomb, 2009), resulting in risks that later develop into supply chain problems and create unanticipated changes in flow (Chopra and Sodhi, 2004). Wagner and Bode, (2008) posit that a supply chain risk can be described as an adverse effect that stems from a supply chain disruption, while a supply chain disruption can impede the normal functioning of business operations. In disaster environments, emergency logistics and supply chain activities are often done in highly hazardous environments, and relief organisations face multiple risks and uncertainties (L'hermitte *et al.*, 2016). This includes unpredictable demand, uncertainty in supply, non-existent and damaged infrastructure, inadequate logistics resources, volatile political situations, security issues, and insufficient information (L'Hermitte *et al.*, 2014). Relief organisations need to respond promptly to these uncertain and changing circumstances and adapt their operations to the requirements of the field environment swiftly and effectively (Van Wassenhove, 2006; Charles *et al., 2010*; L'Hermitte *et al.,* 2015). Along the same line, Aqlan and Lam (2015) noted that for supply chains to be efficient and dynamic, the ability to respond to external and internal risk events swiftly is mandated. This, however, involves a deep understanding of supply chain risks and how to manage them. Risk management is a critical part of supply chain management. There is an intensified need for effective risk management in the global supply networks that are characterised by extreme distances between suppliers and marketplaces and the presence of immense complexities in the commercial environments as opposed to domestic supply chains (Antai and Olson, no date; Manuj and Mentzer, 2008b, 2008a; Blackhurst *et al.,* 2011; Christopher and Holweg, 2011). Consistent with these trends, Craighead *et al.,* (2007) cite supply chain risk management as the single most pressing concern for organisations today. Supply chain risk management (SCRM) entails managing risks that can hinder the performance of supply chains (Bandaly *et al.*, 2012). The strategic significance of SCRM –identifying, evaluating, and managing supply chain-related risks to reduce overall supply chain vulnerability (Manuj and Mentzer, 2008a) –is increasingly apparent. SCRM is rapidly developing into a favoured research area for academicians and practitioners, especially in the modern era wherein firms operate in global environments (Manuj and Mentzer, 2008b).

Conversely, managing risks in emergency supply chains has received little attention. No study has focused on empirically investigating specific risk factors and defining clear categories of risk factors and uncertainties. The climate is constantly changing, and stakeholders have very minimal timeframes to make decisions; this makes risk management critical but challenging (Aqlan and Lam, 2015). In literature, several studies have focussed on analysing the differences between an emergency supply chain and its business counterpart (Oloruntoba and Kovács, 2015; Dubey and Gunasekaran, 2016; Jahre, 2017). Both contexts share significant similarities, such as the critical theories related to the flow of goods, information, and finance (Maon *et al.,* 2009). However, emergency supply chain management operations are fifteen years behind their commercial counterpart. Concepts, models, and tools from the commercial context can be borrowed but are not directly adaptable since the emergency supply chains function in a highly volatile and unstable environment as against the stable and predictable environment of the commercial supply chains (Day *et al.,* 2012; Maon *et al.,* 2009). Supply chain risk management was developed for the commercial context to investigate and manage potential risk factors that can disrupt the supply chain (Ho *et al.*, 2015; Jahre, 2017). Van

Wassenhove, (2006) underlined several disciplines from the commercial context that can benefit disaster relief, one of which is supply chain risk management (risk analysis, vulnerability assessment mapping and supply chain robustness issues). Therefore, this study will review the broader supply chain literature to gather relevant insights and a structured understanding of the challenging and constraining factors that can negatively affect emergency logistics and supply chain operations in disaster relief operations. The following section covers an overview of supply chain risk and supply chain risk management. Various definitions and supply chain risk classifications and types will be examined.

2.6.1 Supply Chain Risk Definitions

All supply chains have an element of risk in them. Supporting this statement, Snyder and Shen, (2006) postulate that "for as long as there have been supply chains, there have been disruptions, and no supply chain, logistics system, or infrastructure network is immune to them". The persistent occurrence of adverse events has drawn more attention from academics and supply chain practitioners to investigate the vulnerability of global supply chains (Christopher and Holweg, 2011; Colicchia and Strozzi, 2012; Wieland and Wallenburg, 2012). In 2010, McKinsey surveyed over 400 senior supply chain executives on the various difficulties facing organisations globally; findings suggested that supply chain risk (SCR) is one of the biggest challenges. However, only 69 per cent reported an existing supply chain risk management process(Butner, 2010; McKinsey, 2010; Bak, 2018). The idea of supply chain risk is not novel since conducting practical business activities mandates organisations to accept some level of risk (Olson and Wu, 2010). On this note, several studies have attempted to define supply chain risk from different perspectives, but no universally accepted definition exists. Table 2.5 presents a summary of various supply chain risk definitions. Baryannis *et al.*, (2019) note that existing definitions from finance and enterprise risk management influenced early definitions of risk. For example, Jüttner, (2005) defined supply chain risk as the "variation in the distribution of possible supply chain outcomes, their likelihood, and their subjective values". Zsidisin, (2003) defined supply risk as "the probability of an incident associated with inbound supply from individual supplier failures or the supply market occurring, in which its outcomes result in the inability of the purchasing firm to meet customer demand or cause threats to customer life and safety". Goh *et al.*, (2007) and Kull and Closs, (2008a) agree with this definition. Jüttner *et al.*, (2003) defined supply chain risk as "the possibility and effect of mismatch between supply and demand". This definition only focuses on the demand and supply sides of the supply chain, ignoring other important aspects such as necessary infrastructures and the environment. Peck, (2006) noted that supply chain risk is "anything that disrupts or impedes the information, material, or product flows from original suppliers to the delivery of the final product to the ultimate end-user.

Interestingly, this definition does not include the flow of finance that goes back and forth in the supply chain. Considering the impact of catastrophes on supply chains, Wagner and Bode, (2006) described supply chain risk as "the negative deviation from the expected value of a certain performance measure, resulting in negative consequences for the focal firm". Considering existing definitions, Heckmann *et al.*, (2015) suggested that risk definitions appear vague and ambiguous, with a wide array of core characteristics. For example, Harland *et al.,* (2003) concluded that supply chain risk is linked to any "chance of danger, damage, loss, injury or any other undesired consequences". Manuj and Mentzer, (2008a) described supply chain risk as an "expected outcome of an uncertain event, i.e., uncertain events lead to existence of risks". Therefore, Heckmann *et al.,* (2015) proposed a comprehensive definition of supply chain risks as "the potential loss for a supply chain in terms of its target values of efficiency and effectiveness evoked by uncertain development of supply chain characteristics whose changes were caused by the occurrence of triggering events". From another perspective, Ho *et al.,* (2015) argue that existing definitions only apply to specific domains; they are centred around a specific function or component of the supply chain and do not encompass the whole supply chain. Hence, the authors proposed a more comprehensive definition: supply chain risk is "the likelihood and impact of unexpected macro and micro level events or conditions that adversely influence any part of a supply chain leading to operational, tactical, or strategic level failures or irregularities. This definition best aligns with the aims and objectives of this study because it tries to capture all aspects of the emergency supply chain and its operational environment. A good definition of supply chain risk should consider adverse events with a low probability of occurrence. However, it can suddenly occur with a high impact on the supply chain and its working environment (Tang and Nurmaya Musa, 2011). The absence of a general understanding and precise definition of supply chain risk will complicate research in any context and prevent access to practitioners and real-life cases for empirical studies.

Table 2.5 Definitions of supply chain risk

Author	Definition
(Jüttner *et al.*, 2003)	The possibility and effect of mismatch between supply and demand
(Jüttner, 2005)	The variation in the distribution of possible supply chain outcomes, their likelihood, and their subjective values
(Zsidisin, 2003)	The probability of an incident associated with inbound supply from individual supplier failures or the supply market occurring, in which its outcomes result in the inability of the purchasing firm to meet customer demand or cause threats to customer life and safety
(Manuj and Mentzer, 2008a)	An expected outcome of an uncertain event, i.e., uncertain events, leads to risks.
(Wagner and Bode, 2006)	The negative deviation from the expected value of a specific performance measure results in negative consequences for the focal firm
(Bogataj and Bogataj, 2007)	The potential variation of outcomes that influence the decrease of value added at any activity cell in a chain
(Ellis *et al.*, 2011)	An individual's perception of the total potential loss associated with the disruption of supply of a particular purchased item from a particular supplier
(Ho *et al.*, 2015)	The likelihood and impact of unexpected macro and micro level events or conditions that adversely influence any part of a supply chain, leading to operational, tactical, or strategic level failures or irregularities.

Supply chain risk management (SCRM)

Like supply chain risk, there is no universally accepted definition for SCRM (Sodhi, Son and Tang, 2012; Ho *et al.*, 2015). Although, Baryannis *et al.*, (2019) suggest there is a consensus among various studies that SCRM involves several steps focused on achieving a particular objective. Table 2.6 provides a summary of these definitions. Most definitions highlight the importance of supply chain partners cooperating and collaborating. However, they do not cover the entire SCRM process, only specific aspects. From a managerial perspective, Jüttner, (2005) defined SCRM as "the identification and management of risks for the supply chain, through a coordinated approach amongst supply chain members, to reduce supply chain vulnerability as a whole". This definition is like that of Manuj and Mentzer (2008a). However, these definitions do not seem to capture the whole process. In a bid to propose a comprehensive definition, Ho *et al.*, (2015) described SCRM as "an inter-organizational collaborative endeavour utilizing quantitative and qualitative risk management methodologies to identify, evaluate, mitigate and monitor unexpected macro and micro level events or conditions, which might adversely impact any part of a supply chain". On the contrary, Fan and Stevenson, (2018) argue that existing SCRM definitions are not internally and externally consistent. Hence, they defined SCRM as "The identification, assessment, treatment, and monitoring of supply chain risks, with the aid of the internal implementation of tools, techniques and strategies and external coordination and collaboration with supply chain members to reduce vulnerability and ensure continuity coupled with profitability, leading to competitive advantage".

Table 2.6 Definitions of supply chain risk management

Author	Definition
(Jüttner, 2005)	The identification and management of risks for the supply chain, through a coordinated approach amongst supply chain members, to reduce supply chain vulnerability as a whole
(Norrman and Jansson, 2004)	To collaborate with partners in a supply chain, apply risk management process tools to deal with risks and uncertainties caused by, or impacting on, logistics-related activities or resources.
(Tang, 2006)	The management of supply chain risks through coordination or collaboration among the supply chain partners to ensure profitability and continuity
(Goh *et al.*, 2007)	The identification and management of risks within the supply network and externally through a coordinated approach amongst supply chain members to reduce supply chain vulnerability as a whole
(Thun and Hoenig, 2011)	Characterized by a cross-company orientation aiming at identifying and reducing risks at the company level and focusing on the entire supply chain.
(Ho *et al.*, 2015)	An inter-organizational collaborative endeavour utilizing quantitative and qualitative risk management methodologies to identify, evaluate, mitigate, and monitor unexpected macro and micro-level events or conditions which might adversely impact any part of a supply chain.
(Fan and Stevenson, 2018)	The identification, assessment, treatment, and monitoring of supply chain risks, with the aid of the internal implementation of tools, techniques, and strategies and external coordination and collaboration with supply chain members to reduce vulnerability and ensure continuity coupled with profitability, leading to competitive advantage

2.6.2 Supply chain risk types and classification

Innovative studies in any field often begin with concept identification and definition and developing categories or taxonomies (Oke and Gopalakrishnan, 2009). This was the case with earlier studies in supply chain risk management. These studies have discussed and classified supply chain risk types from various perspectives. Table 2.7 presents a summary of supply chain risk types. In most cases, the goal and scope of a study define supply chain risk classification (Rangel *et al.,* 2015). Bandaly *et al.,* (2012) argue that risk classification helps to reveal the 'relevant dimensions' of these supply chain risks. Some studies have discussed only supply chain risk types without classification schemes (Fan and Stevenson, 2018). For example, in investigating risk in supply networks, Harland *et al.,* (2003) presented eleven risk types: strategic risk, operations risk, supply risk, customer risk, asset impairment risk, competitive risk, reputation risk, financial risk, fiscal risk, regulatory risk, and legal risk. Cavinato, (2004) discussed supply chain risk types as the five sub-chains to every supply chain: physical risk, financial risk, informational risk, relational risk, and innovative risk. Bogataj and Bogataj, (2007) classified the supply chain risk into supply, process (process or distribution), demand, control, and environmental risks. Based on the previous studies (Chopra and Sodhi, 2004; Schoenherr *et al.,* 2008; Chopra and Sodhi, 2004; Schoenherr *et al.*, 2008), Tummala and Schoenherr, (2011) listed demand risks, delay risks, disruption risks, inventory risks, manufacturing breakdown risks, physical plant risks, supply risks, systems risks, sovereign risks, and transportation risks. Samvedi *et al.,* (2013) presented supply, demand, process, and environmental risks.

Few studies presented supply chain risk classification schemes without integrating their respective risk types. From the literature review and fieldwork findings, Jüttner *et al.,* (2003) concluded that risk classification is imperative for risk assessment. The authors classified supply chain risk types into three categories: environmental risk sources, network-related risk sources and organizational risk sources. Environmental risk sources relate to uncertainties from the supply chain-environment interaction. Uncertainties that arise from the boundaries of various supply chain members are associated with the organisational risk sources. Network-related risk sources are related to uncertainties that emerge from the relationships between the various supply chain partners. Likewise, Sheffi and Rice, (2005) identified three classes of potential supply chain disruptions: random events, accidents, and intentional disruptions. However, the authors argue that different methods are required to estimate each class.

Table 2.7 Summary of supply chain risks

Author	**Risk types**
(Harland *et al.*, 2003)	Strategic, operations, supply, customer, asset impairment, competitive, reputation, financial, fiscal, regulatory, and legal risks
(Jüttner *et al.*, 2003)	Environmental, network-related, and organisational risks
(Cavinato, 2004)	Physical, financial, informational, relational and innovation risks
(Chopra and Sodhi, 2004)	Disruptions, delays, systems, forecast, intellectual property, procurement, receivables, inventory, and capacity risks
(Christopher and Peck, 2004)	External to the network: environmental risks External to the firm but internal to the supply chain network: demand and supply risks Internal to the firm: process and control risks
(Nagurney *et al.*, 2005)	Supply-side risks and demand-side risks
(Wagner and Bode, 2006)	Demand-side risks, supply-side risks, catastrophic risks
(Tang, 2006a)	Operational risks: uncertain customer demand, uncertain supply, and uncertain cost Disruption risks: earthquakes, floods, hurricanes, terrorist attacks, economic crisis
(Wu *et al.*, 2006)	Internal risks: internal controllable, internal partially controllable, internal uncontrollable External risks: external controllable, external partially controllable, external uncontrollable
(Bogataj and Bogataj, 2007)	Supply, process (production or distribution), demand, control and environmental risks
(Deleris and Erhun, 2011)	Operational/technological risks, social risks, natural hazards, economy/competition risks, and legal/political risks
(Blackhurst *et al.*, 2008)	Disruptions/disasters, logistics, supplier dependence, quality, information systems, forecast, legal, intellectual property, procurement, receivables (accounting) inventory, capacity, and management security
(Keow Cheng and Hon Kam, 2008)	Environmental risks, infrastructure risks, service delivery risks, and organisational and relationship risks
(Manuj and Mentzer, 2008a)	Supply, demand, operational and other risks
(Tang and Tomlin, 2008)	Supply, process, demand, intellectual property, behavioural and political/social risks
(Wagner and Bode, 2008)	Demand side, supply side, regulatory and legal, infrastructure risk, and catastrophic risks
(Oke and Gopalakrishnan, 2009)	Supply-related risks: imports, climate, man-made disasters, natural disasters, socioeconomics, loss of key suppliers Demand-related risks: economic, demand variability and unpredictability, and miscellaneous risks
(Rao and Goldsby, 2009)	Organizational risks, industry risks and environmental risks
(Trkman and McCormack, 2009)	Endogenous risks: market and technology turbulence Exogenous risks: discrete events (e.g., terrorist attacks, contagious diseases, workers' strikes) and continuous risks (e.g., inflation rate, consumer price index changes)
(Kumar *et al.*, 2010)	Internal operational risks: demand, production and distribution, supply risks External operational risks: terrorist attacks, natural disasters, exchange rate fluctuations.
(Olson and Wu, 2010)	Internal risks: available capacity, internal operation, information system risks External risks: nature, political system, competitor and market risks

(Ravindran *et al.*, 2010)	Value-at-risk (VaR): labour strike, terrorist attack, natural disaster Miss-the-target (MtT): Late delivery, missing quality requirements
(Lin and Zhou, 2011)	Risk in the external environment Risk within the supply chain Internal risk
(Tang and Nurmaya Musa, 2011)	Material flow, financial flow, and information flow risks
(Thun and Hoenig, 2011)	Purchasing risks and demand risks
(Tummala and Schoenherr, 2011)	Demand, delay, disruption, inventory, manufacturing (process) breakdown, physical plant (capacity), supply (procurement), system, sovereign and transportation risks
(Cagliano *et al.*, 2012)	External risks: catastrophic, political, economic, social, legal, cultural, industrial, and partner risks Internal risks: strategic, tactical, and operational risks
(Lockamy and McCormack, 2012)	Network, operational risks, and external risks
(Vilko and Hallikas, 2012)	Supply risks, operational risks, security risks, macro risks, policy risks and environmental risks
(Samvedi *et al.*, 2013)	Supply, demand, process, and environmental risks
(Ghadge *et al.*, 2013)	Product design information risks, distortion risks, demand risks, demand risks, quality risks, disruption risks, operation risks, financial risks, skill/performance risks, poor management risks, safety/security risks, reputation risks, supply safety risks, geopolitical risks, supply capacity risks, intellectual property risks, regulatory/legal risks, information distortion risks, integration risks, network risks, and technology risks
(Cruz, 2013)	Supply-side risks, demand-side risks, exchange rate risks, and social risks
(Aqlan and Lam, 2015)	Supplier risks, customer risks, process and control risks, technology risks, product risks, occupational risks, culture risks, transportation risks, and commodity risks
(Rangel, de Oliveira and Leite, 2015)	Strategic risks, inertia risks, informational risks, capacity risks, demand risks, supply risks, financial risks, relational risks, operational risks, disruption risks, customer risks, legal risks, environmental risks, and culture risks
(Ho *et al.*, 2015)	Macro risks: man-made and natural risks Micro risks: demand, manufacturing, infrastructural (information, transportation, and financial risks), and supply risks
(Torabi *et al.*, 2016)	Supplier risks, internal risks, environmental and market risks
(Prakash *et al.*, 2017)	Demand, supply, process, and environmental risks
(Tukamuhabwa *et al.*, 2017)	Endogenous risks: demand-side, supply-side, and firm-level risks Exogenous risks: economic and geopolitical risks
(Sreedevi and Saranga, 2017)	Delivery, supply, and manufacturing process risks

Similarly, Wagner and Bode, (2006) classified supply chain risks into three categories but from distinct perspectives: supply-side risk, demand-supply risk, and catastrophic risk. Supply-side risks arise from purchasing, supplier activities and supplier relationships (Zsidisin *et al.*, 2000). Uncertainties arising from customer demand variationNagurney *et al.*, 2005) or downstream supply chain operations (Jüttner, 2005) bring about the demand-side risk. Tang, (2006a) presented two categories of supply chain risks: operational and disruption risks. The authors described operational risks as those supply chain risk factors that are internal to the network, such as uncertain customer demand, uncertain supply, and uncertain cost. Disruption risks are associated with uncertainties from disasters such as floods, war and terrorism, and hurricanes. Lin and Zhou, (2011) grouped supply chain risk factors as: risk in the external environment, within the supply chain and internal risk.

Other studies linked both risk types and risk classification together. Svensson, (2002) discussed that supply chain risk is a complex phenomenon that can segregate into sources and risk types (Manuj and Mentzer, 2008a). Christopher and Peck, (2004) classified supply chain risk into three distinct classes: external to the network (environmental risk), external to the firm but internal to the supply chain network (demand and supply risks) and internal to the firm (process and control risks). This classification scheme is like that of Jüttner *et al.,* (2003), same ideology but different terms. Trkman and McCormack, (2009) classified supply chain risk factors as endogenous risks: market and technology turbulence, and exogenous risks: discrete events and continuous events. Kumar *et al.*, (2010) presented the risk factors as internal operational risks (demand, production and distribution, supply risks) and external operational risks (terrorist attacks, natural disasters, exchange rate fluctuations).

Similarly, Olson and Wu, (2010) categorized the risk factors as internal risks (available capacity, internal operation, information systems risk) and external risks (nature, political system, competitor, and market risks). Wu *et al.,* (2006) discussed supply chain risks in two categories: internal risks (internal controllable, internal partially controllable, internal uncontrollable) and external risks (external controllable, external partially controllable, external uncontrollable). Highlighting the lack of consensus concerning supply chain risk types, Rangel *et al.* (2015) proposed a classification scheme based on the five management processes intrinsic in a functional supply chain: plan, source, make, deliver, and return. Plans are perceived as the foundation of other processes and encompass strategic, inertia, informational, capacity and demand risk. The source covers supply, financial and relational risk. Make consists of operational and disruption risks. Customer risk is the only type under delivery. Also, return covers only legal risks. Environmental and cultural risks are regarded as others in the classification scheme. From a comprehensive literature review, Ho *et al.*, (2015) divided supply chain risk factors into two categories: micro-risk (demand, manufacturing, supply, and infrastructural risk) and macro-risks. The classification is like that of Sodhi *et al.,* (2012) (referred to as catastrophic and operational) and Tang, (2006a) (referred to as disruption and operational risks). Macro-risks are described as adverse external events that are likely to disrupt the activities of an organization. At the same time, micro-risks are perceived as those adverse events that originate from the organisation's internal operations or relationships with other partners in the supply chain.

In comparison, the authors argue that organizations must be much more cautious of a macro than micro-risk. Micro risks cover four risk types: Manufacturing risks are perceived as those adverse events that occur within organizations and prevent the production of quality goods and services at the required time (Wu *et al.,* 2006). Demand and supply risks are those adverse events occurring at the supply chain's downstream and upstream points, respectively (Wagner and Bode, 2008; Ho *et al.*, 2015). In the supply chain, adequate information systems (Chopra and Sodhi, 2004), adequate transportation (Wu *et al.*, 2006) and reliable financial systems are essential to an efficient supply chain. Ho *et al.,* (2015) classified these risks as infrastructural risks.

Most of these risk classification schemes are directed at specific elements of a supply chain (Baryannis *et al.*, 2019). Thus, these supply chain risk classification forms are critical since they inform stakeholders on particular focus points during supply chain disruptions and provide the foundation for risk assessment. The classification schemes of Christopher and Peck, (2004) and Wu *et al.,* (2006) best support the purpose of this research. The study will adapt both classification schemes to propose an initial risk classification model for emergency supply chains in disaster relief operations. From the literature, conclusions can be drawn that supply chain risks originate from either internal activities that organizations have control over or external activities that often have limited or zero control. In addition, dividing the supply chain into different segments will aid in quickly identifying the supply chain risk source.

2.6.3 Supply chain risk management process

Supply chain risk management is an emerging topic (Sodhi *et al.,* 2012; Vahid Nooraie and Parast, 2016). Several studies have approached the topic from diverse perspectives, proposing different scopes and research methodologies. SCRM addresses risk as a situation and involves exposure to two key components: an occurrence and the uncertainty around the potential consequences (Bandaly *et al.*, 2012; Vilko and Hallikas, 2012; Kilubi, 2016). The need to effectively manage supply chain risks has become more apparent in global supply networks due to their sheer size, dynamic nature, and complexity, as well as growing customer demands and expectations (Ponomarov and Holcomb, 2009; Chang *et al.,* 2015) A process is defined to establish a plan (Olson and Wu, 2010). Norman and Jasson, (2004) describe the risk management process as the process of decision-making concerning risks that begins from risk estimation and evaluation. SCRM aims to systematically identify, assess, mitigate, and monitor possible sources of supply chain risks and employ relevant strategies to help prevent or control their impact on the overall operation (Aqlan and Lam, 2015). The stages of the supply chain risk management process vary. However, Wu and Blackhurst, (2009) mention that most definitions of SCRM include the following activities: risk identification and modelling; risk analysis, assessment and impact measurement; risk management, risk monitoring and evaluation, and knowledge transfer. Discussing that organisations must follow a defined route/path to manage global supply chain risks, Manuj and Mentzer, (2008a) proposed a five-step process for global supply chain risk management and mitigation, including: (1) risk mitigation; (2) risk assessment and evaluation; (3) selection of appropriate risk management; (4) Implementation of supply chain risk management strategy; and (5) mitigation of supply chain risks. Jüttner *et al.*, (2003) proposed four primary constructs that make up the supply chain risk management process: (1) assessing the risk sources for the supply chain; (2) assessment of the supply chain risks identifying the supply chain risk concept; (3) matching risk drivers to supply chain strategies; and (4) risk mitigation. Hallikas *et al.*, (2004) suggested that a typical supply chain management process includes risk identification, risk assessment, risk management decisions and implementation, and risk monitoring. Blackhurst *et al.*, (2008) agree with this process structure.

The literature on the supply chain risk management process shows that a standard supply chain risk management process encompasses three critical steps: risk identification, risk assessment and risk mitigation. This research adopts these three steps and structures the following three sections around these steps.

2.6.3.1 Supply Chain Risk Factor Identification

Risk factor identification is the fundamental step of the supply chain risk management process (Kleindorfer and Saad, 2005; Sodhi *et al.*, 2012). By identifying risk factors, stakeholders are informed of the potential adverse events likely to disrupt the supply chain (Norrman and Jansson, 2004). Further steps in supply chain risk management cannot be initiated without identifying supply chain risk factors. This indicates that supply chain risk factor identification determines whether a risk factor is relevant before further assessment (Fan and Stevenson, 2018). Kern *et al.*, (2012) suggest that broadly identifying all potential threats and relevant vulnerabilities within upstream elements of the supply chain is the key objective of the risk identification phase, and this step requires a systematic approach. Risk factor identification covers operational risks and risks present along every critical link in the supply chain.

However, Hallikas *et al.,* (2004) mention that risk factor identification can be challenging since not all risk factors are easy to identify. Therefore, Norman and Jansson, (2004) suggest that supply chain risk factor identification primarily focuses on uncovering potential uncertainties to support a proactive risk management process.

Several studies have utilized diverse methods for supply chain risk factor identification. As suggested by Norman and Jansson, (2004), risk mapping is one important method. Risk mapping involves using a structured approach to map likely adverse events to understand the potential effects of these events on the supply chain. Fault and event tree analyses are the two methods generally utilized to research factors and causes that lead to adverse events (Norman and Jasson, 2004). Furthermore, both techniques logically illustrate the breakdowns that may propagate through a complex system. Ho *et al.,* (2015) mention that early researchers utilized qualitative and quantitative methods to identify possible sources of supply chains. These methods include analytic hierarchy process (AHP), conceptual models (Trkman and McCormack, 2009) and vulnerability maps (Blos *et al.*, 2009). Norman and Jansson, (2004) underline that risk mapping is critical. Others have utilized the AHP (Gaudenzi and Borghesi, 2006) and the hazard and operability (HAZOP) analysis methods (Adhitya *et al.,* 2009). Gaudenzi and Borghesi, (2006) utilised the AHP technique to identify risk factors that are likely to create supply disturbances to improve customer value. Highlighting the lack of a systematic approach to identifying risk factors, Adhitya *et al.,* (2008) proposed the HAZOP analysis to identify supply chain risk factors in a specific part of the network and new sources of risk factors that can emerge from the interactions between the various supply chain components (Colicchia and Strozzi, 2012). Acknowledging the existence of several approaches to risk factor identification, Fan and Stevenson, (2018) discuss that some of these methods have been proposed but not applied; some have been proposed and applied in research, and some have been proposed and applied with evidence from practitioners and companies. Risk factor identification is primarily completed in research with complex approaches such as AHP (Gaudenzi and Borghesi, 2006) and the value-focused process engineering methodology (Neiger *et al.,* 2009).

In contrast, practitioners focus on simple and established methods. For example, the Ishikawa diagram and value stream mapping. Kayis and Dana Karningsih, (2012) proposed a tool to facilitate supply chain risk factor identification. However, no evidence shows that practitioners have utilised or adopted this tool. Another risk factor identification method is the cause-effect diagram. Fan and Stevenson, (2018) argue that this approach is a universal method that has been adopted by both researchers (Lin and Zhou, 2011) and practitioners (Lavastre *et al.*, 2012).

2.6.3.2 Supply Chain Risk Assessment

Following risk factor identification, stakeholders must assess and prioritize the identified risk factors to select appropriate management actions contingent on the situation. This is done in supply chain risk factor assessment. Risk factor assessment concerns evaluating a probable adverse event and the severity of its impact (Harland *et al.*, 2003). Managing risks efficiently along the supply chain must entail a comprehensive, rapid, cost-effective risk factor assessment process (Zsidisin *et al.*, 2004). Cohen and Kunreuther, (2007) discuss that decision-makers can utilize either data or subjective experts' judgements and scenarios to assess supply chain risk factors. Thus, risk factors may be assessed formally, informally, quantitatively, or qualitatively (Fan and Stevenson, 2018). Gaudenzi and Borghesi, (2006) claimed that supply chain risk factor assessment is fundamentally subjective, since different stakeholders have distinct perceptions of what event may lead to a risk and of the nature of upstream/downstream relationships. Integrating objective data and subjective perception of concepts ensures a more comprehensive interpretation of supply chain risks and a more effective and efficient risk factor assessment (Tsai *et al.*, 2008). Based on a comprehensive literature review, Ho *et al.*, (2015) underlined that several studies have proposed numerous risk factor assessment methods, including mathematical programming and data envelopment analysis (DEA) approaches (Talluri and Narasimhan, 2003; Kumar and Alvi, 2006; Talluri *et al.*, 2006; Ravindran *et al.*, 2010; Wu and Olson, 2010; Meena *et al.*, 2011), multi-criteria decision-making and AHP approaches (Chan and Kumar, 2007; Blackhurst *et al.*, 2008; Kull and Closs, 2008b; Ho *et al.*, 2011; Chen and Wu, 2013; Samvedi *et al.*, 2013), fault tree approach (Cigolini and Rossi, 2010), Pugh method application (Dietrich and Cudney, 2011), Bayesian networks (Lockamy and McCormack, 2010; Nepal and Yadav, 2015), decision tree analysis (Ruiz-Torres *et al.*, 2013) and failure mode and effect analysis (FMEA) (Chaudhuri *et al.*, 2013). Fan and Stevenson, (2018) argue that many of the supply chain risk factors assessment studies have adopted formal techniques such as Bayesian belief networks. However, the probability-impact risk matrix is a standard method researchers and organisations utilise(Blackhurst *et al.*, 2008).

Supply chain risk prioritization and risk inter-relationships are two elements of the risk factor assessment process. Fan and Stevenson, (2018) posit that the process may include one or both processes. The prioritization of supply chain risk factors is a process of identifying the most critical risks. Sinha *et al.*, (2004) explain that supply chain risk factors with the most significant level of impact or those that can be mitigated rapidly will be prioritized as the most significant risk factors. A comprehensive and robust risk management process involves considerable investment, and not all organisations can tackle all potential sources of risks. Therefore, risk factor prioritization enables organisations to define relevant risk factors and develop respective actions with the available resources (Zsidisin *et al.*, 2004). Several studies have prioritized supply chain risk factors. Some have tried to determine the relevance of supply chain risk factors by defining supply chain risk factors inter-relationships (Hachicha and Elmsalmi, 2014; Govindan and Chaudhuri, 2016). Other studies have used risk factors assessment tools, including failure modes and effects analysis (FMEA) (Bradley, 2014) and the AHP (Mu and Carroll, 2016).

The occurrence of adverse events along the supply chain is seldom an isolated event. Kayis and Karningsih, (2012) explained that supply chain risks are often interrelated with other risks, and the consequence of a risk factor affects the entire supply chain network. Knowledge of risk factor inter-relationships supports prioritization (Guertler and Spinler, 2015), the development of risk factor treatment plans (Chopra and Sodhi, 2004) and the establishment of management actions (Sarker *et al.*, 2016). Few studies have adopted structural modelling techniques to uncover supply chain risk inter-relationships. *Venkatesh et al.,* (2019) used interpretive structural modelling (ISM) and MICMAC analysis to investigate the inter-relationships of supply chain risks in the apparel industry. The study's fundamental goal is to find the most significant risk that may bring other risks. Similarly, Hachicha and Elmsalmi, (2014) conducted the same study but for the food industry.

2.6.3.3 Supply Chain Risk Factor Mitigation

Reducing supply chain risks to an acceptable level is the primary purpose of risk factor mitigation (Fan and Stevenson, 2018). It covers the reduction of both the likelihood of a risk event and the severity of its impact (Norman and Jasson, 2004). All links in the supply chain (SC) are vulnerable to shocks in today's extremely volatile and unpredictable market (Knemeyer *et al.*, 2009). Because of the upheaval, supply chain risk management is crucial to any business's continued success and prosperity(Wildgoose *et al.*, 2012). Despite the plethora of supporting evidence from other researchers and professionals, many top-level managers still find it challenging to justify specific costly solutions to safeguard against supply chain risk factors that never materialize (Ambulkar *et al.*, 2015). Thus, practical strategies that meet two requirements are needed to persuade businesses to safeguard their supply chains. These methods, first and foremost, should help businesses cut expenses and improve their customers' experiences. Second, businesses must be able to continue regular operations even after a significant disruption has occurred for these plans to be effective (Tang, 2006b). These strategies businesses use to lessen the likelihood of risk factors occurring and their detrimental effects are known as supply chain risk mitigation strategies (Jüttner *et al.,* 2003; Chang *et al.,* 2015). Inter-relationships between these risk factors make applying mitigation strategies challenging since alleviating one adverse event can exacerbate or mitigate another (Chopra and Sodhi, 2004). A wide variety of studies address the topic of generic supply chain risk mitigation. Firstly, various studies have used quantitative approaches or empirical studies to determine the best practices for reducing supply chain risk factors. According to their findings, supply chain risk factors can be mitigated by improving flexibility (Manuj and Mentzer, 2008b; Talluri *et al.*, 2013), fostering cooperative partnerships amongst supply chain participants (Faisal *et al.,* 2006; Lavastre *et al.,* 2012; Chen *et al.*, 2013), effective information sharing (Christopher and Lee, 2004; Faisal *et al.,* 2006), managing suppliers (Xia *et al.*, 2011; Wagner and Silveira-Camargos, 2012), adopting co-opetition (Bakshi and Kleindorfer, 2009), increasing agility (Braunscheidel and Suresh, 2009), implementing corporate social responsibility activities (Cruz, 2013), understanding diverse organization cultures (Dowty and Wallace, 2010) and applying a new pull system called the multi Kanban system for disassembly (Nakashima and Gupta, 2012). Chopra and Sodhi (2004) assert, "*Unfortunately, there is no silver bullet strategy for protecting organizational supply chains. Instead, managers need to know which mitigation strategy works best against a given risk*." To effectively deal with these variations and strengthen supply chain resilience, Tang, (2006b) outlined nine mitigation strategies, including postponement, strategic stock, a flexible supply base, making and buying, economic supply incentives, flexible transportation, revenue management, dynamic assortment planning, and a silent product rollover. Zsidisin and Ritchie, (2009) proposed four categories of mitigation strategies: (1) eliminate the risk, (2) reduce the frequency and consequences of the risk, (3) transfer the risk through insurance and sharing and (4) accept the risk. The nature of risky events and organisational budgets influence the choice of mitigation strategy (Tummala and Schoenherr, 2011). Based on a systematic literature review, Kilubi, (2016) identified eight top supply chain risk mitigation strategies, including visibility and transparency, relationships/partnerships, flexibility, redundancy, collaboration, postponement, multiple sourcing, flexible contracts and joint planning and coordination.

Similarly, the results of AMR's (Advanced Market Research) supply chain risk assessment from 2009 indicate that the most effective measures that have been regularly used to manage risks include closer collaboration with supply chain partners, the use of different sourcing strategies, and redundant suppliers (Tummala and Schoenherr, 2011). Moreover, Wieland and Wallenburg, (2012) think that strategies such as using multiple sources, keeping a buffer stock, and flexible transportation are all reasonable ways to mitigate supply chain risk factors. Sodhi *et al.*, (2012) conclude that broad measures such as enhancing collaboration (including risk sharing), boosting demand, supply, and process flexibilities, and constructing buffers or redundancies across SCs can be implemented to reduce risk.

Second, various quantitative models or frameworks have been proposed for supply chain risk mitigation, such as the so-called super network model, which integrates global supply chain networks with social networks (Cruz *et al.*, 2006), the Supply Chain Risk Structure Model and the Supply Chain Risk Dynamics Model (Oehmen *et al.*, 2009), the house of risk, which combines the QFD and FMEA (Pujawan and Geraldin, 2009), and a two-stage stochastic integer (Hahn and Kuhn, 2012). For secure site location, Hale and Moberg, (2005) applied a five-stage disaster management paradigm. The five components of the framework are preparation, prevention, early warning, rapid response, and closure. On the other hand, the proposed set covering location model seeks to minimize the number of secure site locations rather than the total amount of risk exposed. A dynamic system model of manufacturing supply chains was presented by (Huang *et al.*, 2009). This model can proactively handle disruptive events and absorb the demand shock. Ben-Tal et al., (2011) used multiperiod deterministic linear programming to design an effective logistics strategy to reduce the impact of demand uncertainty on emergency relief supply chains.

Some supply chain risk management frameworks recommend classifying strategies along various dimensions (Jahre, 2017), such as redundancy vs flexibility (Kleindorfer and Saad, 2005; Talluri *et al.*, 2013; Chang *et al.*, 2015); reducing vs coping (Knemeyer *et al.*, 2009; Ghadge, Dani and Kalawsky, 2012; Simangunsong *et al.*, 2012) such as sharing and transferring (Ghadge *et al.*, 2013); monitoring vs collaboration (Hajmohammad and Vachon, 2016); risk types (Chopra and Sodhi, 2004; Tang, 2006a; Ritchie and Brindley, 2007; Manuj and Mentzer, 2008a; Tummala and Schoenherr, 2011; Sodhi *et al.*, 2012; Ghadge *et al.*, 2013; Lavastre *et al.*, 2014; Ho *et al.*, 2015) and proactive vs reactive approaches (Norrman and Jansson, 2004; Kleindorfer and Saad, 2005; Thun and Hoenig, 2011; Kilubi, 2016). Several studies have adopted the proactive and reactive approach. According to (Kilubi, 2016), a reactive strategy involves responding to a problem after it has already arisen. Table 2.8 presents a summary of reactive strategies. Preparedness measures, such as action plans, provide a more manageable and swifter response to a disaster (Knemeyer *et al.*, 2009). As a result, the reactive approach is defined by metrics that are more effect-oriented than cause-oriented. Although it shares some similarities with the proactive strategy, the reactive method falls short because it focuses on reducing the consequences rather than the probability of a risk occurring (Thun and Hoenig, 2011).

Table 2.8 Reactive Mitigation Strategies

Reactive strategies	Source
Building logistics capabilities. Capabilities for supply and information flows, e.g., to reduce cycle times, increase delivery competence, knowledge management and customer service to recover from a disruption quickly.	(Ponomarov and Holcomb, 2009)
Building social capital and relational competencies. Effective communication, trust and information sharing can enable rapid access to resources necessary for recovery, e.g., communication, cooperation, trust, reciprocity.	(Johnson *et al.*, 2013; Wieland and Wallenburg, 2013)
Contingency re-routing. Using alternative routes (transportation) as a contingency measure in case of the threat of disruption to the current route, e.g., turbulence and bad weather at sea	(Wang *et al.*, 2016)
Creating redundancy. The strategic and selective use of spare capacity and inventory that can be used to cope with disruptions, e.g., spare stocks, multiple suppliers, and extra facilities	(Rice and Caniato, 2003; Sheffi and Rice, 2005; Kristianto *et al.*, 2014; Sáenz and Revilla, 2014; Wang *et al.*, 2016)
Demand management. Mitigating the impact of disruptions by influencing customer choices through, e.g., dynamic pricing, assortment planning and silent product rollovers	(Tang, 2006b; Urciuoli *et al.*, 2014)
Ensuring supply chain agility. The ability to respond quickly to unpredictable changes in demand and supply	(Christopher and Peck, 2004; Carvalho *et al.*, 2012; Ponis and Koronis, 2012; Scholten *et al.*, 2014)
Increasing flexibility. The ability of a firm and supply chain to adapt to changing requirements with minimum time and effort	(Rice and Caniato, 2003; Sheffi and Rice, 2005; Tang, 2006b; Pettit *et al.*, 2010; Zsidisin and Wagner, 2010; Ponis and Koronis, 2012; Ambulkar *et al.*, 2015)
Increasing velocity. The pace of flexible adaptations that can determine the recovery speed of the supply chain from a disruption	(Carvalho *et al.*, 2012)
Increasing visibility. The ability to see through the entire supply chain (all nodes and links) to effectively respond to a disruption	(Pettit *et al.*, 2010; Brandon-Jones *et al.*, 2014; Sáenz and Revilla, 2014)
Supply chain collaboration. The ability to work effectively with other supply chain entities for mutual benefit, e.g., sharing information and other resources necessary for response and recovery	(Ponomarov and Holcomb, 2009; Pettit *et al.*, 2010; Jüttner and Maklan, 2011; Ponis and Koronis, 2012; Scholten *et al.*, 2014; Scholten and Schilder, 2015)
Use of information technology. Information technology enhances connectivity and supports other resilience strategies, e.g., visibility and collaboration, which can help coordinate responses to disruptions.	(Kong and Li, 2008; Mensah *et al.*, 2015)

Source: (Kilubi, 2016; Tukamuhabwa *et al.*, 2017)

In this way, a proactive strategy in supply chain risk management can be conveyed through two elements: ex-ante measures with a defined objective to decrease the possibility that supply chain risk arises and ex-ante actions launched to minimize the impact of supply chain risks as they surface (Wakolbinger and Cruz 2011). However, proactive supply chain risk management takes measures before problems emerge (Mitroff and Alpaslan, 2003; Kilubi, 2016). Several researchers have repeatedly argued that the best way to mitigate supply chain risks is to plan for them in advance (Trkman and McCormack, 2009). Thus, the proactive approach to supply chain risk management focuses on identifying potential sources of supply chain risk, quantifying their likelihood, and preparing and enacting effective countermeasures before an undesirable event occurs(Kilubi, 2016). A summary of proactive strategies is presented in Table 2.9

Table 2.9 Proactive Risk Mitigation Strategies

Proactive strategies	Source
Appropriate supplier selection/Procurement. Selection criteria can help minimise disruptions and their impacts, such as political stability in suppliers' territories, quality, capabilities (e.g., technological), financial stability, business continuity, and reliability.	(Pereira *et al.*, 2014; Rajesh and Ravi, 2015)
Building logistics capabilities. Capabilities for managing supply and information flows necessary for minimising vulnerabilities, e.g., risk-hedging capabilities, information technology upgrades, and information sharing.	(Ponomarov and Holcomb, 2009)
Building security. Measures to protect the supply chain against deliberate disruptions, e.g., theft, terrorism, and the infiltration of counterfeits	(Rice and Caniato, 2003; Bakshi and Kleindorfer, 2009; Pettit *et al.*, 2010)
Building social capital and relational competencies. Effective communication and information sharing before the risk event increases risk awareness and limits vulnerability, e.g., communication, cooperation, trust, reciprocity.	(Johnson *et al.*, 2013; Wieland and Wallenburg, 2013)
Co-opetition. Creating and maintaining collaboration between competitors to gain from synergies, e.g., sharing resources for building security and resilience.	(Bakshi and Kleindorfer, 2009; Yilmaz Borekci *et al.*, 2015)
Creating appropriate contractual agreements. Long-term and short-term contracts that can enable flexibility in supply to minimise shortages	(Urciuoli *et al.*, 2014)
Collaboration with the government/Creating public-private partnerships. Contractual agreement between a public agency and a private sector entity to share skills, assets, risks, and rewards to deliver services or facilities to the general public. It increases government interest in private entities' supply chains.	(Urciuoli *et al.*, 2014; Yang and Xu, 2015)
Creating a risk management culture. Ensuring that all organisational members embrace supply chain risk management, and this involves, e.g., top management support and firm integration/teamwork	(Christopher and Peck, 2004; Sheffi and Rice, 2005; Leat and Revoredo-Giha, 2013)
Increasing innovativeness. The motivation and capability to seek and invent new business ideas, e.g., new products, technologies, processes, and strategies that can reduce vulnerability	(Golgeci and Ponomarov, 2013)
Increasing visibility. The ability to see through the entire supply chain (all nodes and links), which helps to identify potential threats	(Pettit *et al.*, 2010; Zhang *et al.*, 2011; Sáenz and Revilla, 2014)

Inventory management. The strategic alignment of inventory management using a system-wide approach to minimise inventory risks	(Boone *et al.*, 2013)
Knowledge management. Developing knowledge and understanding of supply chain structures (i.e., physical and informational) and the ability to learn from changes as well as educate other entities	(Rice and Caniato, 2003; Christopher and Peck, 2004; Ponomarov and Holcomb, 2009; Jüttner and Maklan, 2011; Ponis and Koronis, 2012; Scholten *et al.*, 2014)
Portfolio diversification. Investing in different products to reduce dependence on products and suppliers	(Urciuoli *et al.*, 2014)
Supplier development. Facilitating suppliers with incentives, e.g., financial, training, and technical knowledge to improve efficiency, commitment and reliability	(Tang, 2006b; Leat and Revoredo-Giha, 2013)
Supply chain collaboration. The ability to work effectively with other supply chain entities for mutual benefit, e.g., sharing information and other resources to reduce vulnerability	(Rice and Caniato, 2003; Christopher and Peck, 2004; Bakshi and Kleindorfer, 2009; Ponomarov and Holcomb, 2009; Pettit *et al.*, 2010; Jüttner and Maklan, 2011; Zhang *et al.*, 2011; Ponis and Koronis, 2012; Leat and Revoredo-Giha, 2013; Brandon-Jones *et al.*, 2014; Scholten *et al.*, 2014; Scholten and Schilder, 2015)
Supply chain network structure/design. Constructing the supply chain network for resilience, e.g., balancing redundancy, efficiency, and vulnerabilities.	(Leat and Revoredo-Giha, 2013; Kristianto *et al.*, 2014; Scholten *et al.*, 2014; Cardoso *et al.*, 2015; Reyes Levalle and Nof, 2015)
Sustainability compliance. Compliance with economic, social, and environmental requirements to mitigate associated supply chain risks, e.g., reputational risks	(Soni and Jain, 2011)
Use of information technology. Information technology enhances connectivity and supports other resilience strategies, e.g., visibility and collaboration, which can help in signalling potential disruptions	(Kong and Li, 2008; Mensah *et al.*, 2015)

Source: (Kilubi, 2016; Tukamuhabwa *et al.*, 2017)

2.6.4 Supply chain risk management techniques

Fuzzy sets

Fuzzy sets were initially conceived by Lofti A. Zadeh in 1965 (Zadeh, 1988) with the idea that everything can be described by some degree of uncertainty. In this context, we refer to a multi-valued logic that addresses fuzziness in thinking. Given the intrinsic subjectivity and unpredictability of the associated values, this seems like a fitting application for determining the effect or severity of supply chain risks. Calculating an exact number for these parameters is unrealistic and impractical, as Ma and Wong proposed (2018). As a result, researchers have paid much attention to how fuzzy sets can be used to measure and evaluate risks. In reality, a fuzzy set can be used to capture a variety of parameters, not just risk. Fuzzy sets have also been used to assess performance (Rostamzadeh *et al.*, 2018), the weighting of factors (Samvedi *et* *al.*, 2013), the impact on sustainability (Wu *et al.*, 2017), and the probability of occurrence of risky events. (Nakandala *et al.*, 2017).

An array of methods exists for creating a fuzzy collection. A fuzzy set is the usual notation for an integer with three sets. To give an example, Pournader *et al.*, (2016) created a triangular fuzzy numbered set to determine the impact of risks, which goes as follows: "Extremely low" (1, 1, 3), "Low" (1, 3, 5), "Fair" (3, 5, 7), "High" (5, 7, 9), and "Extremely high." (7, 9, 9). A triangular fuzzy number, represented by a four-number fuzzy set, is also widely employed. Next, we de-fuzz these numbers to get a more precise number. Risk assessment requires more than fuzzy sets, which help quantify uncertain, imprecise factors. Thus, fuzzy set theory is often employed alongside other approaches in the SCRA field (Choudhary *et al.*, 2022).

Analytical Hierarchy Process (AHP)

The AHP is a popular MCDM method. Saaty, (2004) created the AHP, which has three significant steps: creating a hierarchy, determining priorities, and checking for consistency. The objective, the parameters, and the available options are all represented in the hierarchy. When the hierarchy is complete, pairwise comparisons of the alternatives using the criteria are used to create the weights. Similar to how we arrive at weights, we compare the factors against one another. For each pair of findings, we calculate a consistency ratio to verify their reliability. Viswanadham and Samvedi, (2013), Wang *et al.*, (2012), and Schaefer *et al.*, (2019) are all studies that provide examples; they all use performance characteristics as criteria to identify risky suppliers. Intriguingly, the SCRA literature contains several AHP-related expansions. Take Fuzzy AHP, Monte Carlo AHP, DEA-AHP, Grey-AHP, or Delphi AHP as some examples. (Duleba *et al.*, 2021; Mital *et al.*, 2018; Rathore *et al.*, 2017; Salehi Heidari *et al.*, 2018; Samvedi *et al.*, 2013; Viswanadham and Samvedi, 2013; Wang *et al.*, 2012; Zimmer *et al.*, 2017). It is important to remember that AHP has some severe caveats despite being a powerful decision-support instrument. An approximation of reality is achieved by translating a fuzzy knowledge of the world into a precise mathematical one. For this, you will need in-depth knowledge of the relevant field; in our instance, that's supply chain risk. For the outcomes to be satisfactory, it is also essential that the criteria and alternatives be consistent, as are their weights. Another restriction is the lack of thought about feedback or interdependence between criteria and options. Despite its caveats, AHP provides a powerful method and framework for facilitating decision-making when considering these factors (Choudhary *et al.*, 2022).

Analytical Neural Process

Another method that can be traced back to Saaty, (2004) is the Analytic Network Process (ANP), essentially a modification of the AHP framework that considers the feedback or interdependence of the alternatives and criteria we found lacking in AHP. It is important to remember that the decision maker's criteria evaluation is also influenced by the alternatives since the existence of criteria determines which alternatives are considered. MCDM-based SCRA works consider risk factors alongside other factors and potential solutions. Whereas risks are assessed using a variety of factors as criteria in the former, alternatives are the latter's focus. Alternatives and standards are intertwined in both instances.

Consequently, ANP works very well in SCRA. As an illustration, Chand *et al.,* (2017) considered four kinds of risks and four kinds of supply networks (including green supply chains, agile supply chains, lean supply chains, and reverse supply chains) as potential solutions. This situation is where ANP can be effectively leveraged to evaluate risks, as they vary depending on the organization's supply chain type. Martino *et al.*, (2017) also developed risk rankings for the retail fashion sector based on several supply chain goals. However, risk factors in supply chains create intricate networks in which dangers spread from one level to another, even when ANP is used to eliminate the feedback or dependency between criteria and alternatives. This challenge shows that there are limitations to every method, including ANP, which does not consider such flow or cause-and-effect analysis of risks.

Bayesian Networks

An acyclic graphical representation of probabilistic occurrences is called a Bayesian model. (Heckerman *et al.,* 1995). In a Bayesian network, a child node represents an event a parent node triggers, indicating an additional possibility. The likelihood of a node's offspring is calculated using the Bayes Rule of conditional probability. Both deterministic and probabilistic data can be used in Bayesian networks when prior events cause supply chain disruptions. The fact that prior data or expert opinion can be used for risk evaluation makes them particularly applicable to the field of SCRA. Lawrence *et al.,* (2020) created a Bayesian Network to examine supplier disruption due to extreme weather threats. Zheng and Zhang, (2020) developed a Bayesian Network model to evaluate supply chain risk parameters, and Kumar Sharma and Sharma, (2015) suggested a model to predict disruption risks in a supply chain. The latter study finds that the chance of an event becomes constant after a particular horizon. In addition, Garvey *et al.*, (2015) investigated how disruptions affect numerous firms in a supply chain. They concluded that a Bayesian Network helps quantify the spread of danger along that chain. Also, Bayesian Network models can be constructive when evaluating something based mainly on the likelihood of events (Choudary *et al.,* 2022).

Failure mode and effects analysis (FMEA)

FMEA is widely used for risk analysis. (Schneider, 1996). The three pillars of conventional FMEA are the probability of occurrence, the severity of the risk, and the capacity to detect it. These three factors are added to create a Risk Priority Number representing how seriously various events should be taken. (RPN). This helps decide which danger to tackle, such as the one with the highest RPN. This method is commonly employed in SCRA writings (Chen and Wu, 2013; Kumar *et al.,* 2013) and is also widely used in project management (Carbone and Tippett, 2004). It is simple to use but typically requires combining with other methods to catch the ambiguity at hand fully. Another shortcoming is that the connections between the occurrences are ignored.

Interpretive structural modelling (ISM)

Risks can have a domino effect on one another, leading to intricate interconnections that can be hard to tease out when assessing supply chain risks. Such complex systems can be located with the help of ISM. (Kwak *et al.,* 2018). In the food industry, ISM has been used by researchers like Prakash *et al.,* (2017) and Diabat *et al.,* (2012) to spot potential problems, and in the apparel industry, researchers like Venkatesh *et al.,* (2015) have done the same. Diabat *et al.,* (2012) placed forecasting-based risk at the summit of the hierarchy, and Venkatesh *et al.,* (2015) used fuzzy logic to account for uncertainty in expert judgement. The research identified globalization, employee behaviour, and security and safety risks with the highest dependencies. In addition, Kwak *et al.,* (2018) created an empirical model to recognize risks and learn what factors lead to what hazards in supply networks. According to the research, the most influential factors in the spread of supply chain risks are disagreements between trading partners, reliance on third-party logistics providers, a breakdown in logistics management, and a breakdown in sharing relevant information. Though unlikely to materialize, the consequences of these threats would be devastating if they did.

Further research by Prakash *et al.,* (2017) used ISM to assess risks in a perishable food supply chain, resulting in a risk hierarchy. Matrice d'Impacts Croisés-Multiplication Appliquée à un Classement (MICMAC) analysis is commonly used as a follow-up to the ISM method because it provides for classifying risks according to their interdependence and causal strength. High-level risks beyond the organization's authority are identified in the category, such as natural disasters and terrorist attacks. Pfohl *et al.,* (2011) echoed this sentiment, noting that the risks posed by natural catastrophes and terrorist attacks are particularly potent. Lower-level threats, on the other hand, may come from areas such as supplier capacities, transit problems, inaccurate forecasts, and inaccurate point-of-sale data. The research also combined the Risk Priority Number (RPN) with the Risk Mitigation Number (RMN), with the RMN representing the products of the RPNs and the Risk Mitigation Indices (RMIs) of all risks; the RMI captures feasible mitigation methods and has a value between 1 and 0. (and 1 representing an effective risk mitigation strategy) (Choudhary *et al.,* 2022). Noting that ISM is widely used as an experimental research method, we argue that Structural Equation Modelling is required for model validation.

Delphi technique

Dalkey and Helmer created the Delphi method to foretell the future. (Murry and Hammons, 1995). However, it has been widely used in detailed studies of processes like problem-solving and decision-making. The approach's merit rests in that it presumes collective judgements to be superior to an individual. It uses controlled feedback processes from experts whose answers have been statistically validated to prevent the kinds of confrontations that could arise in face-to-face meetings. There is no hard and fast rule about how few specialists must use this method. Moktadir *et al.,* (2018) considered ten experts; Markmann *et al.,* (2013) included eighty experts; Vilko and Hallikas, (2012) had twenty-two experts; and Kwak *et al.,* (2018) sought input from thirty-six experts, all of whom were included in our literature sample. As an instrument for making decisions, the Delphi technique is limited to the preliminary identification of risks. It is also simple to combine with other methods for more thorough evaluation and analysis, such as the AHP, FMEA, ISM, and DEMATEL (Choudhary *et al.,* 2022).

TOPSIS

TOPSIS is a Multiple Criteria Decision Making (MCDM) technique for several alternatives. (Lai *et al.,* 1994; Yoon and Hwang, 1995). In doing so, it establishes a positive and negative ideal response from the available options and evaluates how close the alternatives are to meeting those ideals. That which is most close to the positive ideal solution and most distant from the negative ideal solution is the finest choice. The method is perfect for making decisions in SCRA situations because it is simple to implement. Using six risk areas and thirty-three sub-criteria, Abdel-Basset and Mohamed, (2020) identified the most promising sub-segment of a Chinese telecommunications company's equipment division from the perspective of sustainable SCRM. The optimal location for an Iranian petrochemical plant was chosen by Rostamzadeh *et al.,* (2018) based on seven sustainable risks and forty-four underlying risks. The two reports analyse monetary, organizational, supply-related, ecological, and technological threats.

Additionally, the importance of the criteria weights can be determined unbiasedly with the help of Inter-criteria Correlation (CRITIC). (i.e., the risks). Fuzzy sets also reveal decision makers' uncertainty. Using Fuzzy AHP's weighting system, Rathore *et al.,* (2017) ranked the risks to the food supply chain based on their impact, likelihood, expense, and duration. For both global SCRM and sourcing, Samvedi *et al.,* (2013) and Viswanadham and Samvedi, (2013) employed analogous strategies. Because of its limited usefulness, TOPSIS is typically used with other statistical approaches before any meaningful conclusions can be drawn from the literature (Choudhary *et al.,* 2022).

DEMATEL

The Battelle Memorial Institute's Geneva Research Centre developed DEMATEL. (Gabus and Fontela, 1972). Because of the interconnected and interdependent nature of supply chain risks, structural modelling that evaluates the connections between system elements effectively controls these threats. Interdependencies between risks have many benefits over single-risk approaches. To investigate the causes of supply chain risks, Ali *et al.,* (2019) employed it. The study identified food supply chain risks related to a lack of skilled personnel, man-made disruptions, IT system failures, legal and regulatory risks, and capacity to be in the 'cause' group, while risks related to poor customer relationships, poor-quality products, supplier bankruptcy, change in customer taste, and poor leaderships are in the 'effect' group (Choudary *et al.,* 2022). Song et al., (2017) categorised risks in the sustainable supply chain based on their impact on the supply chain. Using DEMATEL, Rajesh and Ravi, (2015) designed instruments for reducing risks in the supply chain. Typical applications of Grey theory with DEMATEL result in Grey-DEMATEL. It is possible to use the grey theory to deal with incomplete information. Therefore, the combination helps identify systemic dependencies in supply chain risks (Choudary *et al.,* 2022).

Fault tree analysis

Another method that employs logic diagrams drawn from a directed graph of the model of the system under analysis to describe the interdependencies of its constituent parts is Fault Tree Analysis (FTA). In 1961, Bell Telephone Laboratories created it. Several papers were found to have used this method when we looked through the SCRA literature. For instance, Sherwin *et al.,* (2016) developed a fault-tree to analyse potential supply chain disruptions due to late deliveries. Risks in various FTA supply networks were analysed by Lei and MacKenzie, (2019). Materials vendors compete and collaborate to determine the types. The system's design is intuitive thanks to Boolean Logic gates like AND, and OR, . However, it is essential to remember that FTA does not record the reasons for failures. However, FTA can be combined with other methods to evaluate the relative severity of various threats within a system. For instance, Mangla *et al.*, (2016) used FTA in conjunction with Fuzzy Set Theory (FST) and Analytic Hierarchy Process (AHP) to create a logical diagram of risks in sustainable supply networks. Due to the logic diagram's reliance on causation, which FTA does not establish, its utility is constrained in SCRA.

2.6.5 Risks in emergency supply chains

Although risk and uncertainty are present in all business settings (Giunipero and Aly Eltantawy, 2004), the nature and extent of these factors vary from sector to sector (Rao and Goldsby, 2009; Sodhi *et al.*, 2012) as well as between emergency relief and commercial sector (L'hermitte *et al.*, 2015). The literature on supply chain risk management has grown and matured since the turn of the millennium, and the nature of the risks and uncertainties encountered by commercial organisations has been identified (Tang, 2006a; Rao and Goldsby, 2009), such as supplier failure, shortened product life cycles, the demand for more product variety, and changing customer requirements (Swafford *et al.*, 2006; L'hermitte *et al.*, 2015).

All these risks and uncertainties are tied to the supply chain; more specifically, they are linked to supply, demand, and the processes involved (Tang and Tomlin, 2008; Sodhi *et al.*, 2012). These risk factors and uncertainties contribute to the supply chain's vulnerability(Christopher and Peck, 2004). In addition to these localized sources of risk and uncertainty, however, several macro-environmental elements cannot be disregarded, not least since many experts believe that the degree of macro-environmental instability is on the rise (Christopher and Holweg, 2011; Kunz and Reiner, 2012). It is usual for relief organisations to work in volatile circumstances; thus, they must adopt a flexible strategy that improves their capacity to react to risk and uncertainty (Charles *et al.*, 2010). In addition to risk factors and uncertainties associated with demand, supply, and providing aid (Balcik and Beamon, 2008), relief organisations must also cope with complex contextual elements (L'hermitte *et al.*, 2014). These put substantial limits on operations since relief organisations usually work in the world's least developed nations, which often have poor infrastructure, uncertain political environments, and violent wars taking place (Long and Wood, 1995; L'hermitte *et al.*, 2015). The broader external environment creates operational risk and uncertainty, which has a detrimental impact on logistical operations by impeding the flow of humanitarian goods, and it also has a negative influence on the supply chain. Nodes (like ports or warehouses) and links (like highways) throughout emergency supply chains are significantly impacted by external variables (i.e., socio-economic, physical, infrastructural, governance, and security situational elements).

According to L'hermitte *et al., (2014),* disruptions produce expenses, limit access, reduce capacity, and contribute to security risks. The external risks and uncertainties, whether predictable or sudden, cannot be easily removed or even mitigated because they originate from external sources beyond organisations' control(Trkman and McCormack, 2009). This is especially true in increasingly complex and multi-dimensional emergency crises (Kent, 2011). Therefore, the capacity to continually adapt and reconfigure logistics operations is required by external variables, just as it is required by disturbances connected to supply chains. Too much can go wrong during the emergency response operations. However, information on what can go wrong during the emergency response is scattered across many articles and books, leaving researchers at a loss. From several case studies authored or co-authored, van Wassenhove, (2006) identified some critical factors facing stakeholders that can result in risks, including highly volatile operating conditions, safety and security, high staff turnover, the uncertainty of demand and supply, time pressure, a need for robust, flexible equipment, numerous stakeholders, and the role of media. Balcik *et al.,* (2010) discussed pre- and post-disaster operations and highlighted several complicating factors that can disrupt the emergency supply chain. They include the number and diversity of stakeholders and relief actors, donor expectations and funding structures, competition amongst stakeholders, unpredictability, resource capacity/oversupply and cost of coordination. Furthermore, they underlined the differences in geographical, cultural, and organizational policies as agents of operational complexities. McEntire, (1999) conducted direct observations and mentioned inadequate preparedness, inadequate or limited information, challenging assessment of needs, unjust distribution of critical supplies, centralization of decision-making, insufficient aid, and absence of trust amongst emergency managers and stakeholders as challenging factors.

Following a survey of relief organisations, Thomas and Kopczak, (2005) revealed that poor needs assessment and planning, limited coordination and collaboration and manual supply chain process are significant problems that can lead to an unexpected event. Supplementary research identified additional issues such as a lack of experts or professional staff, limited use of technology, poor collaboration, and lack of recognition of the significance of logistics (Thomas and Kopczak, 2005). Highlighting from literature, Altay, (2008) identified the need for capacity building for preparedness, lack of funds dedicated to preparedness, centralized decision making, absence of service standards, need for better coordination, high personnel turnover, uncertainty of demand and supply, cost-effective and robust resources, large number of stakeholders, absence of transparency and accountability, unreliable or incomplete influx of information and poor recognition of the significance of logistics in disaster relief operations. Kovács and Spens, (2009) utilized a case study of Ghana to investigate these factors that disrupt the chain and result in unexpected events. Focusing on the various types and forms of disaster, phases of disaster and the diverse types of relief actors and stakeholders, large number of actors, customs clearance procedures, lack of access to fundamental training, lack of standards and indicators, absence of clear mandates and legislation, low recognition of logistics and inadequate infrastructure were highlighted. Furthermore, low coordination emerged as the most significant factor for emergency managers in the field. Another study by Das, (2016) discussed that the emergency supply chain is likely to be unstable, inclined toward political and military influence and may not fully achieve its objectives due to the absence of coordination and inter-organizational collaboration. Seifert *et al.*, (2018) posited that the lack of technological development is the most critical factor to disrupt the chain. Conducting a study on sustainable emergency supply chains, Karuppiah *et al.*, (2021) identified twenty critical factors that can affect its operations. Facility location problems, short lead times for emergency supplies, bad media and the rapid emergence of new clusters were revealed as the most significant concerning COVID-19. Pathirage *et al.*, (2014) conducted a study on identifying challenging factors that can disrupt the operations of the emergency supply chain. They found numerous factors, including environmental, legal, technological, social, and economic factors, directly influencing the various aspects of disaster management, whereas the political and institutional factors have external influences. The authors highlighted inadequate training of personnel and awareness-raising programs, inadequate funding for economic planning procedures, lack of detection and warning systems, the need to update policies regularly, poor planning, lack of communication, absence of leadership, and deprived institutional planning as critical challenging factors.

In the Indian context, John and Ramesh, (2016) carried out a study to investigate the disruptive factors that can impede the performance of the emergency supply chain and their effect through interpretive structural modelling techniques. Some highlighted factors include a shortage of experienced logisticians, lack of predictable demand patterns, lack of correct need and damage assessment, lack of infrastructural facilities, lack of a central authority, unpredictable occurrence, and inadequate procurement of aid materials. Baldini *et al.,* (2012) identified several challenging factors of the emergency supply chains during disaster response, such as the chain size, coordination, degradation of critical infrastructure, timing, security, and demand. Likewise, Oloruntoba, (2005) identified some of the main challenging factors of successfully responding to a disaster. Factors identified include the scale of devastation, logistics and coordination, donations, damage and needs assessments, security and political issues, social issues, relief based on needs or loss and lack of information. Negi and Negi, (2020) highlighted several disruptive factors of the emergency supply chain, including shortage of logistics experts, manual supply chain processes, inadequate assessments and planning, limited collaboration and coordination, lack of preparedness, disaster relief locations, procurement, etc. Attempting to identify the critical factors likely to disrupt the functionality of the emergency supply chain in response to the COVID-19 pandemic in India, Dohale *et al.,* (2022) determined and validated ten critical factors. The most significant was the lack of government subsidies and support, lack of skilled and experienced rescuers, and lack of technology usage. The summary of the identified factors that can bring about several forms of risks and uncertainties in the emergency supply chain and negatively impact its operations is listed in Table 2.10

Following the discussion on the presence of uncertainty and risk in the working environment of the emergency supply chain, the research must now turn to how to manage risk in emergency supply chains. Supply chain risk management is a concept introduced for the commercial context to aid supply chain managers in preparing for and reacting to network disruption risk.

2.6.6 Managing emergency supply chain risks.

Effective supply chain risk management aims to prevent unanticipated events by implementing suitable risk management and mitigation strategies (Jüttner, Peck and Christopher, 2003;

Norrman and Jansson, 2004; Jüttner, 2005). Given the potentially disastrous effects of risk occurrences, supply chain risk management literature continues to expand and attract significant interest from top managers. While preparedness and strategic planning are becoming more standard in emergency relief, the unpredictable nature of large-scale disasters in magnitude, timing, location, and severity makes them very challenging to plan for in any detail (Kovács and Spens, 2007). During times of crisis, emergency supply chains tend to be lengthy, inefficient, and immature, leaving them vulnerable to more hazards and more likely to collapse. McLachlin *et al.*, (2009) have suggested that supply chain risk management is critical in disaster relief since an emergency supply chain operates in highly volatile environments, and disruption to the supply chain can lead to or contribute to a disaster. However, few studies have linked risk management with emergency supply chains (Jahre, 2017).

Table 2.10 Summary of risk factors in emergency supply chains

RISK FACTORS	**REFERENCES**
POOR DEMAND PROJECTION	(Jahre and Heigh, 2008; Buddas, 2014; Holguín-Veras et al., 2014)
DISTORTION OF INFORMATION	(Jahre et al., 2016; Stauffer et al., 2016)
HIGH VARIATION IN DEMAND	(Balcik and Beamon, 2008; Kovács and Spens, 2009)
HIGH INVENTORY HOLDING COST	(Balcik and Beamon, 2008; Kovács and Spens, 2009)
LIMITED LIFE-CYCLE OF RELIEF SUPPLIES	(Kovács and Falagara Sigala, 2021)
POOR SUPPLIER FLEXIBILITY	(Altay, 2008; John et al., 2019, 2020)
ERROR IN SUPPLIER FULFILMENT	(Holguín-Veras et al., 2014)
INADEQUATE SUPPLIER CAPACITY	(Baharmand et al., 2017)
ABSENCE OF COMPETITIVE PRICING	(Jahre, 2017; Kovács and Falagara Sigala, 2021)
POOR LEVEL OF SUPPLIER RESPONSIVENESS	(Altay, 2008; Jahre and Heigh, 2008)
VARIATION IN TRANSIT TIME	(Barbarosoglu et al., 2002; Baharmand et al., 2017; Oloruntoba and Gray, 2006)
NON-COMPLIANCE WITH SUPPLY CONTRACTS	(John and Ramesh, 2016; Balcik et al., 2010)
PURCHASING KEY SUPPLIES FROM A SINGLE SOURCE	(Kovács and Spens, 2009; Baldini et al., 2012; Kovács and Falagara Sigala, 2021)
EXCHANGE RATE FLUCTUATIONS	(Thomas and Kopczak, 2005; Balcik et al., 2010; Baldini et al., 2012; John and Ramesh, 2016; Jahre, 2017)

LONG-TERM VS SHORT-TERM CONTRACTS	(L'Hermitte and Nair 2021; Dubey et al., 2019; Olanrewaju et al., 2020)
DEFECTIVE OR DAMAGED RELIEF SUPPLIES	(Kovács and Spens, 2009; Holguín-Veras et al., 2012, 2014)
WRONG OR UNSOLICITED RELIEF SUPPLIES	(Kovács and Spens, 2007, 2009)
COUNTERFEIT RELIEF SUPPLIES	(Kovács and Spens, 2009; Holguín-Veras et al., 2012)
DAMAGED TRANSPORT INFRASTRUCTURE	(Barbarosoğlu and Arda, 2004; Thomas and Kopczak, 2005; Kovács and Spens, 2007, 2009)
ABSENCE OF ALTERNATIVE TRANSPORT MODES	(Thomas and Kopczak, 2005; Kovács and Falagara Sigala, 2021)
EXCESSIVE HANDLING OF RELIEF SUPPLIES DURING MODE CHANGES	(Barbarosolu, Özdamar and Çevik, 2002; Kovács and Spens, 2009; Kovács and Falagara Sigala, 2021)
INEFFECTIVE LAST-MILE DELIVERY	(Van Wassenhove, 2006; Oloruntoba and Kovács, 2015)
THEFT OF RELIEF SUPPLIES AND RESOURCES	(Pettit and Beresford, 2009; Baldini et al., 2012)
DAMAGED WAREHOUSING FACILITIES	(Thomas and Kopczak, 2005; Altay et al., 2009; Kovács and Spens, 2009; Baldini et al., 2012; Kunz and Reiner, 2012)
TRANSIT TIME FROM FACILITY LOCATION TO RELIEF SITES	(Dubey et al., 2019; Tayal and Singh 2019)
LIMITED HOLDING CAPACITY OF FACILITIES	(Thomas and Kopczak, 2005; Baharmand et al., 2017; Dubey et al., 2019; Maghsoudi and Moshtari, 2021)
POOR I.T INFRASTRUCTURE	(Schulz and Blecken, 2010; Kabra and Ramesh, 2015)
ABSENCE OF TRANSPARENCY IN INFORMATION DISSEMINATION	(Kovács and Spens, 2007; Altay and Pal, 2014)
THE PRESENCE OF DELAYS DURING INFORMATION TRANSMISSION	(Kovács and Spens, 2007; Altay, 2008; Kumar and Havey, 2013; Pathirage et al., 2014)
THE PRESENCE OF THE WRONG MEDIA	(Holguín-Veras et al., 2014; Maghsoudi and Moshtari, 2021)
DONOR RESTRICTION ON RELIEF SUPPLIES	(Kovacs and Spens, 2009; Oloruntoba and Gray 2009)
POOR FUNDING TRANSPARENCY	(Thomas and Kopczak, 2005; Kovács and Spens, 2009; Dubey et al., 2019)
LIMITED EXPERIENCED PERSONNEL	(Van Wassenhove, 2006; Pettit and Beresford, 2009; Overstreet et al., 2011; Sandwell, 2011; Kovács, Tatham and Larson, 2012)
MISTRUST AMONGST STAKEHOLDERS	(Balcik et al., 2010; Tatham and Kovács, 2010; Moshtari and Gonçalves, 2017)
IMPACT OF FOLLOW-UP DISASTERS	(Cozzolino et al., 2012; Holguín-Veras et al., 2014; L'hermitte et al., 2016; Jahre, 2017)
VARIATIONS IN CLIMATIC CONDITIONS	(Perry, 2007; Jahre, 2017)

FIRE INCIDENTS	(Jahre, 2017)
WAR AND TERRORISM	(Listou, 2008; McLachlin, Larson and Khan, 2009; Jahre and Jensen, 2010; Buddas, 2014; Jahre, 2017)
POOR COMMUNICATION	(Altay et al., 2009; Balcik et al., 2010; Dubey, Altay and Blome, 2019)
THE PRESENCE OF CULTURAL DIFFERENCES	(Maon et al., 2009; Kunz and Reiner, 2012; Jahre, 2017)
CORRUPT PRACTICES	(Altay, 2008; Kunz and Reiner, 2012)
SEXUAL AND GENDER ABUSES	(Oloruntoba, 2005; Kovács and Spens, 2009; Maon et al., 2009; Kunz and Reiner, 2012)
STAKEHOLDERS' POOR JUDGEMENT	(Ergun et al., 2009; Yadav and Barve, 2016)
ABSENCE OF LEGISLATIVE AND SUPPORTIVE RULES THAT INFLUENCE RELIEF OPERATIONS	(Maon et al., 2009; Day et al., 2012; L'hermitte et al., 2014; Maghsoudi and Moshtari, 2021)
SANCTIONS AND CONSTRAINTS THAT HINDER STAKEHOLDER COLLABORATION	(Oloruntoba, 2005; Altay et al., 2009; Maon et al., 2009; Sandwell, 2011; Kunz and Reiner, 2012)

For example, Jahre (2017) researched to establish a connection between emergency logistics and supply chain risk management to understand better how relief organisations prepare for emergency logistics. The author discovered that relief actors employ several proposed strategies, especially those involving strategic stocks, postponement, and collaboration. Choi *et al.*, (2010) included risk management in their emergency relief distribution research in East Africa because some actors demand risk premiums. Emergency supply chains are uncommon since relief goods are free to recipients. Thus, certain relief actors, such as transport providers in disaster zones, purposely take risks in their economic methods. This shows that service providers may profit from emergency supply chains by adjusting service provision and charging a "risk premium". Ling Tay *et al.*, (2022) identified the dominant supply chain risk factors in the disaster management cycle phase. They investigated how supply chain strategies can mitigate the risk factors. Chari *et al.*, (2019) investigated whether barriers prevented emergency supplies from reaching those in Zimbabwe when Cyclone Idai hit. They found that social, political, economic, and infrastructural uncertainties impeded emergency relief efforts after Cyclone Idai. The study also discovered that efforts to lessen environmental and infrastructure problems did not consider different modes of transportation and communication, such as drone technology. There was either insufficient emergency aid, or the aid arrived too late or was damaged. Unfortunately, there were no well-thought-out strategies to safeguard the emergency supply chain against shortage, theft, or spoilage.

Wild and Zhou, (2011) were interested in the relationship between ethical procurement and risk. Schniederjans, Ozpolat and Chen, (2016) explored the risks associated with information sharing via cloud computing to enhance cooperation. L'hermitte *et al.*, (2016) used "risk" to discuss adaptation and long-term operations. Even if such operations are stable and regular, such risks exist, and adaptations are needed. Duran *et al.*, (2013) acknowledge that the development of emergency response capacity, as well as preparedness, are essential components of effective aid, and they suggest that the assurance of the high availability of relief supplies through advanced procurement is the best way to accomplish this goal (inventory pre-positioning). Dual sourcing was recommended by Iakovou *et al.*, (2014) as a proactive risk mitigation sourcing technique. Scholten *et al.*, (2014) demonstrated the significance of cooperation, supply chain re-engineering, agility, risk consciousness, and knowledge management.

In general, the commercial and emergency supply chains have some parallels and differences, which have been observed and examined by several writers (Van Wassenhove, 2006; Balcik *et al.*, 2010; Ertem *et al.*, 2010). The primary objective of a typical SC, which is "getting the right commodities, at the right time, to the right place, and distributing them to the right people," is unquestionably transferable to the overarching structure for disaster relief (Van Wassenhove, 2006). In addition, the fundamental concept of risk management regarding commercial supply chains, which aims to manage risks (including disasters), uncertainties, and vulnerabilities promptly while also being cost-efficient (Kovács and Tatham, 2009), is generally in line with the corresponding emergency supply chain risk management framework. Naturally, the reduction of lead times is the primary concern of a normal emergency supply chain, and operational costs are not given as much consideration during the first few hours after a disruption. The emergency supply operates in volatile contexts, necessitating the development of strategies and practices that allow them to react to risks and uncertainties in demand, supply, and operations (Balcik and Beamon, 2008). One would suggest borrowing concepts from the commercial sector, but several structural, operational, and procedural differences exist between commercial and emergency supply chains. These variables include lead times, political climate, social media, performance monitoring, and equipment. Moreover, relief organisations require specialized and ad hoc supply chain disruption management solutions in emergency relief operations. Existing research suggests that the operational effectiveness of emergency supply chains is contingent on their capacity to adapt rapidly to external interruptions and to conduct dynamic operations (L'hermitte *et al.*, 2015). Supply chains must be responsive (Merminod *et al.,* 2014) and cost-effective (McLachlin *et al.,* 2009; Pettit and Beresford, 2009). Effective emergency relief requires two things: first, that supplies get to the disaster location quickly, and second, that enough goods get there to make a difference. Moreover, both academics and practitioners have highlighted several characteristics that need to be present to provide successful emergency relief in a timely fashion (Iakovou *et al.,* 2014). Oloruntoba and Gray, (2006) define three dimensions that an emergency supply chain should work on: creating a planned strategy to maximize its efficiency, adopting a longer-term/strategic view, and coordinating its activities. In his 2007 paper, Perry offered a complete retrospective case analysis for a model that places disaster response action within the context of nationally led, all-encompassing preparation for such an event. Integrating regionally led activities is an essential part of the disaster management process, and disaster management planning necessitates a comprehensive analysis of natural disaster response operations (Perry, 2007). Natarajarathinam *et al.,* (2009) described the most recent practices and trends in research regarding the management of supply chains during times of crisis. The advancement of emergency relief research, according to Baker and Deham, (2020), must examine more contemporary viewpoints on human response to the disaster and what this means for community and society formation. Through an in-depth literature examination of the success criteria of logistics and supply chain management in the business sector, Pettit and Beresford, (2009) conceptually analyze the critical success factor related to the disaster relief sector. To learn how adaptability and resilience influence emergency supply chain efficiency, Altay *et al.*, (2018) and Dubey (2019tested a model. The research results indicated that supply chain agility and resilience are two critical supply chain active abilities.

Before a tragedy strikes, the emergency supply chain's agility is crucial, but once the disaster has struck, resilience in the supply chain is what matters (Dubey, 2019). Beamon and Balcik (2008) established a methodology for measuring the effectiveness of disaster relief activities by developing appropriate performance criteria. Schulz and Heigh (2009) addressed the 'Development tool indicator' created by The International Federation of Red Cross and Red Crescent Societies (IFRC). The IFRC created this instrument to oversee and direct their ongoing logistics performance improvement. The authors concluded that the tool's success was primarily due to the ease with which stakeholders could participate. In an emergency (Banomyong and Sopadang, 2010), the framework can be used to create a logistical response model; they also discovered that simulation modelling could improve the produced model's validity and dependability. Table 2.11 summarises supply chain strategies implemented in disaster relief operations.

Table 2.11 Supply chain strategies for managing emergency supply chains

ESC Strategies	**Emergency Supply chain strategies and Related works**
Centralisation	Centralised prepositioning (Listou, 2008), Centralised decision-making (Thévenaz and Resodihardjo, 2010), and centralised fleet-hubs (Pedraza Martinez *et al.,* 2011).
Collaboration	Coordination (Van Wassenhove, 2006; Balcik *et al.*, 2010; Akhtar *et al.*, 2012; Kabra and Ramesh, 2015; Moshtari and Gonçalves, 2017; Dubey *et al.*, 2018; Singh *et al.*, 2018; Vega, 2018), supplier relations (Kovács and Spens, 2009), commercial-humanitarian cooperation (Majewski *et al.*, 2010), collaborative procurement (Wild and Zhou, 2011; Falagara Sigala *et al.*, 2022), civil-military coordination (Heaslip *et al.*, 2012), adaptability (Dubey and Gunasekaran, 2016), and orchestrating networks (Oloruntoba and Kovács, 2015), Swift trust and commitment (Kabra and Ramesh, 2015; Prasanna and Haavisto, 2018; Dubey *et al.,* 2019; Dubey *et al.*, 2020)
Flexible supply base	Multiple suppliers (Ertem *et al.,* 2010; Cozzolino *et al.,* 2012; Haque and Islam, 2018; Yang *et al.*, 2019; Kovács and Falagara Sigala, 2021; Kumar *et al.*, 2022), asset transfer mechanism (Bhattacharya *et al.,* 2014), Dual sourcing (Iakovou *et al.*, 2014), flexible sourcing (Day, 2014), buttressing supply chains (Sodhi and Tang, 2014), adaptive entity capacity (Day, 2014), and arms-length and transactional (Oloruntoba and Kovács, 2015)
Flexible supply contracts	Flexible order quantities (Ali Torabi *et al.*, 2018), framework agreements (Balcik and Ak, 2014; Gossler *et al.*, 2019; Falagara Sigala *et al.*, 2022), and options contract (Wang *et al.*, 2015; Liu *et al.*, 2019; Aghajani *et al.*, 2020)
Flexible transportation	Operational mix for fleet (Besiou *et al.,* 2014), alternative transport modes (Holguín-Veras *et al.*, 2012; Yadav and Barve, 2015; Ertem *et al.*, 2017; Maghfiroh and Hanaoka, 2020; Kovács and Falagara Sigala, 2021)
Information Sharing	Demand signal visibility (Day *et al.*, 2012; Ergun *et al.*, 2014), visibility (Maghsoudi *et al.*, 2018; Falagara Sigala *et al.*, 2022), alignment (Dubey and Gunasekaran, 2016; L'hermitte *et al.*, 2016; Dubey *et al.*, 2021), and cloud computing (Schniederjans *et al.*, 2016)
Make-and-buy	Logistics outsourcing (Majewski *et al.*, 2010; Bealt *et al.*, 2016; Nurmala *et al.*, 2017; Falagara Sigala and Wakolbinger, 2019; Kim *et al.*, 2019), and resource sharing (Maghsoudi *et al.*, 2018)
Postponement	Non-earmarking of items (Jahre and Heigh, 2008), rosters (Kovács and Tatham, 2009), non-earmarked funding (Besiou *et al.,* 2014), and standardisation (Jahre and Fabbe-Costes, 2015)
Speculation	Full speculation (Listou, 2008), decentralised prepositioning (Jahre and Heigh, 2008), and unsolicited goods (Holguin-Veras and Van Wassenhove, 2014)
Strategic stock	Secure location (Hale and Moberg, 2005; Ali Torabi *et al.*, 2018), pooling resources (Kovács and Tatham, 2009), vendor-managed inventory (van Wassenhove and Pedraza-Martinez, 2012), prepositioning (Kunz *et al.*, 2015; Falagara Sigala *et al.*, 2022; Kumar *et al.*, 2022), and temporary fleet hubs (Stauffer *et al.,* 2016)
Decision policy	(Day *et al.*, 2012; Holguín-Veras *et al.*, 2012; Kabra and Ramesh, 2015; Yadav and Barve, 2015; Singh *et al.*, 2018)
Cash-based interventions	(Fenton *et al.,* 2014; Heaslip *et al.,* 2015; Garc and Castillo, 2021; Bailey et al., 2008; Harvey and Bailey, 2011)
Risk awareness/Knowledge management	(Pettit and Beresford, 2009; Yadav and Barve, 2015; Singh *et al.,* 2018)

Source: Adapted from Jahre, (2017)

Kovacs and Spens, (2007) established a structure that defines the various logistical procedures, phases, and actors involved in disaster relief. The authors identify and detail the unique aspects of logistics in humanitarian operations, while also acknowledging the importance of lessons learned from commercial logistics for improving emergency logistics. L'hermitte and Nair, (2021) designed a blockchain-enabled architecture to facilitate the coordination of logistical support during crisis situations. The authors stated that using commercial logistical services, such as emergency supply transportation capability and storage space, may increase the speed with which emergency relief products could be mobilized and delivered, improving the effectiveness of emergency response. To analyse whether factors encourage or discourage material consolidation in emergency logistics, Vaillancourt, (2016) constructed a theoretical framework. The author pinpointed the root causes of bottlenecks in disaster relief and reconstruction efforts.

Sheppard *et al.,* (2013) evaluated the local peoples' and citizens' ability to maximize preparation and response to logistical issues during a natural disaster, focusing primarily on the village or municipality level. The authors have created a model that considers the local community's potential role in managing demand and supply-side components, which should result in logistical response systems that are faster, more efficient, and more precise. Similarly, Oloruntoba, (2005) found that locals should be involved in disaster management and relief efforts wherever possible. According to research by John and Ramesh, (2016), skilled logisticians are crucial to efficiently operating emergency supply chains. People from many different backgrounds and areas of expertise work together to rebuild society after natural disasters or other catastrophic events, as Pardasani (2006) reports. Therefore, it is essential to foster long-term changes in economically depressed areas through community involvement and multidisciplinary coalitions.

Information technology (IT) in the form of the RFID system (Radio Frequency Identification Device) is discussed by Baldini *et al.,* (2012) as a potential means of bolstering the safety of emergency supply chain management. In addition to enhancing logistical activities at each stage of the disaster management cycle, the emergency logistics information system ensures the continuity of relief operations by disseminating crucial data at each stage of the cycle's transitions (Tyagi and Kaushal, 2010). Ashhar *et al.,* (2010) talk about how a GIS accessible over the web can be a helpful resource at several points in the disaster management process. Drones have already been the subject of research into their potential use in disaster relief (Tatham *et al.*, 2017; Comes *et al.*, 2018), rescue operations (Xiang *et al.*, 2016), and delivery

(Shavarani *et al.*, 2018). Therefore, using information technology to manage the emergency supply chain is one of the most impactful strategies to provide a better answer to the people impacted (Delmonteil and Rancourt, 2017). As soon as possible after a tragedy, contemporary technologies should be employed to distribute aid among survivors (Eguchi, 2013).

Appropriate distribution of relief personnel and supplies, positioning relief centres, and constructing transportation routes are crucial post-disaster relief responsibilities (Chang *et al.*, 2014). Through a multi-level facility location-allocation problem, Mahdi Shavarani (2019) investigated the optimal placement of relief centres and drone charging stations to facilitate the distribution of emergency relief aid in the aftermath of a natural catastrophe. Ukkusuri and Yushimito's, (2008) modelling of the facility locating problem in the wake of disasters considers vehicle routing and the likelihood of transportation network outages. The optimal supply site was determined using a highly consistent path and an integer programming approach. In addition, better opportunities in the age of vast data may be revealed through location intelligence (i.e., big data analytics backed by artificial intelligence) (Dubey *et al.*, 2019). The investigations were undertaken by various studies (Wang *et al.*, 2016; Zhang *et al.*, 2020) to determine the effect of big data and predictive analytics as an organizational capability on the visibility and coordination of emergency supply chains. The results of these research studies support the hypothesis that this skill substantially affects both metrics.

According to research by Chandes and Paché, (2010), a hub that provides dependability and responsibility can improve emergency supply chain operations using a mutual act method. To better manage disaster-relief logistics, it is essential to have easy access to technical support, particularly in operations management, which includes aspects like transportation optimization and the positioning of regional depots/warehouses. As a result, the combined plan must take the same approach, especially regarding supply prepositioning and the harmonization of relief efforts. The importance of temporary logistics hubs (TLHs) was discovered by Maharjan and Hanaoka, (2019), who also presented the development and implementation of a methodology to determine the order of formation of TLHs to facilitate post-disaster decision-making when resources (mobile storage units used as TLHs) are limited. Régnier *et al.*, (2008) analyse the topic of livelihood recovery after disaster situations using the example of post-tsunami micro-entrepreneurial ventures that contributed to creating employment chances and revenues among the impacted population. Using the insights from the 4PL, Jensen, (2012) provides a glimpse into the work of the humanitarian cluster heads (fourth-party logistic service providers). The article by Abidi and Klumpp, (2015) gives a framework for the idea of fourth-party humanitarian logistics and discusses the significance of 4PL within a humanitarian logistics and supply chain.

Meite, (2010) asserts that sound strategic planning, effective command and control, resource mobilization, the capacity to organize the effort in a logical and timely manner, the ability of the logistics to match with the activities during relief operations, and successfully managing psychological aspects of crises are some of the critical factors that contribute to disaster management success. Kovács and Tatham, (2009) considered vendor-managed inventories, public-private partnerships, shared warehouses for resource pooling, and postponement. An efficient supply chain will be crucial to mobilizing the populace to the safest locations and transporting food and medical supplies throughout the country, as relief organisations are trained to aid in chaotic and challenging conditions. Additionally, because most natural disasters are unanticipated, the demand for commodities during these times is highly uncertain. Thus, managing emergency supply chains is extremely difficult and requires flexibility to operate under significant constraints. Therefore, it is essential to address the problems and effectively handle the logistics of natural disaster aid during any crisis by going through the planning, preparedness, and response phases.

Following discussions on managing risk factors in emergency supply chains, this research must now present several literature gaps identified from this review. These identified literature gaps will support developing and defining the research questions. These questions will structure the subsequent chapters in this research.

2.7 Literature Gaps

Several vital gaps have been identified from the rigorous and comprehensive literature review conducted. Several studies have focused on various aspects of emergency supply chain management, such as logistics. In the commercial sector, supply chain risk management studies continue to increase. However, minimal studies have purposively linked the discipline to supply chain risk management in emergency supply chains, disaster relief operations, and disaster management. This is a significant challenge for the field since the emergency supply chain is built and operates in highly volatile environments, and the system encounters several risks. The primary objective of the emergency supply chain is to save the lives of populations affected by disasters. Thus, any disruption to this supply chain can lead to an evident loss of human life. Hence, more attention should be channelled towards investigating the management of risk factors in the emergency supply chain.

Specifically, the literature gaps identified include the following:

1. The discipline of emergency supply chains is still developing, although several established themes have already been explored. While there has been much talk about supply chain risk management, very few researchers have addressed the topic in this discipline. Research in this area is necessary because it will pave the way for future investigations into how to strengthen the emergency supply chain and disaster relief efforts. Furthermore, the results of such studies will give practitioners and policymakers much-needed direction for dealing with supply chain interruptions during emergency relief efforts. Moreover, commercial supply chain managers, who typically operate in more stable situations, can benefit from research on risk management in emergency supply chains. Activities of the emergency supply chain are conducted in highly volatile environments, and improved capabilities gained from studying emergency supply chain practices can help their commercial counterparts respond effectively in disaster scenarios.
2. Several studies have proposed frameworks for emergency supply chains for different contexts. Risk management is critical in this context since the nature of the operating environment of the emergency supply chain is relatively unstable and unpredictable. In other fields, supply chain risk management literature continues to grow, but the emergency supply chain lacks systematic implementation. This field has yet to witness the emergence of a precise and comprehensive emergency supply chain risk management framework that can guide emergency managers, practitioners and policymakers on the steps to follow to manage risk factors that are likely to disrupt a response operation. Therefore, there is a critical need for a novel framework that encompasses the three fundamental phases of the supply chain risk management process, which will meet the needs of practitioners and policymakers. This novel framework will support decision-making in tackling the challenges of uncertain and complex emergency relief operations.
3. Limited studies have specifically discussed specific emergency supply chain risk factors. Recently, one study has empirically discussed the specific supply chain risk factors for the respective disaster management life cycle phases. Another study has discussed emergency supply chain risk factors that hampered the operations of a particular disaster in Africa. Noting that every disaster is unique and the problems that arise during emergency response operations may differ depending on various factors

such as the disaster's form, impact and location and local conditions in the affected regions. Risks evolve and may evolve differently from one region to another. In a turbulent environment, understanding the main global supply chain risks can work to reduce their impact. However, no study has attempted to empirically and comprehensively identify the risk factors likely to impede the everyday activities of the emergency supply chain. There is a need for academicians and practitioners to channel their attention towards this aspect of the field to provide a knowledge database that will ensure better preparedness in the face of disasters.

4. Another critical gap identified is the lack of literature classifying emergency supply chain risk factors. Studies that have linked risk management to emergency supply chains have directly adapted risk classification models from the commercial sector. Even though one can borrow theories from the commercial sector, it is imperative to consider the unique features of the emergency supply chain. Therefore, there is a need to develop specific risk classification models for emergency supply chains and disaster relief operations. A clear and defined classification model will enable practitioners to identify supply chain components that have been hampered easily.
5. Risk constitutes two characteristics: its likelihood or probability and its severity. Information on prevalent risk factors is vital, but practitioners and policymakers cannot tackle them all. Therefore, another vital piece of information is knowledge about risk factors significantly impacting supply chain activities. In the disaster relief context, no study has attempted to evaluate the severity of the specific risk factors to prioritize and define those risk factors that mandate more stakeholder attention. Hence, such a study is required because awareness of the most important risk factors can enable policymakers and practitioners to tailor their practices and supply chain strategies to eliminate these risks and improve the effectiveness of the response operation.
6. Finally, the ability to mitigate critical risk factors likely impedes any supply chain's normal functioning. Few studies have tried to address this topic in the disaster relief context. However, no study has attempted to empirically identify and evaluate relevant risk mitigation strategies concerning the most critical emergency supply chain risk factors. Such a study will enable practitioners and policymakers to improve the emergency supply chain's robustness rapidly.

2.8 Conclusions

This chapter provides an overview of the research conducted in disaster management. After this comes an explanation of supply chain management and management of the emergency supply chain; based on this, an outline of the distinctive characteristics of the emergency supply chain and discussions on the operational environment of the emergency supply chain are provided. An exhaustive study of the available literature on supply chain risk management is carried out due to the complexities of its operational environment. There will be a discussion on the general definitions of supply chain risk and supply chain risk management. Similarly, the many subcategories and distinct supply chain risks are outlined here. The supply chain risk management process includes three essential steps: identifying, assessing, and taking measures to mitigate the risk. Each stage is broken down, highlighting the strategies to accomplish each step. A review of the scattered studies documenting the risk in emergency supply chains and the methods adopted in the context is reviewed. In the end, this research found several knowledge gaps that currently exist. It put up several research questions that will be answered to fill the identified voids in the existing body of literature.

CHAPTER 3 - RESEARCH METHODOLOGY

"People research to find things out in a systematic way, thereby increasing their knowledge" (Jankowicz, 2005).

3.1 Introduction

In today's world, it is challenging to miss the term 'research' when one pays close attention to the radio, reads the newspaper, or watches the television (Saunders *et al.,* 2019). The word consists of two syllables, *re* and *search.* The prefix *re* means again, anew, or over again and '*search'* implies examining and carefully testing and trying or probing. According to Kumar (2015), "research" has varied meanings and interpretations from diverse disciplines and experts. Although, there is a general agreement that the purpose of research is to utilise a research method to provide answers to a research question. Fig. 3.1 presents the proposed research methodological framework. Specific attributes characterise a valid research process and meet certain requirements, reflecting several research definitions. Grinnell (1993) defines 'research as a systematic investigation that utilises acceptable scientific methodology to solve problems and create new knowledge that is generally applicable. Burns (1997) defines research as a 'scientific investigation to find answers to a problem. Planning research depends on the research question that needs to be answered or the problems that must be solved. Then, thoughts must turn to the required data and the techniques that will be utilised to collect the data (Cameron and Price, 2009). Research methodology refers to the theory of how research is conducted. Thus, a clear understanding defines the researcher's choice of method throughout the study.

Previous chapters have described the theoretical context of this research. The purpose of this chapter is to present the philosophical underpinnings of the research methods. The selected research philosophy suggests critical assumptions regarding how the researcher perceives the world, and these assumptions influence the adopted research strategy and design (Saunders *et al.,* 2010).

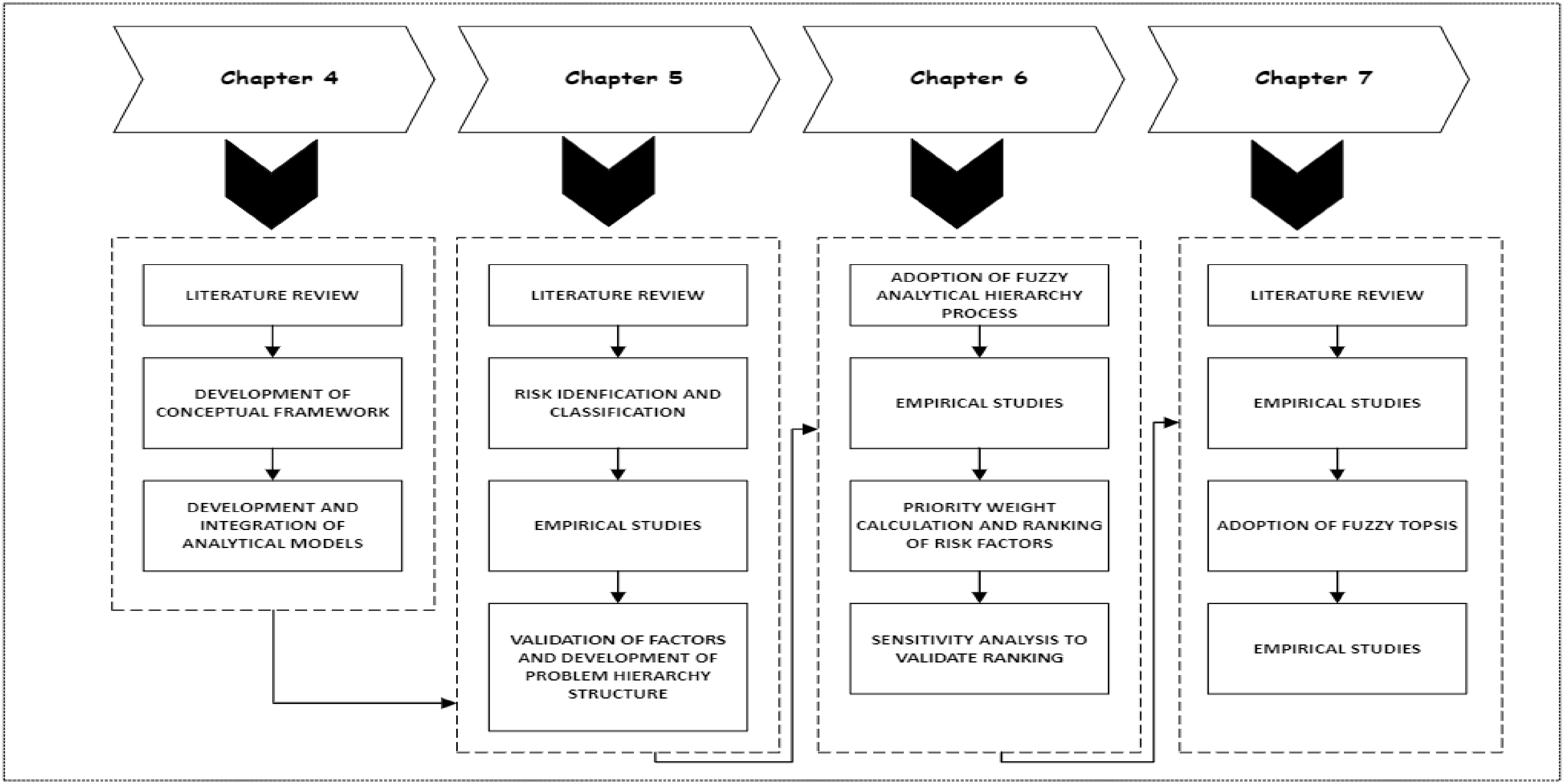

Figure 3.1 Proposed research methodological framework

Source: Author

3.2 Arriving at a Methodology

Before choosing a research methodology, the researcher goes through a complex process. Several studies discuss varied methods and approaches that have been developed to conduct research, both in natural and social sciences. Moreover, various methods and approaches are linked to diverse philosophical and theoretical views (Bryman and Bell, 2007; Creswell, 2013; Kumar, 2019; Saunders *et al.*, 2019). This explains why a researcher struggles when considering a research methodology. However, various academic models exist, specifically developed to guide researchers during the selection process (Saunders et al., 2009; Creswell, 2018). In practice, researchers are advised not to consider any right or wrong model since all available models attempt to provide solutions to existing challenges researchers face. Partington, (2000) suggests that researchers should not favour one approach over another but choose a research methodology that is convenient, appropriate, and relevant to the context of a particular subject matter. Hence, this research will discuss how the researcher selected the final methodology.

3.2.1 The research process – an appropriate model

As stated before, several models can guide a researcher throughout the research process. The purpose of the model is to present the researcher with the various selections that can be made. Specifically, the model showcases how philosophical, theoretical, and methodological perspectives can be linked. An example of this model is proposed by Saunders *et al.,* (2019) and is termed the "research onion" depicted in fig. 3.2.

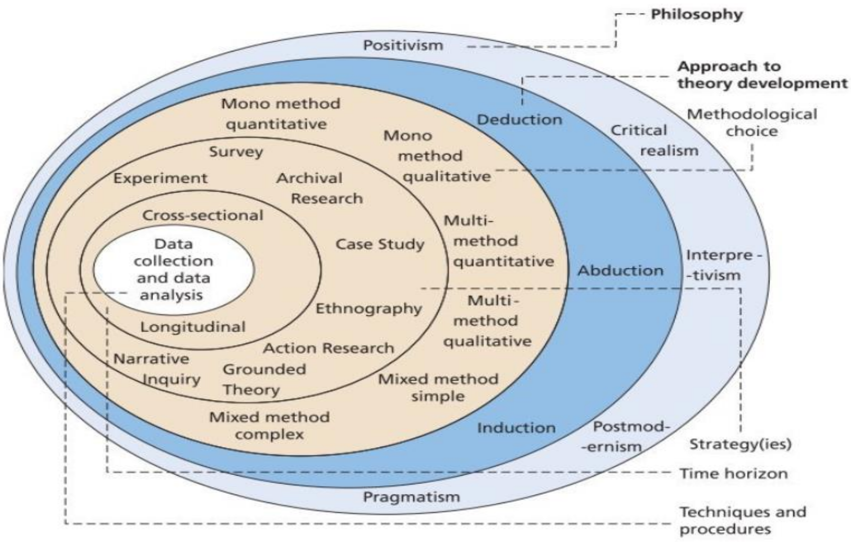

Figure 3.2 The Research Onion

Source: (Saunders *et al.*, 2019)

In most cases, a research plan is developed based on a research question that requires an answer or a problem that needs a solution (Saunders *et al.,* 2019). Subsequently, the research investigates what data is relevant and how this data can be retrieved and analysed, which is a part of the research process at the core of the research onion. When a researcher decides on the methods and techniques adopted for data collection and analysis, Crotty, (1998) underlines that explaining how these choices were made is imperative to ensure the research is comprehensive and relevant to others in the discipline. The 'research onion' proposed by Saunders *et al.,* (2019) showcases the various challenges a researcher will encounter before arriving at a final methodology. Notably, it illustrates a process that begins from understanding the philosophical assumptions of a researcher through a series of phases before concluding on the best methods of data collection and analysis. Therefore, this research adopts this model and systematically peels this 'research onion' and discusses each step or layer of the process that the research will undergo before arriving at the core of the process.

3.2 Research Philosophy

A researcher's attitude, philosophy and worldview significantly contribute to the logistics and supply chain management research process. Creswell and Creswell, (2018) point out that philosophical ideas are not apparent in research (Slife and Williams, 1995); they still influence the entire research process. Thus, they need to be known. Research philosophy is the system of beliefs and assumptions about knowledge development. So, critical assumptions about how a researcher views the world are underpinned in the research philosophy. Irrespective of a researcher's awareness, varied assumptions will be made at every stage of the research process (Burrell and Morgan, 2016), including ontological and epistemological assumptions (Saunders *et al.,* 2012). Ontological assumptions refer to assumptions concerning the nature of reality. The philosophical study of being and existence (Remenyi et al., 1998) shapes how research projects are perceived and studied. Hence, an ontology defines the researcher's choice of what to research. Alternatively, Epistemological assumptions are associated with the nature of valid and legitimate knowledge (Solem, 2003; Bryman, 2012; Saunders *et al.,* 2019) and how it is being communicated to others. The multidisciplinary context in business and management infers different forms of knowledge and epistemologies. Moreover, the variety of epistemologies presents the researcher with multiple choices of methods. Nevertheless, the researcher must clearly understand the effects of varied epistemological assumptions on the adopted research methods and the nature of the research findings (Saunders *et al.*, 2019).

Table 3.1 Comparison of various research philosophical stances

	Ontology (Nature of reality or being)	Epistemology (what constitutes acceptable knowledge)
Positivism	Real, external, independent. One true reality (universalism) Granular (things) Ordered	Scientific method Observable and measurable facts Law-like generalisations Numbers Causal explanation and prediction as contribution
Critical realism	Stratified/layered (the empirical, the actual and the real) External, independent Intransient Objective structures Causal mechanisms	Epistemological relativism Knowledge historically situated and transient Facts are social constructions Historical causal explanation as construction
Interpretivism	Complex, rich Socially constructed through culture and language Multiple meanings, interpretations, realities Flux of processes, experiences, practices	Theories and concepts too simplistic Focus on narratives, stories, perceptions and interpretations New understanding and worldviews as contribution
Postmodernism	Nominal Complex, rich Socially constructed through power relations Some meanings, interpretations, realities are dominated and silenced by others Flux of processes, experiences, practices	What counts as 'truth' and knowledge is decided by dominant ideologies Focus on absences, silences and oppressed/repressed meanings, interpretations and voices. Exposure of power relations and challenges of dominant views as contribution
Pragmatism	Complex,rich, external 'Reality is the practical consequences of ideas Flux of processes, experience and practices	Practical meaning of Knowledge in specific contexts 'True' theories and knowledge are those that enable successful action Focus on problems, practices and relevance Problem solving and informed future practice as contrition

Source: (Saunders *et al.,* 2019)

Irrespective of these differences, the epistemological assumption of the researcher influences the definition of legitimacy in research. An ingenious set of assumptions defines a reliable research philosophy which will emphasise the choice of methodology, research strategy and research methods. Thus enabling the researcher to produce a sound research project (Easterby-Smith *et al.,* 2012; Saunders *et al.,* 2019). Saunders *et al.,* (2019) posit that there are five essential philosophies in business and management: positivism, critical realism, interpretivism, postmodernism and pragmatism. As discussed earlier, adopting these philosophies depends on the researcher's ontological and epistemological perception of the world (Bryman and Bell, 2007; Saunders *et al.,* 2009). Consequently, Table 3.1 compares the philosophical stances in business and management research.

Pragmatism philosophy suggests that concepts are only relevant when they can support action. According to Creswell and Creswell, (2018), the pragmatism philosophy originates from several studies (Cherryholmes, 1992; Murphy, 1990; Patton, 1990; Rorty, 1990). Pragmatism takes several forms. However, it is viewed as a philosophy that evolves from actions, situations, and consequences (Creswell, 2009). Saunders *et al.,* (2019) mention that this philosophical stance brings together objectivism and subjectivism, facts and values and varied contextualised experiences by considering various instruments of action and their practical consequences in specific contexts, including theories, concepts, ideas, hypotheses, and research findings. Moreover, the pragmatist researcher is fundamentally concerned with reality and acknowledges that ideas' practical effects should enable various actions' success. The pragmatist researcher accepts that the world is perceived differently and that even a research process has multiple realities. Patton, (1990) described pragmatism as one philosophy interested in integrating what works and practical answers to research problems. Alternatively, the pragmatist researcher does not emphasise research methods but focuses on the research problem and question. Moreover, they accept the existence of diverse knowledge and approaches and can utilise all available to understand and solve a research problem. (Kelemen and Rumen, 2008). Adopting the views of Cherryholmes, (1992) and Morgan, (2007), Creswell and Creswell, (2018) established some views on pragmatism.

- Pragmatism is not committed to any one system of philosophy and reality. This applies to mixed methods research in that inquirers draw liberally from quantitative and qualitative assumptions when they engage in research.
- Individual researchers have the freedom of choice. In this way, researchers are free to choose the research methods, techniques, and procedures that best meet their needs and purposes.
- Pragmatists do not see the world as an absolute unity.
- Truth is what works at the time. It is not in a duality between reality independent of the mind and within the mind.
- The pragmatist researchers look to the '*what* and *how'* to research based on the intended consequence.
- Pragmatists agree that research always occurs in social, historical, political, and other contexts.

- From the perspective of mixed methods researchers, pragmatism connects a research problem to multiple methods, different worldviews, assumptions, and different forms of data collection.

Accordingly, pragmatism supports this study. This study aims to analyse the risk factors likely to disrupt the effective functioning of emergency supply chains during immediate disaster response operations. A generic conceptual framework will be developed and supported with different analytical models covering the three main phases of supply chain risk management: risk identification, risk assessment and mitigation. The flexibility of pragmatism will permit the researcher to freely choose the methods, techniques, and research procedures (Creswell and Creswell, 2018) that will best meet the aim and objectives of this study.

3.3 Research Approach

The theory is required in research projects. Although the use of theory may or may not be made clear in the research design, the research findings and conclusions reveal the adoption of theory in the study. Saunders *et al.,* (2019) explain that the degree to which a study is linked to theory, either through development or examination, poses a dilemma for the research design. Researchers often display this challenge through their approach to reasoning: deductive, inductive or abductive. Table 3.2 highlights the differences between these approaches. According to Ketokivi and Mantere (2010), reasoning deductively implies that a researcher initially establishes theory-based assumptions from which conclusions are drawn.

Moreover, the conclusions will only be acceptable and valid if all these theory-driven premises are actual. Precisely, a deductive researcher initiates a project with theory, usually by reviewing academic literature and later develops a research strategy to examine the theory (Saunders *et al.,* 2019). The deductive approach encompasses more than a few characteristics. One is the adoption of highly structured methodologies that will enable process replication and reliability since deductive researchers mainly tend to understand causal relationships between concepts and variables. Conversely, an inductive researcher starts with data collection to explore a fact and moves on to develop a theory, such as developing a conceptual framework. Inductive reasoning is applicable when a gap is perceived in the disparity between the conclusions drawn and observations made, considering that the conclusions are backed by the observations made (Saunders *et al.,* 2019).

Table 3.2 Differences between various research approaches

	Deduction	Induction	Abduction
Logic	In a deductive inference, when the premises are true, the conclusion must also be true.	In an inductive inference, known premises are used to generate untested conclusions.	In an abductive inference premises are used to generate testable conclusions.
Generalisability	Generalising from the general to the specific.	Generalising from the specific to the general	Generalising from the interactions between the specific and the general
Use of data	Data collection is used to evaluate propositions or hypotheses related to an existing theory.	Data collection is used to explore a phenomenon, identify themes and patterns and create a conceptual framework	Data collection is used to explore a phenomenon, identify themes and patterns, locate these in a conceptual framework and test this through subsequent data collection and so forth.
Theory	Theory falsification or verification	Theory generation and building	Theory generation or modification; incorporating existing theory where appropriate, to build new theory or modify existing theory.

Source: (Saunders *et al.*, 2019)

As an alternative to deductive or inductive reasoning, a researcher might take an abductive approach, i.e., combining deduction and induction (Suddaby, 2006). Specifically, an abductive researcher can begin from data to theory or theory to data. The researcher starts by studying a ‘surprising fact’ and then tries to comprehend its convincing theory. Although several credible concepts can explain observations, a few will provide more accounts of their occurrence. These critical theories will facilitate the revelation of more ‘surprising facts’ (Van Maanen *et al.,* 2007) that will likely surface at any point in the research process (Saunders *et al.,* 2019). Discussions suggest that directly applying a purely deductive or inductive approach can be challenging or impossible. However, the abductive approach is flexible, allowing it to be adopted by several researchers from diverse disciplines and philosophies.

Different reasons define the choice of an approach to theory development. Easterby-Smith *et al.*, (2012) highlighted three reasons. First, the research approach influences the research design, which can be described as the general configuration of a piece of research that covers the form of data collected and from where, and how the data can be utilised to provide valid findings. Secondly, it supports the researcher’s methodological choice and strategies that should be adopted in the research process. Finally, knowledge of conventional research traditions enables the researcher to integrate a suitable research design that can withstand research difficulties. From another perspective, Saunders *et al.,* (2019) argued that the researcher's philosophy influences the choice of a research approach, the research aim, and the nature of the research topic. Moreover, a researcher's philosophy attracts a particular researcher approach; the positivists will most likely choose a deductive approach, an interpretivist selects an inductive approach, and the postmodernist, pragmatist and critical realist lean towards an abductive approach.

The pragmatism philosophy supports the focus and aim of this study. The pragmatist asserts that there are several ways of interpreting the world and that diverse methods are suitable for use in a particular research study. Hence, this underpins the researcher's decision to adopt the abductive research approach.

3.4 Research Design

During a research journey, the researcher curates a path or road map to uncover solutions for the research problem. This road map is the research design. According to Kerlinger (1986):

"A research design is a plan, structure and strategy of investigation so conceived as to obtain answers to research questions or problems. The plan is the complete scheme or programme of the research. It includes an outline of what the investigator will do from writing the hypotheses and their operational implications to the final analysis of data".

The research design is a researcher's general plan that concerns selected procedures to answer the research problem. Kumar, (2019) discusses that the research design involves the procedures a researcher proposes to adopt for the choice of respondents, retrieval and analysis of information and presentation of research findings. Similarly, Saunders *et al.,* (2019) note that a research design reflects the study's objective, specification of data sources, means of data collection and analysis, ethical considerations and likely challenges the researcher will encounter during the overall research process. Specifically, the research design encompasses a researcher's methodological choices, strategies, and time horizon. Choosing a research design depends on several factors, including the research problem's nature, personal experiences and the researcher's audience. Kumar, (2019) explains that the variations in philosophical views in conjunction with the primary purpose of a study very much define the focus, approach and method of enquiry and consecutively influence the structural aspects of the research design. A researcher's philosophy, methodological choices, research strategies and time horizon are different aspects of the research design (Creswell, 2009).

3.4.1 Methodological choice: quantitative, qualitative, or mixed methods research design

During a research journey, the quantitative, qualitative, or mixed-method research design is bound to be utilised. Newman and Benz, (1998) underline that researchers must not view qualitative and quantitative designs as polar opposites; instead, they represent different ends of a continuum. A research study will either be more of a qualitative design than a quantitative one or vice-versa (Creswell, 2009). At the centre of the continuum is the mixed-method research design encompassing elements from both the qualitative and quantitative design. Several differences exist between the qualitative and quantitative research designs. Saunders *et al.,* (2019) highlight that qualitative research design utilises non-numeric data, including words, images, audio recordings, video clips and other similar materials, while the quantitative research design is linked to the adoption of numbers and closed-ended questions. However, the author suggests this distinction is narrow, and researchers will likely encounter challenges. Creswell, (2009) discusses that the researcher's philosophical assumption, types of research strategies and methods adopted throughout the research process can inform a more comprehensive manner of differentiating qualitative and quantitative research design.

Accordingly, Saunders *et al.,* (2009) discuss that quantitative research designs are linked to positivism since the data collection techniques are generally predetermined and highly structured. However, Walsh *et al.,* (2015) underline that the relationship between quantitative research design, positivism and deductive reasoning approach is generally perceived as philosophically exaggerated. In qualitative research designs, Denzin and Lincoln, (2018) explain that researchers must define and understand the subjective and socially constructed meanings of what is being studied. Hence, it is often linked to interpretive philosophy. Saunders *et al.,* (2019) highlight that researchers often refer to qualitative research designs as naturalistic because they usually conduct the research in a natural setting or context to ensure trust, participation, access to meanings and in-depth understanding. Quantitative research explores the interconnections between numerical variables examined using several statistical and graphical techniques (Saunders *et al.,* 2015).

Moreover, controls are incorporated to ensure that the information retrieved from respondents is valid. This research design can be explicitly defined and recognised since it is specific, well-structured and is often tested for validity and reliability. According to Kumar (2019), the qualitative research design is centred around people discovering, exploring, and explaining situations, feelings, perceptions, attitudes, values, beliefs, and experiences.

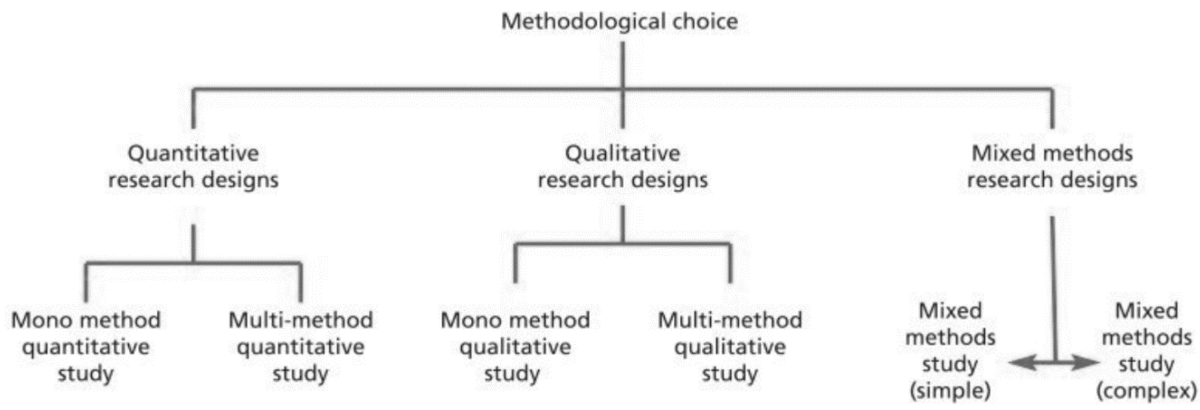

Figure 3.3 Methodological choices

Source: (Saunders *et al.*, 2019)

Consequently, it is a flexible research design and often more deductive. Likewise, Yin, (2018) explains that several qualitative research strategies begin the research process by adopting a deductive approach to examine an existing theory. In contrast, Saunders *et al.,* (2019) underline that several qualitative studies utilise the inductive approach to theory development at the start of the research process to ensure the development of a more comprehensive theoretical standpoint than already exists.

Qualitative and Quantitative research designs utilise data collection techniques. Both research designs may utilise a single or multi-method data collection technique. See Fig 3.3. Questionnaires and structured observations are typical examples of quantitative research designs. In the qualitative research design, the semi-structured interview is a typical example. Multi-method implies adopting two or more quantitative or qualitative methods for the research process. However, only methods from a respective research design can be mixed.

Mixed methods research design

When a research project utilises a combination of qualitative and quantitative research design, that study is said to have adopted a mixed-method research design. Saunders *et al.*, (2019) define mixed methods research as "the branch of multiple methods research that integrates quantitative and qualitative data collection techniques and analytical procedures in the same research project". Creswell and Clark, (2011) described it as "a method which focuses on collecting, analysing, and mixing both quantitative and qualitative data in a single study or series of studies. Its central premise is that using quantitative and qualitative approaches, in combination, provides a better understanding of research problems than either approach alone".

The mixed method research design extracts its characteristics from qualitative and quantitative research designs. Molina-Azorin *et al.,* (2017) posit that the researcher's philosophy influences how qualitative and quantitative research are combined and guides the choice of data collection and analysis technique. For the pragmatist, the world is perceived, understood, and interpreted in varied ways, and the combination of several research methods is acceptable in one research project. However, pragmatists adopting the mixed method research design is not inevitable unless the selected methods are appropriate and reliable to solve the research problem (Saunders *et al.,* 2019). Nastasi *et al.*, (2010) explain that the research context, question, and potential consequences influence the pragmatist methodological choice. Also, qualitative and quantitative research designs are critical to the pragmatist. Hence, the pragmatist usually adopts qualitative, quantitative, and mixed-method research designs. An abductive, deductive, or inductive approach to theory development applies in the mixed-method research design. Tashakkori and Teddlie, (2010) note that in mixed-method research, the purpose and scope of the research are often guided by theory. Saunders *et al.,* (2009) discuss various ways of combining qualitative and quantitative research design and several variations of mixed methods research design now exist (Creswell and Clark, 2011; Nastasi *et al.*, 2010).

In this study, the mixed method research design will be utilised. A qualitative research design will extract existing information to develop the generic conceptual framework and analytical models. For the identification, assessment, and mitigation of emergency supply chain risk identifying, assessing, and mitigating emergency supply chain risk factors, qualitative and quantitative research designs will be combined. More details concerning the data collection and analytical techniques will be discussed in later sections.

Purpose of Research

During the research journey, a variation of purpose influences the research design. Saunders *et al.,* (2019) discuss that a research design may be explorative, explanatory, descriptive, evaluative, or a combination of these. An exploratory study is best suited when a researcher intends to gather relevant knowledge and understanding concerning a particular topic. To collect data, questions beginning with "What" and "How" are generally utilised to study a particular research problem. Literature review and unstructured interviews are methods involved in the exploratory study (Saunders *et al.*, 2009). The exploratory study is flexible and adaptable to change. Thus, researchers adopting this study must be open to directional change throughout the research process.

In contrast, researchers looking to understand the causal relationships between variables adopt the explanatory study to gain insights into a situation or problem. “Why” and “How” questions often begin the research questions and questions developed for data collection. The descriptive study is often seen as an extension of the exploratory study or a forerunner of an explanatory study. Researchers utilise this study to obtain a clear picture of an event, person, or situation. On the other hand, the evaluative study is adopted to analyse performance and effectiveness (Saunders *et al.,* 2019). Researchers utilising the mixed method research design regularly combine different purposes in one research project. Based on its aims and objectives, this present study adopts a combined purpose in its design. The research process will utilise a sequential exploratory research design study for the literature review to gather background knowledge on emergency supply chain, disaster management and supply chain risk management, identify and assess specific risk factors and select the appropriate risk mitigation strategies.

3.4.2 Research strategy

To achieve a goal, one requires a plan of action referred to as a strategy. Saunders *et al.,* (2019) define a research strategy as “a plan of how a researcher will answer his or her research question”. It serves as a bridge that links a researcher’s philosophy to other selected methods, including methods for data collection and analysis (Denzin and Lincoln, 2018). Several research strategies are linked to specific research philosophies and approaches to theory development (Saunders *et al.,* 2019). However, linking strategies to particular elements is not essential; the purpose of a research strategy is to enable a researcher to achieve a certain level of coherence throughout the research process and meet the aim and objectives of the research (Saunders *et al.,* 2019). Research strategies are not mutually exclusive; a researcher can combine several strategies in one research project.

Survey

One popular strategy across several disciplines is the survey strategy. It is often associated with the deductive approach to theory development in research and is very much applicable for exploratory and descriptive purposes. Saunders *et al.,* (2009) discuss that the survey is easy to explain and comprehend. However, general views indicate that this strategy appears and sounds authoritative to the respondents. Questionnaires, structured observations and structured interviews are different data collection techniques for the survey strategy. Researchers utilise the questionnaire to economically retrieve standardised data from a large sample of respondents, allowing for easy comparison (Saunders *et al.,* 2019). However, other research strategies will provide more comprehensive data than the survey. A key drawback will be the ease and capacity to conduct the questionnaire survey wrongly.

This study will adopt and utilise the survey strategy at several points in the research process. Specifically, empirical information relating to emergency supply chain risk factors and appropriate strategies for risk mitigation will be retrieved for essential stakeholders and decision-makers with the help of the questionnaire survey. Where possible, the study will conduct semi-structured interviews and observations to gather more information necessary for the respective research question.

3.4.3 Time-horizon

Upon completion of the research project, the answers to the research questions should reflect whether it is a snapshot taken at a particular time or a series of snapshots and a representation of events over a given period. Saunders *et al.*, (2019) discuss two time-horizons: Cross-sectional and longitudinal studies. Cross-sectional studies, like most academic research studies, examine a phenomenon at a given time. Moreover, the time for study is limited. In contrast, the longitudinal study offers the capacity to investigate change and development. This research study is a time-based study that is focused on investigating how risks exist and can be managed in emergency supply chains at a specific time. However, future improvements will be suggested. The study will have no access to actual events. Hence, this study is a cross-sectional study.

3.5 Data Collection and Analysis

In this section, the study presents a comprehensive explanation of the methods adopted for data collection and analysis. A mixed-method research design is utilised to manage risk factors in the emergency supply chain. The fundamental life cycle of supply chain risk management consists of three primary phases: risk identification, risk assessment and risk mitigation. Each phase utilised specific data collection and analysis methods detailed in the following sub-sections. Precisely, this study will primarily adopt the survey strategy for empirical data. In the first phase, the research will utilise a questionnaire survey to ascertain the comprehensiveness of the risk factors identified from the literature review. Furthermore, the survey will validate the risk classification method employed. The second phase will utilise another questionnaire survey to assess and quantify the significance level between the identified risk factors. In the third phase, two questionnaire surveys will be adopted. The first questionnaire will validate the risk mitigation strategies identified from the literature review and extract more strategies from industrial and academic experts. This survey will ensure the comprehensiveness and robustness of the research. Subsequently, the final survey will be used to quantify or determine the priority ratings of the identified risk mitigation strategies that will improve the resilience of the emergency supply chain. In the following sub-section, this study will present the data analysis methods for each phase of the emergency supply chain risk management process. A summary of all these methods utilised in the three phases of emergency supply chain risk management is presented and described in Table 3.3

Table 3.3 A summary of data collection and analysis research methods

Steps	**Approaches**	**Purposes**
Risk factors identification	Literature review	To identify the existing risk factors that are likely to impede the normal functioning of the emergency supply chain during disaster response operations
	Questionnaire survey	To determine the risk factors reliability and validity, ensure all factors are included. Moreover, to assess the appropriateness of the risk classification method put forward.
	Face-face interviews	To further assess the developed hierarchical model to ensure it is appropriate and comprehensive
Risk assessment	Fuzzy Analytic Hierarchy Process survey (Web-based questionnaire) (LJMU survey creator)	To evaluate the degree of importance of the identified risk factors based on pair-wise comparisons.
Risk mitigation strategies identification	Literature review	To identify the existing supply chain strategies that emergency supply chain managers and decision-makers utilise to manage the supply chain
	Empirical studies (Questionnaire survey Semi-structured Interviews)	To ensure comprehensiveness, validate the identified mitigation strategies and identify other strategies omitted.
Risk mitigation strategies evaluation	Fuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) (Questionnaire survey)	To determine the degree of significance of the risk mitigation strategies under different risk contexts

3.5.1 Data collection

Supply chain risk management involves three critical steps: risk identification, risk assessment and risk mitigation and the data collection methods will be presented according to the respective phases. This study involves three forms of data collection methods: literature review involving both online and offline documentation (secondary data collection), questionnaire surveys (primary data collection) and interviews (primary data collection). Primary data collection involves collecting new data from experts or true direct observation, while secondary data involves retrieving already existing information. The field of the emergency supply chain is in its infancy, and minimal studies have been done on risk management in the emergency supply chain. Hence, it is essential to adopt a research design that is comprehensive and robust (mixed-method research design). The mixed-method research design utilises both qualitative and quantitative methods in the research process. Therefore, this research uses qualitative and quantitative methods to retrieve the necessary data since few studies are concerned with managing risk in emergency supply chains.

Generally, an empirical study aims to authenticate the validity of information using empirical data. This research will conduct several empirical studies to validate and better understand the specific risk factors that can most likely disrupt the emergency supply chain. Furthermore, the empirical studies will also support identifying and evaluating the mitigation strategies that will enable the emergency supply chain to become more resilient in the face of disruption. Chapters five, six and seven will contain the data collected from these empirical studies. Different forms of questionnaire surveys will be utilised for data collection.

The first sub-section will introduce the data collection methods utilised in chapter five. Chapter five will cover the risk identification and classification phase of the research. The chapter will cover questionnaire surveys and interviews to identify emergency supply chain risk factors and validate the appropriateness of the classification and hierarchical model. Subsequently, the following sub-section discusses data collection methods that will be adopted in chapter six. Chapter six covers the risk assessment phase of the risk management process. One questionnaire survey is developed and deployed to determine the level of importance of the respective risk factors. The priority weights of the risk factors will be calculated. The final phase of the risk management process is risk mitigation. This will be covered in chapter seven. The third sub-section will cover the data collection methods utilised in the risk mitigation phase. These data collection methods will be used to identify, validate, and evaluate the risk mitigation strategies. The research will utilise a literature review and questionnaire surveys to identify and validate the mitigation strategies. Then, another questionnaire survey will be developed and deployed to experts to determine the mitigation strategies' degree of importance or priority rating.

A questionnaire survey is an effective tool encompassing structured questions for data collection and statistical analysis. According to Bryman and Bell, (2011), the questionnaire survey is a critical data collection tool that interprets and quantifies individual opinions and behaviours. One advantage of the questionnaire survey is that it permits data collection without a skilled person (interviewer). Saunders *et al.*, (2019) note that the questionnaire survey can assist in reaching a wide range of diverse respondents through electronic media. Moreover, it can help collect qualitative and quantitative data in less time and cost less. Contrarily, Bryman and Bell, (2011) highlighted some drawbacks of the questionnaire survey, including (I) the risk of missing data and (ii)more data cannot be collected with the questionnaire. Furthermore, the authors suggest a short questionnaire survey containing closed questions to prevent perceived drawbacks.

3.5.1.1 Data collection methods in risk factors identification and classification

Risk identification and classification is the first step in the supply chain risk management process. Several methods can be used to identify risk factors, including historical data collection, interviews, focus-group meetings, and relevant documentation review (Waters, 2007). Several studies have utilised literature review to identify supply chain risk factors (Barry, 2004; Wagner and Bode, 2006; Chari *et al.*, 2020; Rogers *et al.*, 2016). This study conducted an initial literature review in chapter 2 to identify the risk factors that are likely to affect the normal functioning of the emergency supply chain during disaster response operations. Saunders *et al.*, (2019) describe a literature review as a time-saving and cost-effective research method since the data has already been collected. A comprehensive literature review is usually of high quality, and the retrieved data can be integrated with data from other qualitative methods, such as experts' judgement. Following a comprehensive literature review, this research invited several experts from diverse backgrounds to take part in validating the identified risk factors and exploring other potential risk factors that have been omitted. Subsequently, the experts were invited to participate in developing and validating the structural hierarchy risk taxonomic diagram. Expert selection was based on professional working experience, job position, and qualification for the research topic.

From the literature review in chapter 2, this study identified several risk factors for the first part of the qualitative data collection and developed a questionnaire survey. Five experts, including one humanitarian consultant and four academic doctors, were asked to review the questionnaire to ensure its clarity, question precision, and ease of comprehension. Significant changes were made based on the feedback received, and a final draft was produced. After that, ethical approval was obtained to validate the questionnaire content and participant consent further. The research moved on to validate the comprehensiveness of the identified risk factors to ensure none was omitted and the development of a valid structural hierarchy risk taxonomic diagram. Appendix I and II presents a sample of this questionnaire's final draft.

A sample is a critical part of any survey research. The sample of people significantly represents the target population relevant to the study (Bryman and Bell, 2011). As suggested by Saunders *et al.,* (2019), there are various methods for sampling in research, including the probability sampling technique (simple random, systemic, stratified random and multi-stage cluster samplings) and the non-probability sampling technique (convenience, purposive, snowball and quota samplings). Bryman and Bell, (2007) discuss that the non-probability technique is a sampling technique that does not involve random selection of participants and is relevant for in-depth qualitative research (Saunders *et al.,* 2019). This study utilises the non-probability sampling technique, particularly purposive and snowballing sampling. In the purposive sampling technique, researchers utilise personal judgements to select participants relevant to their study purpose and objectives. In the snowballing sampling technique, researchers utilise a sample of experts to establish connections with other experts in the field (Saunders et al., 2009). Experts from disaster management, humanitarian supply chain, emergency supply chain, supply chain management and risk management fields are the target population in this study.

Experts from diverse backgrounds and geographical regions were contacted to participate in this study. The goal was to capture wide-ranging and reliable views of the subject matter. Several criteria were put in place for the selection of experts. Firstly, the expert must be a professional working in an organisation connected to the field of study. The organisations include non-governmental organisations (NGOs), relief organisations (ROs), governments or private organisations. Professionals from academic institutes, including universities, must be versatile and conduct research in the discipline. Years of work experience is another criterion used to include or exclude experts. Experts with less than ten years of working experience were excluded from the research. Another criterion adopted in the study is the country of operation;

industrial practitioners targeted are those involved in disaster relief operations, specifically in a sizeable sudden-onset disaster. These experts have been in the field and understand the working operations and factors that are likely to disrupt an emergency supply chain. Although every disaster and emergency supply chain developed is unique, the wide-ranging views captured in this study will provide a generic understanding.

The goal of the survey in this phase of the research was to investigate and validate the risk factors likely to disrupt the normal functioning of the emergency supply chain in disaster response operations based on the knowledge and insights of subject experts. Moreover, the research also utilised the questionnaire to construct and validate the structural hierarchy risk taxonomic diagram. Several experts were contacted to complete the final draft of the questionnaire survey. However, only 24 responses were received, 5 of which were not suitable for this research on account of being incomplete or the respondent did not match the inclusivity criteria of the study. Saaty, (2001) explains that a small sampling size is suitable to complete any research if the sample encompasses experts experienced in the discipline. Experts in a discipline often share similar beliefs and insights. Hence, the number of responses received was satisfactory. Chapter 5 presents detailed information on the experts and the sample selection process.

The questionnaire comprised 48 statements, and experts were required to answer each statement using the following 5-point Likert scale: very unimportant, less unimportant, moderate, less important, and very important. Field, (2013) notes that the five-point Likert scale is a top-rated measurement tool widely used to scale data in survey research. The Likert-scale enables survey participants to express their views freely and clearly on a particular subject matter with adequate agreement (Saunders *et al.,* 2019). In this research, the five-point Likert scale has been adopted to allow data received to be easily analysed and for the survey respondents to remain focused on the questions asked.

Based on the results, twenty-eight risk factors have been identified, and a structural hierarchy risk taxonomic diagram provides a comprehensive risk database for emergency supply chain management research.

3.5.1.2 Data collection methods for risk factors assessment

Risk assessment is the second stage in the supply chain risk management process. Based on the instructions for the questionnaire development in the previous section, questionnaire B was developed to elicit expert opinions on the emergency supply chain risk factors concerning their weight priority. The initial draft of an AHP questionnaire was developed and sent to the supervisory team for review and approval. Based on the comments and feedback from the supervisory team, some modifications were made, and a final draft was completed. After that, the developed questionnaire (see Appendix III) was sent to diverse experts in the field with sufficient years of working experience. The experts from different geographical regions within the disaster management and emergency supply chain management discipline were selected. Chapter 6 provides comprehensive detail on the questionnaire development and distribution.

3.5.1.3 Data collection methods for risk factors mitigation

Risk mitigation is the last phase of the supply chain risk management process. To complete this phase, the research followed an empirical approach. Firstly, the researcher reviewed available and accessible literature, reports, and official documentation to identify the current implemented supply chain strategies. Next, questionnaires and semi-structured interviews were conducted to validate the identified supply chain strategies and uncover other strategies omitted from the expert's perspective.

Following the risk assessment phase, the study found the most significant risk factors likely to challenge emergency managers in disaster relief operations. After that, the research moved on to review available literature. Firstly, the researcher reviewed studies that presented relevant cases, that is, those that report in-depth case studies of organisations' supply chain strategies for disaster preparedness and response in disaster relief. Moreover, the retrieved strategies are practised in the emergency supply chain context. Secondly, the study reviewed organisational reports. Notably, these reports were retrieved from a website, "reliefweb.int," and other relevant supply chain strategies were identified.

Additionally, the study conducted semi-structured interviews and a questionnaire survey (see Appendix IV) simultaneously to validate the identified supply chain strategies and uncover other initially omitted or overlooked strategies. The questionnaire survey was developed following the instructions in 3.5.1.1 and distributed to experts. These experts were required to describe the relevance of the identified strategies and suggest other relevant strategies that have been omitted. For the interview, a similar process was conducted. Experts were initially contacted to seek their willingness to participate in an interview. During the interview, the selected experts were presented with strategies and asked to describe the relevance of the identified strategies in the study's context. In addition, they were asked to mention and discuss other strategies that have been ignored.

Finally, based on the result from the process detailed above, the study designed and developed another TOPSIS-based questionnaire (see Appendix V) to investigate the efficiency of the selected supply chain strategies concerning the respective significant risk factors. This questionnaire was initially developed and sent to the supervisory team to ensure question precision and clarity of the questionnaire. A final draft was developed and distributed to the selected experts. This questionnaire is presented in the appendix section. Chapter 7 presents a complete description of the risk mitigation process.

3.5.2 Data analysis methods

Data analysis is an integral part of the research process since it aims to assess the data collected throughout the process to enable the researcher to conclude. Several methodologies and techniques are imperative for data analysis to ensure credible and reliable results based on the data retrieved (Yin, 2009). In research, it is crucial to develop precise and straightforward strategies that encompass the use of relevant analytical tools to achieve the purpose of any study. As earlier stated, this study adopts the mixed method research design. Therefore, the study initially utilises the fuzzy-AHP to analyse the feedback from the questionnaire developed for the risk assessment phase. Then, fuzzy-TOPSIS has been utilised to analyse the questionnaire survey from the risk mitigation phase.

3.5.2.1 Fuzzy Sets

Fuzzy set theory (FST) is a mathematical approach developed by Zadeh, (1965) to deal with uncertain, imprecise, vague, and ambiguous information retrieved from computational perception. The FST is developed on a fundamental concept of set. Based on the conventional set theory, an element of a crisp set can either belong to the set or not. This implies that an element can be either 1 or 0. However, the fuzzy set theory introduced a more relaxed condition for an element in a crisp set. A fuzzy set is defined by a membership function that maps elements to degrees of membership within a specific interval, usually [0, 1]. If the value assigned is zero, the element does not belong to the set (it has no membership). If the value assigned is one, the element belongs entirely to the set (it has total membership). Finally, if the value lies within the interval, the element has a certain degree of membership. Fuzzy set theory adopts fuzzy logic to mathematically point out uncertainty and vagueness linked with notional activities of human beings such as thinking and reasoning. The fuzzy logic encompasses flexible and robust attributes that can enable tools to overcome real-world problems with uncertain intrinsic parameters, which are approximate values rather than exact.

It is a beneficial way to convert linguistic terms into fuzzy numbers to tackle the ambiguities involved in linguistic estimation. Triangular and trapezoidal fuzzy numbers are usually adopted to deal with the vagueness of decisions related to the performance levels of choices concerning each criterion. When the most promising values of a trapezoidal fuzzy number are the same number, it becomes a triangular fuzzy number. This means that a triangular fuzzy number is a special case of a trapezoidal fuzzy number. Because of its intuitive appeal and computational efficiency, the triangular fuzzy number is the most widely used membership function for many applications. Triangular fuzzy numbers are usually employed to capture the vagueness of the parameters related to the decision-making process. Triangular fuzzy numbers are expressed with boundaries instead of crisp numbers to reflect the fuzziness surrounding the decision-makers when they conduct a pairwise comparison matrix. A character tilde "~" is placed above a symbol if the symbol represents a fuzzy set. A brief review of some essential definitions of fuzzy logic is presented below.

Definition 1. A fuzzy set $\tilde{A}$ is a subset of a universe of discourse X, which is a set of ordered pairs and is characterised by a membership function $U_{\tilde{A}}(x)$ representing a mapping $U_{\tilde{A}}: X \rightarrow [0, 1]$. The function value of $U_{\tilde{A}}(x)$ for the fuzzy set $\tilde{A}$ is called the membership value of x in $\tilde{A}$. It is assumed that $U_{\tilde{A}}(x) \in [0, 1]$, where $U_{\tilde{A}}(x) = 1$ reveals that x completely belongs to $\tilde{A}$, while $U_{\tilde{A}}(x) = 0$ indicates that x does not belong to the fuzzy setae $\tilde{A}$.

$$\tilde{A} = \{(X, U_{\tilde{A}}(x))\}, \quad x \in X \tag{3.1}$$

Where $U_{\tilde{A}}(x)$ is the membership function, and C = {x} represents a collection of elements x.

Definition 2. A fuzzy set $\tilde{A}$ of the universe of discourse X is convex if

$$U_{\tilde{A}}(\lambda X_1 + (1 - \lambda)X_2 \geq min(U_{\tilde{A}}(X_1), U_{\tilde{A}}(X_2))\ \forall x \in [X_1, X_2],\ where\ \lambda \in [0, 1] \tag{3.2}$$

Definition 3. A fuzzy set $\tilde{A}$ of the universe of discourse, X is normal if the max

$$\max U_{\tilde{A}}(x) = 1 \tag{3.3}$$

Definition 4. A fuzzy number $\widetilde{N}$ is a fuzzy subset in the universe of discourse X, which is both convex and normal.

Definition 5. The α-cut of the fuzzy set $\tilde{A}$ of the universe of discourse X is defined as

$$A_{\propto} = \{x \in X \mid U_{\tilde{A}}(x) \geq \alpha\} \text{ where } \alpha \in [0, 1] \tag{3.4}$$

Definition 6. It is a TFN if the membership function $U_{\tilde{A}}(x)$ of fuzzy set $\tilde{A} = (l, m, u)$ in-universe X is defined as follows, where l, m, u are real numbers and $l \leq m \leq u$.

$$\mu_{\tilde{N}}(x) = \begin{cases} 0 & (x < 1) \\ \frac{x-l}{m-l} & (l \leq x \leq m) \\ \frac{r-x}{r-m} & (m \leq x \leq u) \\ 0 & (x < u) \end{cases} \tag{3.5}$$

Definition 7. Alternatively, by defining the interval of confidence level α, the TFN can be characterized using the following equation.

$$\forall \alpha[0, 1]\ \tilde{M}_{\alpha} = [l^{\propto}, u^{\propto}] = [(m-l) \propto + l, -(u-m) \propto + u] \tag{3.6}$$

Definition 8. Suppose $a = (a_1, a_2, a_3)$ and $b = (b_1, b_2, b_3)$ are two TFNs, the distance between them is calculated as

$$d_v(\tilde{a}, \tilde{b}) = \sqrt{\frac{1}{3}[(a_1 - b_1)^2 + (a_2 - b_2)^2 + (a_3 + b_3)^2]} \tag{3.7}$$

3.5.2.2 Fuzzy Analytical Hierarchy Process

In many professional situations, experts are confronted with a set of alternatives that they need to choose from, for example, when selecting a supplier or technology and making this kind of decision is intuitive when considering a single attribute or criterion since these experts can select the attribute with the highest degree of relevance. When there are several criteria with varied degrees of importance, decision-making becomes complex and challenging for experts. Hence, formal methods are needed to ensure a structured means of decision-making. The Analytic Hierarchy Process (AHP), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and Data Envelopment Analysis are examples of formal decision-making methods.

The Analytic Hierarchy Process (AHP) is a general theory of measurement. It is used to derive ratio scales from both discreet and continuous paired comparisons. These comparisons may be taken from actual measurements or from a fundamental scale which reflects the relative strength of preferences and feelings. According to Vadiya and Kumar, (2006), the AHP has been a tool for decision makers and researchers since its inception. In addition, the AHP tool is suggested to be one of the most widely used multi-criteria decision-making tools. The AHP solves multi-criteria (or attribute) decision-making (MCDM) problems, particularly when involving qualitative assessment parameters. An MCDM problem could be solved analytically if all the parameters are well-defined and quantifiable. Unfortunately, many evaluation criteria are subjective and qualitative. This makes expressing preferences using exact numerical values complicated. Hence, decision-making becomes challenging (Chan and Kumar, 2007).

In contrast, AHP analyses an MCDM problem by setting up a hierarchy of criteria and sub-criteria, which could be either quantitative or qualitative. This can be done by introducing pair-wise comparisons between those criteria, assessed by professionals or experts in the corresponding area (Wang *et al.,* 2012). Although AHP is a celebrated method for MCDM problems, it cannot process uncertain variables, mainly when qualitative assessment is needed (Wang *et al.,* 2008). The pairwise comparison, the essence of AHP, introduces imprecision because it requires judgements of experts. In conventional AHP, the pairwise comparison is established using a nine-point scale, which converts the human preferences between available alternatives as equally, moderately, strongly, very strongly or highly preferred. Even though the discrete scale of AHP has the advantages of simplicity and ease of use, it is not sufficient to consider the uncertainty associated with mapping one's perception to a number.

In practical cases, experts might be unable to assign exact numerical values to their preferences due to limited information or capability (Chan and Kumar, 2007; Xu and Liao, 2013; Liu *et al.,* 2020). Decision-making in the real world is a multifaceted process due to uncertain vagueness and ambiguity in the environments. Ambiguity refers to the type of uncertainty in which the selection of multiple options among assets of alternatives is plausible. In other words, the meaning of ambiguous statements cannot be resolved using a procedure consisting of a finite number of steps. However, a concept may be considered vague if its extension is unclear or imprecise due to the uncertainty about the objects that belong to the concept or difficulty defining precise boundaries for some domains of interest. The significant difference between ambiguity and vagueness is that specific interpretations of vague concepts may interpret ambiguous concepts. Confronting these uncertainties requires the application of some distinct methods, such as fuzzy set theory.

Fuzzy set theory has proven advantages within vague, imprecise, and uncertain contexts, and it resembles human reasoning in its use of approximate information and uncertainty to generate decisions. It was specially designed to mathematically represent uncertainty and vagueness and provide formalised tools for dealing with the imprecision intrinsic to many decision problems. Fuzzy AHP extends the traditional AHP through its combination with fuzzy set theory to solve hierarchical fuzzy problems. Although the fuzzy AHP method requires tedious computations, it offers several benefits, including its ease of understanding, capturing uncertain, imprecise judgements of experts by handling linguistic variables, and effectively handling qualitative and quantitative data in multi-attribute decision-making problems. The fuzzy AHP approach used in this research is composed of the steps of Chen *et al.*, (2015) and given as follows.

- Developing the hierarchical structure of the decision problem.

The hierarchical structure is developed by combining all the factors and sub-factors specific to the research problem. The hierarchical structure is obtained based on the validated risk categories, sub-categories, risk types and risk factors.

- Establishing a group of decision-makers.

A committee of decision-makers is formed. To obtain an objective decision, the background of decision-makers should be considered. Decision-makers are experts who have experience with the research topic. Each committee member is required to provide judgements based on personal knowledge and expertise. The decision-makers must determine the relative weights of the risk categories, sub-categories, risk types and risk factors.

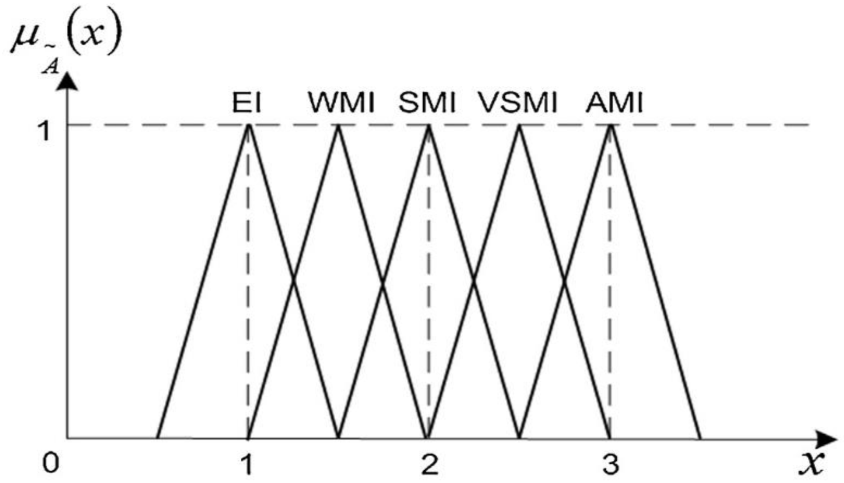

Figure 3.4 Linguistic scale for relative importance

- Determining the Linguistic variables and fuzzy conversion scale.

The decision-makers compare the importance or preference between each pair of factors. Consider a problem at a level with n elements. Each set of pairwise comparisons for a level requires n(n-1)/2 judgements, which are further used to construct a positive fuzzy reciprocal comparison matrix. The comparison of one factor over another can be done with the help of questionnaires, which are in the form of linguistic variables. A linguistic variable is a variable whose values are words or sentences in a natural or artificial language. In this research, triangular fuzzy numbers are used to represent subjective pairwise comparisons of decision-makers, namely, “equal importance”, “weak importance”, “strong importance”, “very strong importance”, and “absolute strong importance”. The triangular fuzzy conversion scales and linguistic scales proposed by Patil and Kant (2014) are used to convert such linguistic values into fuzzy scales, as demonstrated in Figure 3.4 and Table 3.4.

Table 3.4 Linguistic variables and Fuzzy scales for importance

Linguistic scale for importance	**Triangular fuzzy scale**	**Triangular fuzzy reciprocal scale**
Equal Importance (Eq)	(1, 1, 3)	(1/3, 1, 1)
Weak Importance (Wk)	(1, 3, 5)	(1/5, 1/3, 1)
Strong Importance (ST)	(3, 5, 7)	(1/7, 1/5, 1/3)
Very strong Importance (Vs)	(5, 7, 9)	(1/9, 1/7, 1/5)
Absolute strong Importance (As)	(7, 9, 11)	(1/11, 1/9, 1/7)

- Establishing comparison matrices.

Consider a problem at one level with n factors, where the relative importance of factor $i \; to \; j$ is represented by triangular fuzzy numbers $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$. One decision-maker considers factor i is strongly more important as compared with factor j; he/she may set $\tilde{a}_{ij} = (1, 3, 5)$. If factor j is thought to be strongly more important than factor $i,$ the pairwise comparison between $i \; and \; j$ could be presented by $\tilde{a}_{ij} = (1/5, 1/3, 1)$. As in the traditional AHP, the comparison matrix $\tilde{A} = \{\tilde{a}_{ij}\}$ can be constructed as:

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \dots & \tilde{a}_{2n} \\ \dots & \dots & \dots & \dots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \dots & 1 \end{bmatrix} = \begin{bmatrix} 1 & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ {}^{1}/_{\tilde{a}_{12}} & 1 & \dots & \tilde{a}_{2n} \\ \dots & \dots & \dots & \dots \\ {}^{1}/_{\tilde{a}_{1n}} & {}^{1}/_{\tilde{a}_{2n}} & \dots & 1 \end{bmatrix} \tag{3.8}$$

- Calculating the consistency index and consistency ratio of the comparison matrix.

To ensure a certain quality level of a decision, the consistency of an evaluation must be analysed. Saaty, (1980) proposed an index to measure consistency. This index can indicate the consistency of the pairwise comparison matrices. To investigate their consistency, the fuzzy comparison matrices need to be converted into crisp matrices (Chen, 2011). Several defuzzification methods exist (Chang, 1996; Chen *et al.,* 2015) for obtaining a crisp number from the triangular fuzzy number. This thesis adopts the method proposed by Chang *et al.,* (2009) is utilised to defuzzify the fuzzy numbers. This method can clearly express fuzzy perception. Owing to the display of preference (α) and risk tolerance (λ), the decision-makers can understand the uncertainties they face under different circumstances. A triangular fuzzy number denoted as $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ can be defuzzified to a crisp number as follows.

$$(a_{ij}^{\alpha})^{\lambda} = [\lambda . l_{ij}^{\alpha} + (1 - \lambda) u_{ij}^{\alpha}], \qquad 0 \le \lambda \le 1, \quad 0 \le \alpha \le 1, \tag{3.9}$$

where $l_{ij}^{\alpha} = (m_{ij} - l_{ij}) \times \alpha + l_{ij}$, denotes the left-end value of α-cut for $a_{ij}, u_{ij}^{\alpha} = u_{ij} - (u_{ij} - m_{ij}) \times \alpha$ denotes the right-end value of α-cut for a_{ij}. Remarkably, α can be considered a stable or fluctuating condition and is any value from 0 to 1. The decision-making environment stabilizes when increasing α. The degree of uncertainty is the highest when $\alpha = 0$. Additionally, λ can be considered as the degree of a decision-maker's optimism; its range is between 0 and 1. When λ is 0, the decision-maker is highly optimistic. Conversely, when λ is 1, the decision- maker is pessimistic.

After all the elements in the comparison matrix are converted from triangular fuzzy numbers to crisp numbers, the comparison matrix is now expressed as follows:

$$[(A^{\alpha})^{\lambda}] = \left[(a_{ij})^{\lambda}\right] = \begin{bmatrix} 1 & (a_{12}^{\alpha})^{\lambda} & \dots & (a_{1n}^{\alpha})^{\lambda} \\ (a_{21}^{\alpha})^{\lambda} & 1 & \dots & (a_{2n}^{\alpha})^{\lambda} \\ \dots & \dots & \dots & \dots \\ (a_{n1}^{\alpha})^{\lambda} & (a_{n2}^{\alpha})^{\lambda} & \dots & 1 \end{bmatrix} \tag{3.10}$$

A comparison matrix's consistency index (CI) can be computed using the following equation.

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{3.11}$$

Where λ_{max} is the largest eigenvalue of the comparison matrix, and n is the dimension of the matrix. The consistency ratio (CR) is the ratio between the consistency of a given evaluation matrix and the consistency of a random matrix Saaty, (1980).

$$CR = \frac{CI}{RI(n)}, \tag{3.12}$$

RI(n) is a random index that depends on the matrix's size, as shown in Table 3.5. If a comparison matrix's CR is equal to or less than 0.1, it can be acceptable; when the CR is unacceptable, the decision-makers are encouraged to repeat the pairwise comparisons. The online software package completes this step to calculate the eigenvalues of all comparison matrices.

Table 3.5 The random consistency index (RI)

Size (n)	1	2	3	4	5	6	7	8
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40

Source: Patil and Kant, (2014)

- Constructing the representative matrix of all decision-makers.

Each judgement matrix represents the opinion of one decision-maker. Aggregation is necessary to achieve a group consensus of decision-makers. In conventional AHP, there are two basic approaches for aggregating individual preferences into a group preference, namely aggregation of individual judgements (AIJ) and aggregation of individual priorities (AIP) (Chen *et al.,* 2015). The concepts and ideas employed in the conventional AHP can also be used in the fuzzy AHP. In the AIJ approach, the group judgements matrix is obtained from the individual judgement matrices. This means that the group judgement matrix is considered the judgement matrix of a "new individual", and the priorities of these individual judgement matrices are derived as a group solution. However, in the AIP approach, the group members act individually. Specifically, from the individual judgement matrices, individual priorities are initially derived and then from these, the group priorities. AIJ is often performed using geometric mean operations, whereas AIP typically uses arithmetic mean operations. Geometric mean operations are commonly used within the application of the AHP for aggregating group decisions, and only the geometric mean satisfies the Pareto principle (unanimity condition) and homogeneity condition. Therefore, the AIJ approach is utilised in this thesis to aggregate group decisions.

Consider a group of k decision-makers involved in the decision-making process: pairwise comparison of n elements is made. As a result of the pairwise comparisons, a set of $K\ matrices, \tilde{A}_k = \{\tilde{a}_{ijk}\}, where\ \tilde{a}_{ijk} = (l_{ijk}, m_{ijk}, u_{ijk})$ represents the relative importance of element $i\ to\ j$, as assessed by the expert k. The triangular fuzzy numbers in the group judgement matrix can be obtained by using the following equation [24]:

$$l_{ij} = \min_{k=1,2,\dots,K}(l_{ijk})$$

$$m_{ij} = \sqrt[K]{\prod_{k=1}^{K} m_{ijk}} \qquad (3.13)$$

$$u_{ij} = \max_{k=1,2,\dots,K}(u_{ijk})$$

- Calculating the priority weight of risk factors.

There are several methods for calculating priority weights with fuzzy-AHP. These methods are systematic approaches to an alternative selection and justification problem using fuzzy set theory (Zadeh, 1965) and hierarchical structure analysis. Decision-makers usually find that it is more confident to give interval judgements than fixed value judgements. This is because decision-makers are in-capable of being explicit when giving preference to a criterion due to the fuzzy nature of the comparison process. Table 3.6 compares the various fuzzy AHP methods in the literature, which have important differences in theoretical structures. This thesis utilises the Chang, (1996) extent analysis method. This method has been widely used in different applications, such as evaluating lecturers' teaching performance (Chen *et al.,* 2015) and supplier selection problems (Lima Junior *et al.*, 2014). Extent analysis utilises linguistic variables to express computation complexity made by different decision-makers. Moreover, the steps of this approach are relatively easier than the other fuzzy AHP approaches and similar to the conventional AHP.

If the object set is denoted by $P = \{p_1, p_2, \ldots, p_n\}$ and the objective set is denoted by $Q = \{q_1, q_2, \ldots, q_m\}$, then according to the concept of extent analysis for each objective O_i is performed, respectively. Therefore, the m extent analysis values for each object are obtained with the following signs:

$N_{oi}^1, N_{oi}^2, \ldots, N_{oi}^m,\ \ where\ i = 1, 2, \ldots, n, where\ all\ the\ N_{oi}^j\ (j = 1, 2, \ldots, m)$ are triangular fuzzy numbers.

The steps of the Chang’s extent analysis method can be as follows.

Step 1. The value of fuzzy synthetic extent concerning the ith object is defined as

$$F_i = \sum_{j=1}^{m} N_{oi}^j \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m} N_{oi}^j\right]^{-1} \tag{3.14}$$

The value of $\sum_{j=1}^{m} N_{oi}^j$ can be found by performing the fuzzy addition operation of m extent analysis values from a particular matrix such that

$$\sum_{j=i}^{m} N_{oi}^j = \left(\sum_{j=1}^{m} n_{1j}, \sum_{j=1}^{m} n_{2j}, \sum_{j=1}^{m} n_{3j}\right) \tag{3.15}$$

and the value of $\left[\sum_{i=1}^{n}\sum_{j=1}^{m} N_{oi}^{j}\right]$ can be obtained by performing the fuzzy addition operation of $N_{oi}^{j}(j = 1, 2, \ldots, m)$ such that

$$\sum_{i=1}^{n}\sum_{j=1}^{m} N_{oi}^{j} = \left(\sum_{i=1}^{n} n_{1j}, \sum_{i=1}^{n} n_{2j}, \sum_{i=1}^{n} n_{3j}\right) \tag{3.16}$$

and $\left[\sum_{i=1}^{n}\sum_{j=1}^{m} N_{oi}^{j}\right]^{-1}$ can be calculated by the inverse of Eq. (10) as follows:

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} N_{oi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} n_{3j}}, \frac{1}{\sum_{i=1}^{n} n_{2j}}, \frac{1}{\sum_{i=1}^{n} n_{1j}}\right) \tag{3.17}$$

Table 3.6 The comparison of different fuzzy AHP methods

Sources	The main characteristics of the method	Advantages (A) and disadvantages (D)
Van Laarhoven and Pedrycz (1983)	- Direct extension of Saaty's AHP method with triangular fuzzy numbers - Lootsma's logarithmic least square method is used to derive fuzzy weights and fuzzy performance scores	(A) The opinions of multiple decision-makers can be modelled in the reciprocal matrix. (D) There is not always a solution to the linear equations
Buckley (1985)	- Extension of Saaty's AHP method with trapezoidal fuzzy numbers. - Uses the geometric mean method to derive fuzzy weights and performance scores.	(A) It is easy to extend to the fuzzy case. (A) It guarantees a unique solution to the reciprocal comparison matrix. (D) The computational requirement is tremendous.
Bonder *et al.*, (1989)	- Modifies van Laarhoven and Pedrycz's method. - Presents a more robust approach to the normalization of local priorities	(A) The opinions of multiple decision-makers can be modelled. (D)The computational requirement is tremendous.
Chang (1996)	- Synthetical degree values - Layer simple sequencing - Composite total sequencing	(A) The computational requirement is relatively low. (A) It follows the steps of crisp AHP. It does not involve additional operations. (D) It allows only triangular fuzzy numbers to be used.
Cheng (1996)	- Builds fuzzy standards. - Represents performance scores by membership functions. - Uses entropy concepts to calculate aggregate weights	(A) The computational requirement is relatively low. (D) Entropy is used when probability distribution is known. The method is based on both probability and possibility measures.

Source: (Büyüközkan, Kahraman and Ruan, 2004)

Step 2. the degree of possibility of $N_1 = (n_{11}, n_{12}, n_{13}) \geq N_2 = (n_{21}, n_{22}, n_{23})$ is defined as

$$V(M_2 \geq M_1) = \sup_{y \geq x}[min(\mu_{M_1}(x), \mu_{M_2}(y)] \quad (3.18)$$

When a pair (x, y) exists such that $y \geq x$ and $\mu_{M_1}(x) = \mu_{M_2}(y)$, then we have $V(M_2 \geq M_1) = 1$. Since $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$ are convex fuzzy numbers, we have that

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M_1}(d) = \begin{cases} 1, & if\ m_2 \geq m_1 \\ 0, & if\ l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & otherwise, \end{cases} \quad (3.19)$$

Where d is the ordinate of the highest intersection point D between μ_{M_1} and μ_{M_2} (see Fig. X). To compare M_1 and M_2, we need both the values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$.

Step 3. The degree possibility for a convex fuzzy number to be greater than k convex fuzzy numbers $M_i (i = 1, 2, \ldots, k)$ *can be defined by*

$$V(M \geq M_1, M_2, \ldots, M_k = V[(M \geq M_1)\ and\ (M \geq M_2)\ and \ldots and\ (M \geq M_k)]$$
$$= \min V(M \geq M_i), \quad i = 1, 2, 3, \ldots, k. \quad (3.20)$$

Assume that,

$$d'(A_i) = minV(S_i \geq S_k). \quad (3.21)$$

For $k = 1, 2, \ldots, n;\ k \neq i$. Then, the weight vector is given by

$$W' = (d'(A_1), d'(A_2'), \ldots, d'(A_n))^T \quad (3.22)$$

Where $A_i (i = 1, 2, \ldots, n)$ *are n elements*.

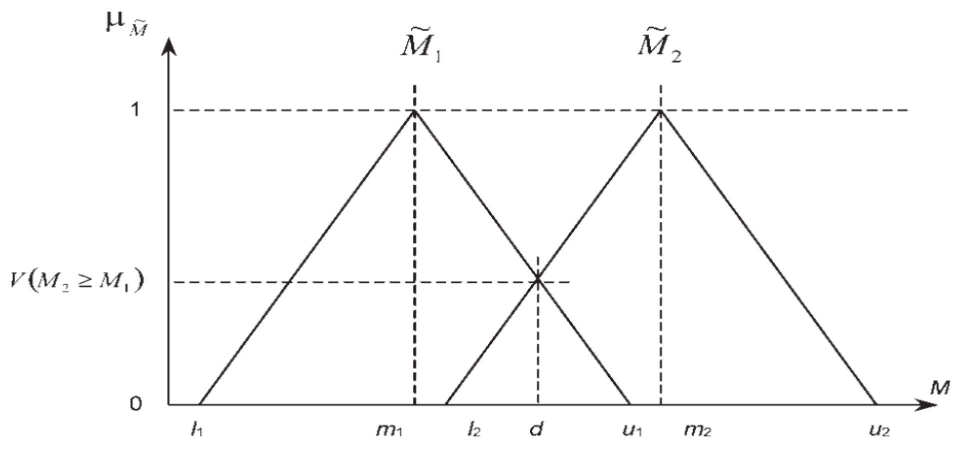

Figure 3.5 The intersection between $\widetilde{M}_1$ *and* $\widetilde{M}_2$

Step 4. Via normalisation, the normalised weight vectors are

$$W = (d(A_1), d(A_2), \ldots, d(A_n))^T, \tag{3.23}$$

Where W is not a fuzzy number.

3.5.2.3 Fuzzy TOPSIS

Hwang and Yoon are credited with developing TOPSIS, a classic multi-criteria decision-making process (1981). The theory behind it is that the best option is the one that is furthest from the negative ideal solution (NIS) and closest to the positive ideal solution (PIS) (Patil and Kant, 2014; Venkatesh *et al.*, 2019). The PIS strives to achieve the reverse of what the NIS does: maximise the benefit criteria while minimising the cost criteria (Venkatesh *et al.*, 2019). Crisp values indicate subjective opinions in the classic TOPSIS technique. However, it is only sometimes possible to make precise measurements in practice. Besides, the prevalence of researcher bias has criticised TOPSIS's applicability (Afshar *et al.*, 2011; Aydogan, 2011). Therefore, fuzzy theory can be incorporated into TOPSIS, which not only aids in evaluating human inputs about values but also facilitates the investigation of criteria problems in ambiguous circumstances (Kuo *et al.*, 2007; Sun, 2010; Choudhary and Shankar, 2012; Sindhu *et al.*, 2017). Relying on linguistic value rather than crisp value is the way to go. Several studies have incorporated fuzzy TOPSIS. Venkatesh *et al.*, (2019) proposed a fuzzy AHP-TOPSIS model for supply partner selection in continuous aid humanitarian supply chains. Kabra and Ramesh, (2015) developed a fuzzy AHP-TOPSIS model to explore the barriers to coordination in humanitarian supply chains. Nazam *et al.*, (2015) formulated the fuzzy AHP-TOPSIS framework to calculate the weight of each risk criterion and rank the risks associated with implementing green supply chain management practices in a fuzzy environment. This was done to rank the risks associated with green supply chain management practices. When it comes to understanding how important it is to carry out the appropriate risk assessment when putting green supply chain initiatives into action, the researchers and practitioners can benefit from the models that have been proposed.

The procedures for building the Fuzzy-TOPSIS analysis are described below (Patil and Kant, 2014),

STEP 1: *Choose the linguistic rating values for the alternative with respect to the criteria.*

Let us assume there are m possible alternatives called $A = \{A_1, A_2, \ldots, A_m\}$ which are to be evaluated against the criteria, $C = \{C_1, C_2, \ldots, C_n\}$. The criteria weights are denoted by w_j $j =$

$\{1, 2, \ldots, n\}$. The performance rating of each expert $D_k(k = 1,2, \ldots, K)$ for each alternative A_i $(i = 1,2, \ldots, m)$ with respect to the criteria $C_j(j = 1,2, \ldots, n)$ are denoted by $\tilde{R}_k = \tilde{X}_{ijk}(i = 1,2, \ldots, m; j = 1,2, \ldots, n; k = 1,2, \ldots, K)$ membership function $\mu\tilde{R}k(x)$. This study will use the scale presented in Table 3.7.

Table 3.7 Linguistic scales for alternatives ratings

Linguistic variables	Triangular fuzzy number
Very Poor	(1,1,3)
Poor	(1,3,5)
Moderate	(3,5,7)
Good	(5,7,9)
Very Good	(7,9,11)

Source: Patil and Kant, (2014)

STEP 2: *Calculate the aggregate fuzzy rating for all alternatives.*

If the fuzzy ratings for all experts are described as TFN, $\tilde{R}_k = (ak, bk, ck), k = 1,2, \ldots, K$ were,

$$a = \min_k\{ak\}, \quad b = \frac{1}{K}\sum_{k-1}^{k} b_k, \quad c = \max_k\{c_k\} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \quad (3.24)$$

If the fuzzy rating of the kth decision maker is $\tilde{X}_{ijk} = \left(a_{ijk}, b_{ijk}, c_{ijk}\right), i = 1,2, \ldots, m, j = 1,2, \ldots n$ then the aggregated fuzzy ratings $\tilde{X}_{ij}$ of alternatives with respect to each criterion are given by $\tilde{X}_{ij} = \left(a_{ij}, b_{ij}, c_{ij}\right)$, where

$$a_{ij} = \min_k\{a_{ijk}\}, b = \frac{1}{K}\sum_{k-1}^{k} b_{ijk}, \quad c = \max_k\{c_{ijk}\} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \quad (3.25)$$

STEP 3: *Construct the fuzzy decision matrix.*

The fuzzy decision matrix for the alternatives $(\widetilde{D})$ is constructed as follows:

$C_1 C_2 C_n$

$$(\widetilde{D}) = \begin{matrix} A_1 \\ A_2 \\ \cdots \\ \cdots \\ A_3 \end{matrix} \begin{bmatrix} \tilde{X}_{11} & \tilde{X}_{12} & \cdots & \cdots & \tilde{X}_{1n} \\ \tilde{X}_{21} & \tilde{X}_{22} & \cdots & \cdots & \tilde{X}_{2n} \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ \tilde{X}_{m1} & \tilde{X}_{m2} & \cdots & \cdots & \tilde{X}_{mn} \end{bmatrix} i = 1, 2, \ldots, m: j = 1,2, \ldots, n \ldots \ldots \ldots \ldots \ldots \ldots \quad (3.26)$$

STEP 4: *Construct the normalised fuzzy decision matrix.*

The raw data are normalised using linear scale transformation to bring the various criteria scales into a comparable scale. The normalised fuzzy decision matrix $\tilde{R}$ is given by:

$$\tilde{R} = [r_{ij}]_{m\times n}, i = 1,2, \ldots . m; j = 1,2, \ldots, n, \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . \quad (3.27)$$

Where,

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right) \text{ and } c_j^* = \max_i\{c_{ij}\} \ (benefit\ criteria) \ldots \ldots \ldots \ldots . . \quad (3.28)$$

$$\tilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right) \text{ and } a_j^- = \min_i\{a_{ij}\} \ (cost\ criteria) \ldots \ldots \ldots \ldots . . \quad (3.29)$$

STEP 5: *Construct the weighted normalised matrix.*

The weighted normalised matrix $\tilde{v}$ for criteria is computed by multiplying the weights (w_j) of evaluation criteria with the normalised fuzzy decision matrix $\tilde{r}_{ij}$.

$$\tilde{V} = [\tilde{v}_{ij}]_{m\times n}, \quad i = 1,2, \ldots m; j = 1,2, \ldots, n \text{ where } \tilde{v}_{ij} = \tilde{r}_{ij}(.)W_j \ldots \ldots . . \quad (3.30)$$

Note that $[\tilde{v}_{ij}]_{m\times n}$ is a TFN represented by $(a_{ijk}, b_{ijk}, c_{ijk})$.

STEP 6: *Determine the fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS).*

The FPIS and FNIS of the alternatives is computed as follows:

$$A^* = (\tilde{v}_1^*, \tilde{v}_2^*, \ldots, \tilde{v}_n^*) \text{ where } \tilde{v}_j^* = (\tilde{c}_j^*, \tilde{c}_j^*, \tilde{c}_j^*) \text{ and } \tilde{c}_j^* = \max_i\{\tilde{c}_{ij}\} \ldots \ldots \ldots \ldots . \quad (3.31)$$

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \ldots, \tilde{v}_n^-) \text{ where } \tilde{v}_j^- = (\tilde{a}_j^-, \tilde{a}_j^-, \tilde{a}_j^-) \text{ and } \tilde{a}_j^- = \min_i\{\tilde{a}_{ij}\} \ldots \ldots \ldots \ldots \ldots \quad (3.32)$$

$i = 1,2, \ldots, m; j = 1,2, \ldots, n$

STEP 7: *Calculate the distance of each alternative from FPIS and FNIS.*

The distance (d_1^+, d_1^-) of each weighted alternative $i = 1,2, \ldots m$ from the FPIS and FNIS is computed as follows.

$$d_1^+ = \sum_{j-1}^{n} dv\left(\tilde{v}_{ij}, \tilde{v}_j^*\right), \qquad i = 1,2,\dots,m \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (3.33)$$

$$d_1^- = \sum_{j-1}^{n} dv\left(\tilde{v}_{ij}, \tilde{v}_j^-\right), \qquad i = 1,2,\dots,m \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (3.34)$$

STEP 8: *Calculate the closeness coefficient (CC_i) of each alternative.*

The closeness coefficient CC_i represents the distances to the fuzzy positive ideal solution (A^*) and the fuzzy negative ideal solution (A^-) simultaneously. The closeness coefficient of each alternative is calculated as follows:

$$CC_i = \frac{d_1^-}{d_1^- + d_1^+} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. \quad (3.35)$$

STEP 9: *Rank the alternatives.*

In this step, the different alternatives are ranked according to the closeness coefficient (CC_i) in decreasing order.

3.6 Conclusion

This chapter detailed the research philosophy, approach, design, data collection, and analysis methods. Systematically discussing each layer of the research onion provides a comprehensive understanding and insights into the choice of final research methodology. As explained and justified, the nature of this research question and aims allows for a mixed-method design and an abductive research approach. These choices reflect decisions made concerning the methods of data collection and analysis that are appropriate to fulfil the aims and objectives of this study. Table 3.8 summarises key elements and final position of this study’s research methodology. Moreover, the final research methodology tries to fill the research gap pointed out by Kunz and Reiner, (2012), who underlined the need for conducting relevant and appropriate research in the discipline that involved the collection of data with the use of appropriate empirical methodologies such as survey, since it helps to understand the reality of the disaster/emergency relief context.

Table 3.8 Summary of Research Methodology

Key Elements	**Final Position**
Research Philosophy	Pragmatism
Research Approach	Abductive Reasoning
Methodological Choice	Mixed-Methods
Research Purpose	Sequential Exploratory
Research Strategy	Survey
Time-Horizon	Cross-Sectional Studies
Data Collection	Questionnaires; Semi-structured Interviews
Data Analysis	Fuzzy-AHP; Fuzzy TOPSIS

CHAPTER 4 EMERGENCY SUPPLY CHAIN RISK MANAGEMENT FRAMEWORK

4.1 Introduction

The purpose of this chapter is to address the lack of attention given to risk management in emergency supply chains. Chapter 2 reveals the research gaps that exist in the field of supply chain risk management and emergency supply chains. A conceptual framework is developed to address this gap. A framework is a set of basic theoretical standards and practical guidelines that describe what the organisation does, what it is attempting to do, how it will do it and ensure that every step is done in the right structures. A novel integrated conceptual framework is developed based on emergency supply chains and risk management. The framework provides a systematic approach with step-by-step guidance to identify, assess and mitigate risks in the emergency supply chain to reduce operational disruption and save lives.

4.2 Conceptual Framework for Risk Management in Emergency Supply Chain

4.2.1 The research context of the emergency supply chain

The aftermath of the 2004 Indian Ocean tsunami, characterized by outcries of logistical failures, marked a turning point in the logistics and supply chain activities in the disaster relief context (Kovacs and Spens, 2011). Since then, academics and industrial practitioners have been paying more attention to the discipline, and more research has been done to tackle strategic issues. Tatham *et al.*, (2009) suggest that this discipline has a growing community that continues to collaborate with stakeholders and decision-makers. Moreover, the discipline now covers several conference tracks, special editions of journals, and an independent journal. Day *et al.*, (2012) highlighted five arguments for conducting more research in the emergency supply chain context:

1. Current approaches are not sufficient, and there is room for further improvement.
2. Human suffering and the economic impact of disasters continue to grow.
3. Disaster relief operations involve the participation of several stakeholders, including governments, non-governmental organizations (NGOs), commercial organizations, and private organizations.
4. Provision of diverse research opportunities that can be beneficial to their commercial counterparts.
5. The field exposes researchers to other outcomes beyond cost.

These factors provide a broad perspective of the emergency supply chain, demonstrating that it is not an isolated field of study but one that combines philanthropic and academic interests in operations improvement. These factors are the foundation for a research agenda reflecting the emergency supply chain and its commercial counterpart while incorporating expertise from other research fields (Day *et al.,* 2012). Nevertheless, the quality and quantity of emergency supply chain research has been limited. Numerous studies are conceptual, and there is a dearth of relevant and rigorous empirical studies (Kovacs, 2012). The emergency supply chain context requires the development of novel analytical models and other research approaches to tackle real-life empirical situations. The operating environment of the emergency supply chain is complicated and challenging, and several studies in the field neglect these factors (Day *et al.,* 2012). Apte, (2009) emphasizes that researchers should consider the complex nature of the emergency supply chain since its activities are often conducted in highly volatile environments. Therefore, there is a burden for researchers to present solutions that can be adopted generally (Chandes and Pache, 2010; Kunz and Reiner, 2012), irrespective of the distinct nature of every disaster.

Accordingly, there is a need to improve research in the field (Overstreet *et al.,* 2011; Kovacs, 2012). Several studies have suggested that limited research links theory to practice (Altay and Green, 2006; Kunz and Reiner, 2012; Leiras *et al.,* 2014; Kunz *et al.,* 2017). Bringing both the private and academic sectors together can improve the research outputs, and such connections will be of great value since there are extensive potential impacts in practice (Leiras *et al.,* 2014). The absence of relevant research in a field can lead to the disinterest of practitioners in academic outputs (Corbett and Van Wassenhove, 1993). Besides, it is challenging to assess research findings in the field. To curb this challenge, the Journal of Humanitarian Logistics and Supply Chain Management makes its content freely available to the public for six months after publication.

Numerous scholars have described the field as critical, considering emergency supply chain performance's financial and moral consequences (Jabbour *et al.,* 2017; Banomyong *et al.,* 2019; Anaya-Arenas *et al.,* 2014). However, recent studies published in the field have not made a relative impact on practice, i.e., practical implementation in emergency relief organisations (Charles *et al.,* 2010; Kunz *et al.,* 2015; Jahre *et al.,* 2016; Kunz *et al.,* 2017). Impactful research is interesting as well as important (Cachon, 2012). Tatham *et al.,* (2013) describe the field as a body of knowledge that is still emerging since findings from several literature reviews suggest that the research in the discipline is still inadequate. For example, Behl and Dutta,

(2019) discussed that research has covered numerous aspects of emergency supply chain management. However, there exists a diverse scope of already mentioned literature gaps that researchers still ignore. The growing interest in emergency supply chains among researchers is informed by the potential of this research field to positively impact the lives of vulnerable populations through the development and implementation of adapted systems (Kunz *et al.,* 2017). As such, Tatham *et al.,* (2009) highlight some contributions the academic community can make to the emergency supply chain in practice, including the provision of objective evidence for improved operational performance, development of methodologies and concepts for process improvement in the field, transfer knowledge and best practices from commercial supply chain management, provide education and training for professionals to ensure high standards and inform stakeholders and decision-makers of the relevance of improved operational performance. These contributions reflect a holistic and strategic perception of the emergency supply chain. Understanding only a restricted field domain can be very dangerous for a researcher.

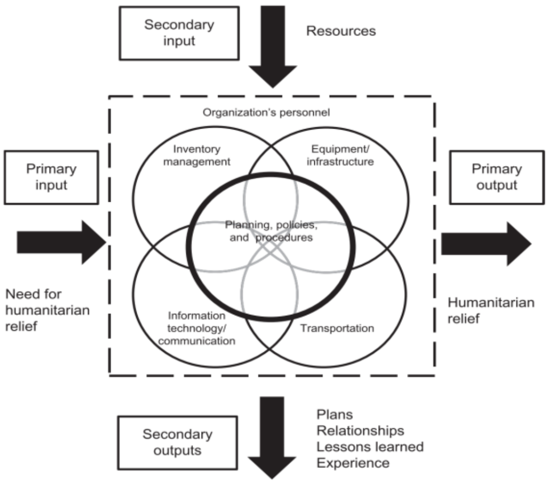

Figure 4. 1 Emergency logistics research framework

Source: (Overstreet et al., 2011)

Carroll and Neu (2009) underline that research in the field is increasing but lacks coordination and coherence due to a lack of a key theoretical framework. The need for more practical and impactful results and the presence of many disciplines in the field have resulted in insignificant theories, as pointed out by Richey (2009). In order to address this issue, Overstreet *et al.,* (2011) proposed a research framework aimed at identifying and classifying the state of the field and providing a path to direct further research. This framework can bolster the relevance and rigour of emergency supply chain research, covering various components of emergency logistics and supply chain and integrating academic research and practitioners' needs.

4.2.2 Theory development in emergency supply chains

Emergency supply chain activities operate in highly complex environments, requiring theories since they help us "to make sense of the complex environment in which we live and work" (Chicksand *et al.,* 2012). Nevertheless, studies argue that the theoretical base in the field is necessary for its maturity (Jahre *et al.,* 2009). When conducting emergency supply chain research, researchers aim to generate information about how the field can help communities become more resilient and responsive to disasters. Arlbjørn and Halldórsson, (2002) argue that knowledge creation depends on both the development of model theories and the application and modification of those existing. Several theoretical and methodological initiatives have ensured knowledge in supply chain management, such as abductive reasoning (Kovacs and Spens, 2005), an overview of research approaches (Spens and Kovacs, 2006), theory building (Kovacs and Spens, 2007b; Randall and Mello, 2012), research schools (Gammelgaard, 2004), and logistics and supply chain management theories (Defee *et al.,* 2010; Chicksand *et al.,* 2012; Kembro *et al.,* 2014). These initiatives can be adopted to develop conceptual frameworks in emergency supply chains (Overstreet *et al.,* 2011). Considering the complexities and unique features of the discipline, the academic community can assist in the careful selection, evaluation, adaptation (if necessary) and application of critical theories from commercial supply chain management (Tatham *et al.,* 2009). Several important theories exist in supply chain management and other related disciplines. However, stakeholders must remember the contextual characteristics of emergency supply chains when adapting and utilizing these theories, especially since the main objective of emergency supply chains is to save lives (Jahre *et al.,* 2009).

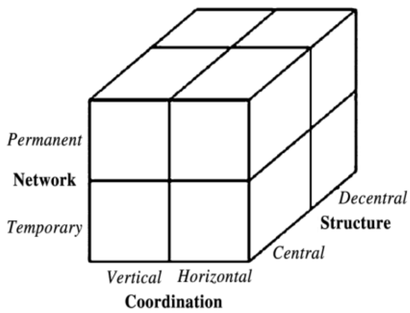

Figure 4.2 Three dimensions as a basis for theoretical development

Source: Jahre *et al.,* (2009)

Accordingly, highlighting the need for a theoretical base and considering the distinctiveness of the operating environments of emergency supply chains, Jahre *et al.,* (2009) proposed three dimensions (see Fig. 4.3) that researchers can utilize as a starting point for theory development: permanent networks developed in the preparedness phase and temporary networks created in response to specific disasters; vertical coordination when supply chains extend into unknown areas and horizontal coordination between stakeholders and decision-makers in distinct operations; and centralized structures at a central geographical location and de-centralized structures at decentralized locations to improve the immediate response operations. Moreover, these dimensions can help define theories from commercial supply chain management and other research areas that can be applied to emergency supply chain management, although theories focused on postponement and speculation strategies are more significant for the field.

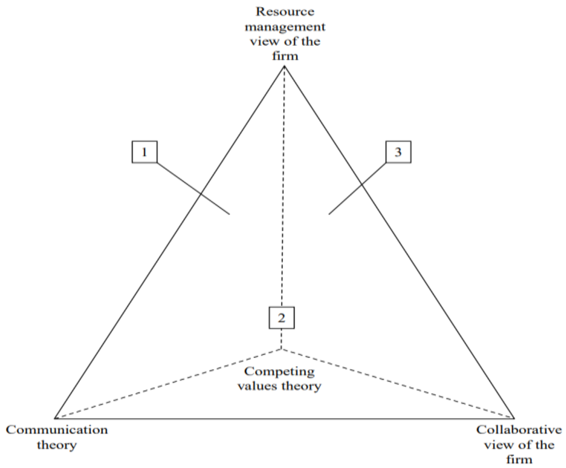

Figure 4.3 The supply chain disaster and crisis pyramid

Source: Richey (2009)

Richey, (2009) proposed the supply chain disaster and crisis pyramid, which covers three essential elements: collaboration, communication, and contingency. These elements were discussed from the perspectives of relationship management theory (collaboration), communication theory (communication), and competing values theory (contingency). The top of the pyramid was theoretically described best by the resource-based view. Part 1 of the pyramid reflects organizations seeking resources for their needs, with communication lines disrupted. Part 2 links collaboration and communication to resources which could be provided by parts 1 and 2. Part 3 seeks to provide an optimal resource allocation through balancing cooperation and competition. While this pyramid is not meant to be the only source of discussion on viable theories for emergency logistics and supply chain management, it is the initial step that may encourage other scholars to create models tailored to their research question.

4.2.3 Development of the conceptual framework

Supply chain risk management aims to mitigate unanticipated and anticipated risks, such as delays. Unexpected, unpredictable, and infrequent interruptions, such as natural disasters, disease outbreaks, and financial crises, are abnormal risks. Emergency supply chains (ESCs) are created rapidly in response to large-scale disasters to deliver critical supplies quickly, safeguard people and infrastructures, and restore livelihoods. For the ESCs to perform effectively, the community characteristics, disaster types, uncertainty and complexity must all be considered by relief organisations at a strategic level. Risk events must be identified and their likelihood and impact assessed to put preventative, corrective, or mitigation measures in place (Atkinson, 2006). Thus, a flexible supply chain must be created with the capacity to respond to unforeseeable occurrences and utilize whatever is necessary to achieve a desirable output (Scholten *et al.*, 2010). The associated performance targets (e.g., lead time, quality, cost) can be attained through strategic coordination, integration and management, ensuring lives are saved in special and complex emergency supply chain conditions (Gattorna, 2006, 2009; Kleindorfer and Saad, 2005). Risks are process disturbances that constrain the optimal performance of a system. A clear understanding of risk mandates understanding a larger system since no system performs smoothly during a disrupted process (Buddas, 2014). Mitigating risk may involve its elimination or acknowledgement (Johnston and Clark, 2005). Effective management of risk has become the principal interest of relevant actors and decision-makers in emergency relief operations for survival and to efficiently thrive in the uncertain and dynamic environments disasters present.

Consequently, risk management has emerged as a natural extension of emergency supply chain management with the primary objective of identifying the potential risk sources and proferring suitable action strategies to mitigate the risk. Given the intrinsic complexity of supply chain risk and the wide range of supply chain methods, case studies and conceptual framework building appeared to be most frequently used (Bak, 2018). Regardless of the situation, the supply chain risk management framework shows an integrated process across several settings before a turbulent disruption. As stated by Kovács and Spens, (2011), emergency logistics does not adhere to a single set of guiding theories. Instead, it draws ideas and concepts from several fields. A framework is created for managing risks in emergency supply chains by adapting concepts from operations and commercial supply chain management to disaster relief settings.

Developing an effective SCRM framework is critical and requires skills and expertise in multiple disciplines. Several qualitative and quantitative conceptual frameworks have been put forward to address different SCRM processes. The majority of these studies concentrated on two SCRM processes: risk assessment and mitigation (Oke and Gopalakrishnan, 2009; Peck, 2005; Smith et al., 2007; Cheng and Kam 2008; Wagner and Bode, 2008); and risk identification and mitigation (Kleindorfer and Saad, 2005; Blome and Schoenherr 2011; Giannakis and Louis, 2011; Speier *et al.*, 2011; Hahn and Kuhn 2012; Kumar and Havey, 2013). According to Kern *et al.*, (2012), efficient risk identification benefits the subsequent risk assessment, improving risk mitigation. These three SCRM processes have a substantial relationship; hence, three processes rather than just two should receive greater attention (Ho *et al.,* 2015). Some academics created a conceptual framework for the processes of risk identification, assessment, and mitigation (Ritchie and Brindley, 2007; Foerstl *et al.*, 2010; Bandaly *et al.,* 2012; Kern *et al.*, 2012; Ghadge *et al.*, 2013; Fan and Stevenson, 2018). Their framework has five main parts: risk identification, risk assessment, risk repercussions, risk management response, and risk performance results. Ritchie and Brindley, (2007) offered a generic framework comprising five elements: risk context and drivers, risk management influencers, decision-maker characteristics, risk management responses and performance for managing the supply chain. This generic framework aligns with the purpose of this study since it encompasses an overall picture of the supply chain risk management process. Therefore, considering the distinctiveness of emergency logistics and supply chains in disaster relief operations, this study borrows and adapts this conceptual framework from the supply chain management literature.

Fig 4.5 depicts the schematic representation of the proposed framework. The framework is a dynamic process and consists of eight major components: disaster influence, community characteristics, disaster conditions, risk context and drivers, decision-makers, risk management process, risk management strategies, and performance outcomes. The framework is centred on the risk management process and encompasses concepts of considering the environment and its distinct characteristics, identifying risk sources, and utilizing strategies per situational influences. The components resemble contingency theory as it provides an understanding of the situational influences of risk management strategies. Each component provides insight into how the framework works overall in developing a risk-supportive environment since the main purpose is to provide an efficient relief supply while reducing human suffering. The decision-makers are essential in the risk management process as they are responsible for making decisions towards mitigating the risk level. As risks can come internally or externally, the decision-makers must have the capacity to manage these sources. Risk management strategies will ultimately be based on the risk context and drivers, while performance outcome serves as a measure to evaluate the efficiency of the strategies.

4.2.3.1 Disaster influence

Significant distinctions exist between disasters, their effects, and how incidents develop (Kovacs and Moshtari, 2019). Disasters can be man-made or natural (Salam and Khan, 2020). The magnitude of these disasters may vary from mild, with only a few injuries and minimal damage, to large, with hundreds of fatalities (Altay *et al.*, 2009). Disasters can start quickly or slowly and cascade onto one another. Additionally, various calamities can strike the same area at different times. De la Torre *et al.*, (2012) illustrate the devastation brought on by the rainy season in Haiti following the 2010 earthquake, which included two different types of disasters, each with its unique characteristics and difficulties (Kovacs and Moshtari, 2019). Disasters can result in deaths, homelessness, sickness, and economic losses. According to Akkihal, (2006), a natural disaster is determined by two aggregated variables: the magnitude and frequency of fluctuations in geological and climatic systems at a specific place and time and the vulnerability or capacity of a community to absorb geological or climatic shocks. The population density, settlement structure and infrastructure determine the community's vulnerability level. Despite disasters continuing to occur, society’s ability to withstand the impact of natural disasters has increased due to industrialization (Akkihal, 2006). Denser, less well-structured communities are more vulnerable to severe and wider-reaching disasters. The effects of disaster can grow in proportion to population expansion, climate change, and global connectedness. Advancement of new technology also provides higher accuracy in predicting disasters, though they remain largely unpredictable, making relief work mostly dependent on fast training, education, and people's preparedness on the ground (Salam and Khan, 2020). Major natural disasters can potentially have a critical impact on communities and infrastructure, resulting in significant human losses and massive destruction (Thevenaz and Resodihardjo, 2010). CRED (2022) states that 396 natural disasters struck countries worldwide in 2019. The effects of these natural catastrophes killed 11,755 people, affected 95 million people, and caused $US 130 billion in economic damage. Over the last quarter-century, the incidence and size of emergency crises have increased dramatically (OCHA, 2017). While natural disasters are becoming less frequent, their impact on human safety, health, and the environment is growing (Kovacs *et al.*, 2010; Seifert *et al.*, 2018). The type and scale of a disaster, combined with environmental and physical characteristics, can influence the needs of an affected population (the supply type and quantity), the degree of uncertainty, the quality of information, and the level of complexity for emergency relief activities. For example, on January 12, 2010, Port-au-Prince, Haiti's capital city, was rocked by a magnitude 7.0 MW earthquake (USGS, 2010), resulting in a significant death toll of between 217,000 and 230,000 people, with an estimated 300,000 people injured and one million residents displaced (Associated Press, 2010). The earthquake and the ensuing devastation put a tremendous strain on the population and infrastructure (Forbes.com, 2010), with over 30,000 commercial buildings and one million residential structures collapsing (Renois, 2010).

Similarly, Hurricane Katrina made landfall in August 2005, leaving 80% of New Orleans flooded with as much as 20ft of water and resulting in the breakdown of critical infrastructures, including power supplies and lines, sewerage systems, and communication lines (Thévenaz and Resodihardjo, 2010). This, in turn, meant that local, state, and federal officials were then reliant on contradictory reports and erroneous information, highlighting the importance of communication and technology infrastructure in order to boost the efficiency of disaster relief efforts (Perry, 2007; Pettit and Beresford, 2009; Dubey *et al.*, 2019a).

4.2.3.2 Community characteristics

The local environment, cultural, and political factors are critical in disaster relief operations (Kovacs and Moshtari, 2019). The natural environment in which a natural disaster occurs also significantly influences emergency response. When preparing for disaster relief operations, stakeholders should consider several factors such as geography/topography, level of development, population density, social, and political factors. The topography and condition of the affected area can significantly impede access to victims; search and rescue operations will be impaired if the terrain is mountainous or flooded or if roads are blocked off (Thevenaz and Resodihardjo, 2010). Long (1997) states that logistics and supply chain requirements differ worldwide. Different regions have characteristics that impede or intensify relief activities. For example, Haiti has an extreme terrain and a coastline that stretches 1,771km. This challenges the development of suitable transportation networks. Some communities are situated in isolated areas and, thus, quickly become isolated, with the provision of critical supplies to the affected population being related to travelling long distances with little or almost no existing infrastructure.

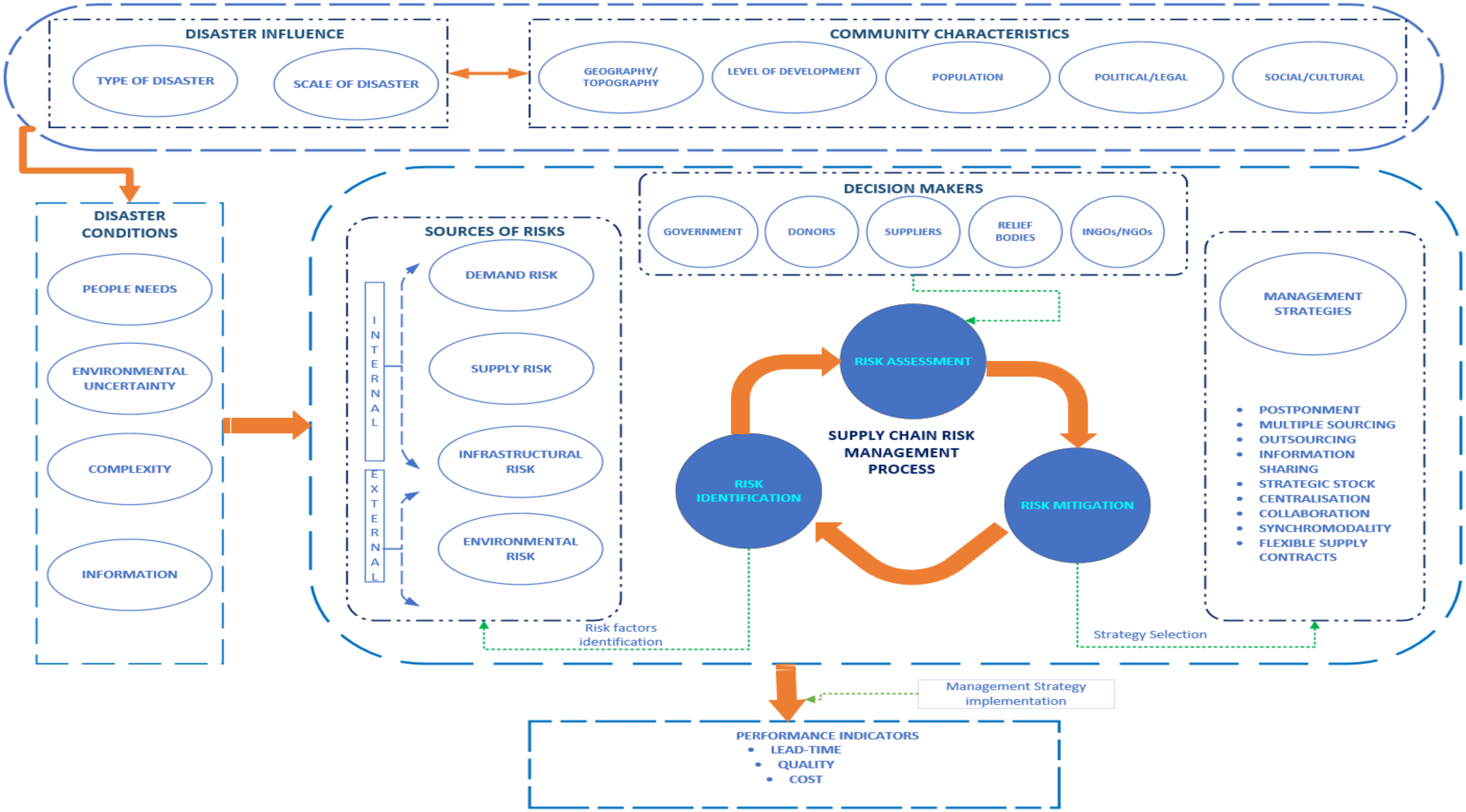

Figure 4.4 A novel comprehensive framework for risk analysis in emergency supply chains

After the South-East tsunami struck, Aceh province in Indonesia suffered considerable devastation, with hundreds of towns cut off for several days due to the destruction of most roads, bridges, boats, telecommunication networks, and water and energy supplies. Over 110,000 people were killed in Aceh and North Sumatra, and over 600,000 victims required assistance. Due to the large number of victims, the mass material damage, and the unexpected nature of the incident, rescue attempts were hindered. In India, the tsunami hit the distant Nicobar Islands as well as the coastal regions of Southern India. A year later, most of the mainland's coastal regions had been reconstructed, but the Nicobar Islands still required some basic infrastructure (Altay *et al.*, 2009).

Furthermore, when time constraints and weather conditions are added to the mix, logistical challenges for the responders will result. Emergency responders will be unable to get help if the roads leading to the victims are destroyed and if a severe storm prevents the deployment of helicopters. Because victims will only be able to survive for a short time on their own when trapped under rubble, time will further strain first responders. The disaster may have wrecked the structural pathways to deliver this relief to the affected populations, even when enough aid resources (food, water, and medicine) were available (Thevenaz and Resodihardjo, 2010). In general, higher levels of development imply more sophisticated transportation, communication, and human resource infrastructure. Regardless of social standing or economic circumstances, natural disasters affect populations; however, their effects vary depending on the social and economic environment of the affected area (Doherty, 2004). Research has found that "societies that suffer from a fragile physical environment, poor economies, and inadequate social and institutional frameworks are disproportionately likely to produce a calamity out of a natural hazard" (Ozerdem, 2006). Natural disasters often have a greater impact on communities with high levels of poverty and crime, weak infrastructure, loose family ties, few business opportunities, or deserted areas (Thevenaz and Resodihardjo, 2010). The infrastructure of places like Haiti generally lags behind that of the developed world and can easily be overwhelmed when disaster strikes. For example, land transportation in Haiti is challenging due to inadequate roads, bridges, and public transportation (Than, 2010). Healthcare and education services are almost non-existent, and NGOs typically play a vital role in operating them (Salam and Khan, 2020). Population density is also important, as higher density often leads to more fatalities and destruction (Altay *et al.*, 2009). For example, the 2010 Haiti earthquake devastated its densely populated capital city, resulting in 230,000 deaths, 300,000 injuries, and displacement for over one million people (Yates and Paquette, 2012). The 2007

Pisco earthquake in Peru was felt in the Andes and Altiplano, and compared to the total district population, areas closest to the epicentre had a higher density of victims; however, the presence of diverse factors led to a comparatively lower death toll of 500 people (Chandes and Pache, 2010). These factors included the time of the earthquake (6:40 PM, when most affected individuals were no longer at work or school) and the second earthquake that followed 60 seconds later, allowing people to leave their homes before they collapsed. Despite the blocked highways and other initial challenges, assistance arrived swiftly.

NGOs, local/federal government, and even the military are just a few supportive organizational networks that constitute a community. NGOs can identify local needs, take preventive measures, and successfully allocate resources. Government entities can greatly aid the coordination of the distribution process. Additionally, the military units have advanced logistical skills created specifically for emergencies (Long, 1997). A successful disaster management project must build strong ties with the local network and stakeholders to identify its effectiveness (Salam and Khan, 2020). According to Briones *et al.*, (2019), disasters can be better controlled based on these relationships, and prompt actions can be taken.

Furthermore, the organisation of the decision-making process and the cooperation between the numerous entities involved have a significant bearing on the emergency response (Thevenaz and Resodihardjo, 2010). Disaster-stricken areas frequently lack the organisational capacity to handle things. For example, in Indonesia, the "relief agencies brought balance as they took over the activities, but they realized they had to rely on the military as the administrative infrastructure had been destroyed, and the only organized governing authority in the region was the military" (Altay *et al.*, 2009). Another important characteristic to consider is the political/legal factor. A more balanced and equitable distribution of resources is typically ensured in societies that have a free press and a democratic government in place. A free press typically ensures that information on disaster situations is of a higher calibre. In a democracy, representatives held accountable for their actions are more likely to attend to the community's demands. A democratic system also enables the development of various administrative entities that can aid in disaster assistance (Altay *et al.*, 2009). The social and cultural norms of the affected population are critical.

Regarding distribution methods and supply types, it is important to respect the values and beliefs of communities affected by disasters. Therefore, giving rations with pork extract in areas with a high Muslim population would be counterproductive. Some cultures are more accepting of foreigners and have fewer gender role distinctions. Less rigid cultures can offer relief managers information of greater quality and fewer requirements.

4.2.3.4 Disaster conditions

In order to optimise the effectiveness of disaster relief operations, disaster relief teams must have a thorough understanding of the disaster relief situation and be able to organise the information, manage logistics and employ appropriate technology to improve the efficiency of aid delivery. Disaster relief organisations must carefully consider factors such as the population density of the area, as well as its geography and topography, in order to ensure that supplies are accessible and distributed to affected populations. Technology plays a critical role in disaster relief, from collecting and mapping data to analysing the data and optimising the supply chain (Altay *et al.*, 2009). For example, advanced analysis tools, such as Geographic Information Systems (GIS), can improve information systems' efficiency in collecting, analysing, and managing information (Altay *et al.*, 2009). Additionally, simulators can provide better situational awareness and aid decision-making (Prasad et al., 2010). Furthermore, technological advancements can also help to reduce risk by introducing robust and efficient communication networks.

In conclusion, disaster relief efforts need to be tailored to the specific needs of the affected population, and technological assistance can improve the speed and efficiency of relief operations. Technology can also provide essential information to facilitate the delivery of supplies and aid to the affected population and optimise the effectiveness of disaster relief operations. The type and severity of a disaster will determine how uncertain things are. Additionally, the availability and usability of commodities are randomly impacted by the damage to supply and service providers, which are directly affected by the effects of an earthquake. As a result, it should be remembered that the entire transportation system is vulnerable and may become completely inoperable (Barbarosoglu and Arda, 2004).

Additionally, distant, underdeveloped, densely populated areas with constrained community networks and closed political systems tend to produce more uncertainty (Altay *et al.*, 2009). Information systems have suffered from a lack of investment partly due to a conflict between goals. The efficiency of relief organisations is frequently determined by how much of their budgets go into providing supplies, with those who spend the least on administrative costs deemed the most effective. Consequently, organisations are hesitant to invest in costly, complicated information systems. (Long, 1997). Unfortunately, most remote places lack established organizational networks, and communication infrastructures are either underdeveloped or neglected, making it difficult to give accurate information.

Additionally, information may be restricted or censored in areas with autocratic and corrupt regimes (Altay *et al.*, 2009). The scattered nature of relief efforts and the sheer number of stakeholders involved make the issues quickly complex. Logistical challenges during disaster assistance are often not subject to 'hard' limits and can be difficult to model mathematically. In addition, armed conflicts, human rights violations (for example, the kidnapping and rape of women and children in Darfur), and political or ideological attitudes toward relief (such as North Korea's blockade of relief shipments from South Korea in response to the April 2004 train explosion) all add constraints to the problem making it even more difficult to manage.

4.2.3.5 Managing emergency supply chains

The emergency supply chain must manage the crisis conditions established by the community's needs, level of uncertainty, information quality, and complexity to produce the appropriate performance outcomes mentioned previously. The five important components of such a supply chain are sources of risk or disruptions, stakeholders, management methods, risk management process, and performance outcomes. It must be adaptable enough to adjust to the ever-dynamic operating environment.

Sources of risk

When one considers the supply chain in a more holistic sense, theoretically or practically, this raises the possibility of a few distinct levels inside the supply chain. These levels are referred to as the primary and secondary levels, respectively. The organisations involved in the primary level chain are typically those with a major involvement in delivering added-value goods or services. On the other hand, the organisations involved in the secondary level chain (or chains) provide a more indirect, albeit still valuable, contribution to the chain and its product or service delivery outcomes. Together with the United Nations (UN), several significant INGOs (and national NGOs) are actively engaged in a variety of disaster relief activities (Dietrich, 2013). The UN High Commissioner for Refugees and the World Food Programme are multilateral UN organisations funded solely by voluntary donations, mostly from donor states in cash and in-kind (Fuchs et al., 2014; Dietrich, 2013; Dreher *et al.,* 2011;). There is a wide variety of organisations that fall under the umbrella of international non-governmental organisations (INGOs), such as Cooperative Assistance and Relief Everywhere and the Oxford Committee for Famine Relief (Oxfam) (Palttala et al., 2012; Brunt and McCourt, 2012). Many different NGOs exist globally, each with their mission to promote a particular cause over the long term, whether it is gender equality, food security, agriculture, eliminating child labour, or any other ongoing help activity. Many others are only able to provide emergency aid in the near term.

There is a wide variety of international non-governmental organisations (INGOs) and national non-governmental organisations (NGOs), even under one umbrella term (Bennett, 2013). Some international non-governmental organisations (INGOs) and non-governmental organisations (NGOs) focus on a particular field, such as health (with organisations like Médecins sans Frontières), while others focus on a specific region (e.g., South Pacific, the Caribbean, Asia, or Africa). Some, like Oxfam, have been around for decades, providing continuous assistance, while others pop up only when disaster strikes. International military intervention in support of emergency action and the duty to protect is a position backed by some and has the backing of the United Nations (Evans *et al.*, 2013; Duffield, 2012).

On the other hand, many refuse to do so to stick to their beliefs of non-violence, religious neutrality, or neutrality. Therefore, a sizable and intricate international emergency aid network has formed, continually expanding and diversifying. Organizations like the United Nations and the military, as well as for-profit businesses and non-governmental organisations (NGOs), all have a hand in emergency relief activities (including household names such as Amnesty International, the International Federation of Red Cross and Red Crescent Societies, Oxfam International and Médecins Sans Frontières). These organisations are at the primary level of the emergency supply chain since they are directly involved in delivering critical relief supplies to the affected population. Donors are central to disaster relief aid funding, sourcing, transportation, delivery, distribution, and governance in many ways. They are located at the secondary level of the emergency supply chains.

Moreover, there is a wide variety of donors to choose from (Brech and Portrafke, 2014; Dreher *et al.*, 2011). Individuals, corporations, and even governments may all contribute financially. In the last decade, numerous formerly aid-receiving nations like India, China, Iran, and Eastern European nations like Russia have switched roles and become givers. These "new" donor governments have varying motivations for helping, and their NGOs may not adhere to more traditional assistance delivery methods (Brech and Portrafke, 2014; Dreher *et al.*, 2011). Donors contribute financing for relief and non-governmental organisations, but this advantage comes with a cost, as more frugal donors want to know where and how their money is being spent and to see clear, verifiable outcomes. According to Oloruntoba and Grey (2009), failure to attain efficiency may result in the loss of life and "in the loss of important donor cash for international NGOs." Donors want more accountability, transparency, and value for their money from the humanitarian aid (HA) agencies they fund. Hence, relief organisations must be more professional in running their businesses to meet these stricter performance and accountability standards (Thomas and Kopczak, 2005). Rising levels of natural and conflict-related catastrophes (Roh *et al.*, 2008; Perry, 2007) place further strain on resources and performance, necessitating more simultaneous relief activities throughout the globe (Oloruntoba and Kovacs, 2015).

Risk factors can come from various sources, including the external environment within an industry, a specific supply chain, partner relationships, or organizational activities (Olson and Wu, 2010). All stakeholders will be affected by risk drivers that come from the external environment (Benini *et al.,* 2009; Jahre *et al.,* 2009). The emergency response might also be affected by the natural environment where a natural disaster happens. The terrain and state of the affected area can make it very hard to reach victims. Search and rescue operations will be harder if the area is mountainous, flooded, or blocked roads (Thévenaz and Resodihardjo, 2010). Add the weather and the need to get things done quickly; the responders will struggle with logistics. For example, if the roads to get to the victims have been destroyed, and a storm is too strong to use a helicopter, then emergency workers will not be able to get help to the victims. If victims are buried under debris, they can only live independently for a few days, putting more pressure on rescuers. So, even though there may be enough food, water, and medicines to help, the disaster may have destroyed the infrastructure needed to get this help to the people who need it. Because of Katrina's effects, it was hard for emergency workers to do their jobs. Flooded streets in New Orleans made it hard to get to the police and fire dispatch centres and stopped people from leaving for several days after the storm hit. These conditions made it harder for search and rescue teams and state and local emergency responders like medical teams, firefighters, and law enforcement officials to do their jobs. These first responders put themselves in dangerous situations to do their jobs (Thévenaz and Resodihardjo, 2010).

Political factors impact emergency logistics operations and operational choices. An unconvinced administration is more likely to limit aid workers' ability to enter the nation and bring in supplies after a crisis (Kunz and Reiner, 2012), whereas a cooperative government would welcome aid workers to its soil (McLachlin and Larson, 2011; Van Wassenhove, 2006). The effectiveness of the logistical response is heavily influenced by the security situation in a nation, which in turn relies on the government (or its absence) (Long and Wood, 1995). Moreover, relief organisations will need to adjust their methods of operation based on factors such as the local market economy, the availability of local suppliers, the literacy rate of the population, and the cultural and religious norms of the area (Altay *et al.*, 2009; Dowty and

Wallace, 2010; Maon *et al.,* 2009). Some necessities may be obtained from local vendors in an economically developed region, and locally recruited workers can fill logistical tasks. All materials must be imported, and expatriate workers must oversee much of the work in a less-developed atmosphere (Kunz and Reiner, 2012).

The types of risks supply chains may be exposed to vary in different industries. For example, in the automotive manufacturing industry, supply chains may be at risk of disruption due to parts shortages or rising costs due to a supplier being unable to deliver on time. On the other hand, in the healthcare industry, supply chains may be exposed to risks such as product recalls, increased demand for sanitary products, and medical shortages due to pandemics or natural disasters. Additionally, in all industries, supply chains are potentially exposed to risks related to cyber security, such as malware attacks, data breaches, and phishing scams. Ultimately, supply chain stakeholders need to be aware of the risks they may face to create proactive strategies to mitigate the impact of such disruptions. By understanding the specific risks present in their industries, supply chain managers can develop contingency plans to reduce the impact of any unexpected supply chain disruptions. For example, suppliers in the automotive manufacturing industry could be asked to meet certain quality and delivery standards to ensure minimal parts shortages.

Similarly, in the healthcare industry, comprehensive crisis management plans could be prepared in advance to ensure an adequate supply of goods in the event of any unexpected issues. Risks can come from the way the supply chain is set up. Disaster relief supply chains come in a wide variety of forms (Matopoulos *et al.,* 2014; Holguin-Veras *et al.*, 2012; Day *et al.,* 2012; Maon *et al.,* 2009; Kovacs and Spens, 2007; Oloruntoba and Gray, 2006). Emergency supply chains are one example; supply chains for longer-term, protracted, ongoing help for recovery, rehabilitation, rebuilding, and development are another (Matopoulos *et al.,* 2014). The variety of possible configurations of relief assistance supply chains is largely due to the sheer complexity and diversity of stakeholders and their respective goals (Oloruntoba and Kovacs, 2015). However, the overarching goal of any disaster relief operation should be to deploy an efficient and successful emergency supply chain (Pettit and Beresford, 2005), which needs strategic methods rather than a "whatever it takes" mentality (Gattorna, 2009). However, bearing in mind the varied and complex settings within the emergency supply chain, a significant amount of human interaction is required to generate creative solutions quickly to save lives (Gattorna, 2006). According to Gattorna, (2009), this can only be accomplished with a fully flexible supply chain that is intended to react to unplannable events and, as a result, makes use of whatever it takes to achieve a satisfactory result without considering cost, utilization, or relationships (Scholten *et al.*, 2010). Some organisations can lower industry risk by choosing which vendors to work with. Considerations for partner-specific risks include the partner's financial stability, the quality of its products, how well its information systems work together and what they can do.

Decision makers

Every decision-maker has a unique risk profile. Some are naturally more risk-averse than others, and vice versa. The extent to which groups make decisions collectively varies among organizations. Whereas a more hierarchical structure might funnel authority over a decision down to a single department, a flatter structure might encourage employees to have a more excellent hand in making essential choices. Recent experiences or the organization's incentive and penalty structure may influence one's or a group's perspective on risk. Different groups (government, military, NGOs, and donors) help along the emergency supply chain, from initial demand assessment through final product delivery to the affected population. Governments and non-governmental organizations (NGOs) are the principal actors in a typical emergency supply chain. Governments have most of the power because they influence the political and economic climates and because the decisions they make directly impact the operations of supply chains. For the first sixty days of the relief effort following the tsunami that struck India in 2004, for example, the Indian government did not in any way invite international aid agencies to participate and instead relied solely on supplies sourced from local sources. This situation occurred even though the Indian government was aware of the existence of international aid organizations (Thomas and Fritz, 2006). Other key stakeholders in the emergency supply chains include the armed forces, donors, and the media. The government plays a crucial role in emergencies by coordinating with relief organisations and enacting rules that enable or prohibit foreign aid. Although coordination remains challenging, it is getting more attention because there are not as many resources in the world as there used to be, people are worried about who is responsible for what, and new global information technologies could open new opportunities (Yadav and Barve, 2015).

Most scholars also agree that coordination between the different people in the emergency supply chain can make the first response efforts more effective (Van Wassenhove, 2006; Chandes and Paché, 2010). With more significant disasters in recent years, the need to collaborate and share risks has grown dramatically (Chakravarty, 2014). Over a million people had to leave their homes 36 hours before Cyclone Phailin hit land. The cyclone was one of the largest emergency evacuations ever done in a record time. The Odisha Disaster Rapid Action Force (ODRAF), the National Disaster Response Force (NDRF), the Central Reserve Police Force (CRPF), the Odisha State Armed Police (OSAP), and the Indian Air Force (IAF) worked closely together on these efforts (Yadav and Barve, 2015). Without a government policy or disaster legislation, it may be worth mentioning that functional organizational structures have grown from some planning basis (e.g., a national or several provincial plans) in many situations. Suppose there is no ambiguity about who should take appropriate action under the demands of disaster impact; actors should be aware of their responsibilities. The management style of the emergency supply chain must be well-thought-out so that all the participating departments know their specific roles and responsibilities (Yadav and Barve, 2015).

Supply chain risk management process

Every business has a responsibility to react to potential dangers, but there are many ways in which this can be done. First, risks must be identified. Then, organizational performance must be measured to monitor and review processes. After the risks have been recognized, appropriate responses must be chosen. An implicit trade-off between decreasing costs and increasing insurance coverage can help to reduce risks. Most options for organizations entail determining which risks the organization can manage given its experience and capabilities and which risks the organization should outsource to others at some cost. Some risks can be mitigated, while others must be completely avoided.

Performance indicators

Various metrics and evaluation models can be used to evaluate an organisation's success. Profitability is a key metric for evaluating for-profit enterprises. Government agencies, on the other hand, must measure the quality of their services and the money spent on those services. Kleindorfer and Saad, (2005) propose eight primary motivators for supply chain disruption/risk management when evaluating an organization's success, including corporate image, liability, employee health and safety, cost reduction, regulatory compliance, community relations, customer relations, and product improvement. Emergency supply chains, which lack any profit goals and mainly rely on the contributions of volunteers and donations, require different evaluation models from those in conventional supply chains. There are several approaches to assessing the success of a relief system coordinated across several organisations in the wake of a major disaster. Several studies (Kovács and Spens, 2007; Pettit and Beresford, 2005; Sheu, 2007; van Wassenhove, 2006) state that any disaster relief operation aims to offer timely and adequate aid to the affected communities. Ultimately, the success of the disaster relief system depends on whether the survivors are helped, how many lives are lost, and how much property is damaged (Day, 2014). Metrics of velocity, effectiveness and reactivity can be applied when considering the accomplishment of this goal.

Additionally, the importance of certain metrics may fluctuate during a disaster relief operation. The first 72 hours of a relief effort, the reaction phase, are the most critical period. The goal here is to use system bottlenecks to your advantage so that those requiring certain resources and talents can access them. Supply chain operations such as sourcing, transportation and distribution can significantly impact the speed at which goods are made available (Kovács and Spens, 2007). The overall disaster relief effort can be greatly impacted by how quickly the reaction phase occurs (Sheu 2007). At this time, it is typically important to opt for the quickest alternative, despite the associated cost, as this can help save lives and avoid further infrastructure breakdowns that can cause delays (Perry, 2007; Day, 2014). After the initial phase of reaction, the metrics will focus on effectiveness. During the first 90-100 days of recovery, it is prudent to prioritize cost-effectiveness by finding a balance between efficiency and productivity (Van Wassenhove 2006). As noted by Long and Wood (1995), cost-effective food distribution to centralised facilities could be of benefit. However, the difficulty of affected persons to travel to the feeding location should be considered alongside the advantages. Additionally, it is essential to maintain a high level of responsiveness throughout the relief operation or the capacity to promptly supply adequate resources in response to constantly changing needs (Oloruntoba and Gray 2006; Perry 2007; Sheu 2007). Relief efforts are more likely to be successful (Day, 2014).

4.3 Integrated analytical model for ESC risk management.

The novel conceptual framework proposed provides a generic and comprehensive picture of the various phases involved in tackling various disruptions that are likely to impede the effectiveness of the emergency supply chain. The core of the developed framework is the supply chain risk management process. Several studies on risk management show that a typical risk management process has three steps: identifying risks, assessing risks, and mitigating risks (Kleindorfer and Saad, 2005; Kern *et al.,* 2012). At the same time, some studies say there needs to be an ongoing risk monitoring and risk management process that is always changing to meet the needs of the changing environment (Bode and Wagner, 2009; Kern *et al.,* 2012). When environmental conditions shift and new risks emerge, effective risk management methods weaken and fail to respond if not subject to continual development.

Consequently, Kern *et al.,* (2012) contend that, over the long term, risk management operations must be coupled with a continuous improvement strategy. Therefore, this study will utilize the three fundamental supply chain risk management processes to develop an integrated risk management model for emergency supply chains. The integrated risk management model will involve a dynamic, interactive, parallel, and continuous process, supporting the development and optimization of the three fundamental processes. Fig 4.6 presents a schematic diagram of the model. The idea of risks has been inextricably linked with the supply chain for as long as anybody can remember; a supply chain provides an evident picture of what an organisation is all about. Simplifying operations is a critical matter that should be dealt with in the upstream of an organization as well as in the downstream supply chain since it reduces the risk of legal, financial, operational, confidential information, and reputational harm. The management of risk sources is a constructive decision-making process that establishes a platform for understanding a situation's engineering, social, political, and economic aspects. This platform can then formulate an appropriate response to the scenario. In managing supply chains, risk management involves analyzing these elements to determine how closely they are linked to the possibility of disruption. This necessitates the development of a technique that enables the study of such a situation from all angles to evaluate organizational, supply chain networks, and environmental hazards, resulting in suitable risk management solutions. The model developed for emergency supply chain risk management comprises three independent analytical models, i.e., risk identification, risk assessment and risk mitigation. The activities and techniques used to develop the model are detailed in the following subsections:

4.3.1 Emergency Supply Chain Risk Factors Identification

This analytical model focuses on identifying, validating, and classifying emergency supply chain-specific risk factors. For this purpose, a comprehensive literature review is conducted to extract relevant information from the available literature. High-level surveys are conducted to get insights from emergency supply chain practitioners and policymakers. Identifying risks is crucial to supply chain risk management (Neiger *et al.,* 2009). Risk identification is the process of identifying, characterizing, recording, and communicating potential hazards that may arise and have a positive or negative impact on the supply chain operation (Aqlan and Lam, 2015). Only the identification of threats initiates additional risk management activities. The objective of risk identification is consequently to identify all relevant risks. This suggests that an early decision is required to determine whether a risk is deemed significant and will thus be further evaluated. There are several techniques for identifying supply chain risks, such as the Hazard and Operability (HAZOP) analysis method (Adhitya *et al.,* 2008), supply chain mapping, checklists or check sheets, event tree analysis, fault tree analysis, failure, mode, and effect analysis (FMEA) and Ishikawa cause and effect analysis (Tummala and Schoenherr, 2009). The purpose of a strategic supply chain map is to assist businesses in managing and adapting their supply chains in ways that are in line with their overall business goals and objectives (Rao and Goldsby, 2009). Potential threats can be better spotted if the whole supply chain has been mapped. Second, check sheets or checklists can record failure rates by event.

Data collection and histogram creation are standardised through these forms (Tummala and Schoenherr, 2011). One possible application for checklists is in assessing suppliers' reliability (or risk) by keeping track of any late deliveries they have made. Third, in the case of a supply chain breakdown, a graphical depiction of all possible outcomes caused by the breakdown may be created using an event tree or fault tree analysis. There are some superficial similarities between the two types of trees, but key distinctions exist, such as whether the tree represents a single or several event routes (Tummala and Schoenherr, 2011). Alternatives can be planned for, for instance, by first outlining the chain of events that a breakdown in the supply chain can trigger. FMEA is a tool used to detect "possible hazards during the production of a product and throughout its usage by the end customer, during the design phases" (Tummala and Schoenherr, 2011). One may perform such an analysis using this SC before committing to a supply chain to study and estimate what could go wrong and how serious the ramifications would be.

In an Ishikawa cause and effect analysis, all potential connections between putative causes and failure occurrences are explored. Cause and effect diagrams are also frequently called fishbone diagrams because of their structure (Tummala and Schoenherr, 2011). These diagrams might be used to identify the real root cause of the incident if a supply chain problem has been found. Interviews, focus groups, literature reviews and high-level surveys are examples of other risk identification methods. This research adopts the literature review and high-level survey methods. The literature review serves as a foundation for the risk identification process. Information on emergency supply chain risk factors is derived from existing documents, including journal articles, books, and organisational and governmental reports. After that, an initial hierarchy structure is developed.

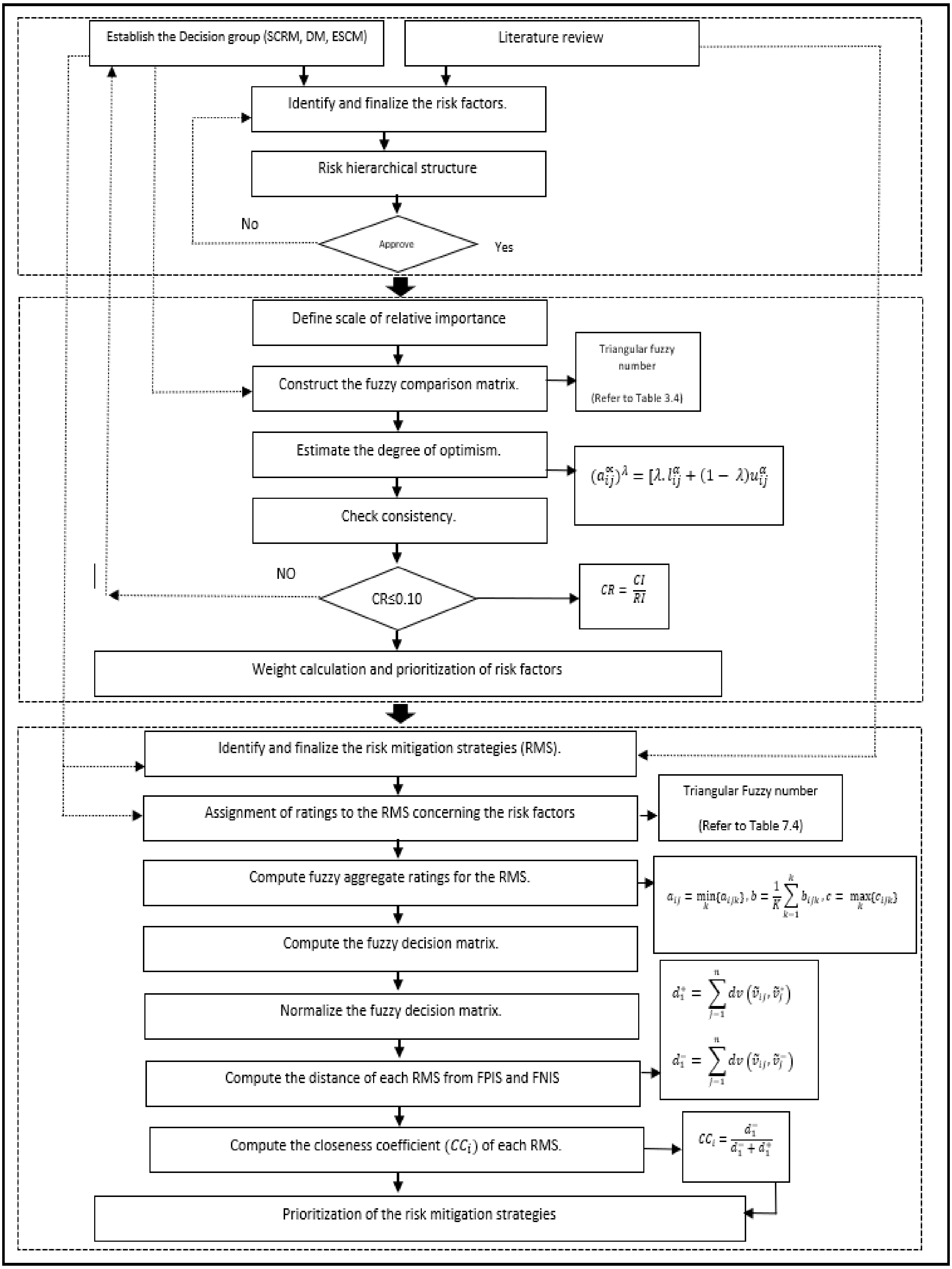

Figure 4. 5 Integrated Analytical Model for Risk Analysis in Emergency Supply Chain

The literature review provides an overview of the many potential factors that might have negative effects on emergency supply chain performance. It is evident, however, that not all potential threats can be easily identified. Identifying risk variables can be difficult enough without having to deal with feedback loops and dependent event chains (Hallikas *et al.,* 2004). Thus, the acquired risks are analyzed by completing the high-level survey to check the risk categorisation approach's applicability and ensure its comprehensiveness and validity. In addition, a preliminary evaluation is carried out to measure the critical degree of identified risk factors since the fundamental objective of this study is centred around risk factors that require the greatest attention from practitioners.

4.3.2 Emergency Supply Chain Risk Factors Assessment

This analytical model focuses on the weighting and prioritising of emergency supply chain risk factors. The fuzzy-AHP technique is used to assess and rank these risk factors for making decisions about preparing for and responding to the risks. Risk assessment is the second stage of the supply chain risk management process. Nearly all definitions of risk assessment draw on the same two components: an appraisal of the probability that the risk event will occur and an estimate of the potential consequences if it does (Kern *et al.,* 2012). According to Baird and Thomas, (1985), the main objective of a risk assessment is to find out as much as possible about a form of risk so that it can be avoided, its likelihood and effects lessened, it can be accepted, or plans for what to do if it happens are made. It gives a quantitative assessment of the importance of the risks, which would assist decision-makers in understanding which risk requires more attention. Numerous studies have been conducted on risk management, and a wide range of approaches and models have been developed to address the many issues that arise in supply chain risk management. Providing representative statistical indicators of the frequency and intensity of negative events from the preceding period is the primary challenge of risk assessment (Radivojevic and Gajovic, 2014). Due to the large number and variety of individual risks, the lack of homogeneity of statistical samples, and the limited number of identical repetitions of the initial events that caused the risk, the problem is not easily solved in most cases (Govindan and Chaudhuri, 2016). Several factors, such as the quantity and quality of data on the observed system, the complexity and dynamics of the system, the number of subsystems, the relations between subsystems, the length of the observation period, the expected future development of the system, the availability of human resources, the level of costs, the influence of the environment, and similar considerations, inform the selection of methods and models for analysis and assessment of risk. For these reasons, supply chain risks are typically evaluated not using statistical methods and models but intuition, experience, knowledge, prejudice, and other non-statistical methods that are busted for risk assessment. If there is a lack of representative statistical data for risk assessment, the AHP and FAHP methods can be especially helpful (Radivojevic and Gajovic, 2014), and this study adopts this method.

4.3.3 Emergency Supply Chain Risk Factors Mitigation

This analytical model focuses on the strategies that can improve the robustness and resilience of the emergency supply chain. A comprehensive literature review and semi-structured interviews are conducted to identify and validate such strategies. Fuzzy-TOPSIS technique is used to evaluate the effectiveness of these supply chain strategies concerning the most important emergency supply chain specific risk factors. The first step is to determine which risk to target for reduction—those with the highest impacts, uncertainties, and chances of materialization. Next, appropriate countermeasures are selected for mitigating each risk (Manuj and Mentzer, 2008a). These measures may include contractual arrangements, insurance, processes, personnel, and technology decisions. The effectiveness of the countermeasures should be evaluated to determine if they have successfully reduced the risk (Manuj and Mentzer, 2008a). Risk mitigation strategies can range from simple cost-cutting measures or process changes to more complicated approaches such as technology investments and information-sharing partnerships (Manuj and Mentzer, 2008b). In the former, relatively low-cost measures like better inventory control, rearranging shipping schedules, and reducing transportation costs have proven effective (Wagner and Bode, 2006; Manuj and Mentzer, 2008b). On the other hand, setting up collaborative relationships with service providers such as carriers, warehouses, or vendors and instituting extended supply chain finance (SCF) programs are examples of the more comprehensive approaches (Manuj and Mentzer, 2008b, 2008a). The most important aspect of any risk mitigation strategy is ensuring it is implemented. A thorough risk management approach should also consider post-implementation checks to ensure that the risk is reduced or eliminated and that unused resources are repurposed appropriately. The use of multiple criteria/attributes decision-making, Bayesian theory, System Dynamics (SD), Data Envelopment Analysis (DEA), and Structural Equation Modelling (SEM) have been extensively explored in the SCRM literature to aid in the analysis and mitigation of supply chain risks. Despite their potential for achieving reliable outcomes, each option comes with challenges. For instance, Bayesian theory requires much data; Data Envelopment Analysis focuses on how well an organization performs with its inputs; and Artificial Neural Networks, Genetic Algorithms, and Simulation-based Methods require advanced knowledge of computer programming languages and large amounts of quantitative data. When examining the advantages and drawbacks of MCDA techniques, the TOPSIS approach is useful and offers several benefits. It is used to rank potential solutions and select the most favourable options. It is adept at efficiently dealing with various weight estimation methods and can scale up to evaluate risk mitigation measures. However, it cannot deal with the fuzziness and imprecision that are inherently present in the cognitive process of mapping decision-makers perceptions. This limitation is addressed by employing the Fuzzy TOPSIS method, which combines the theory with fuzzy set theory. Fuzzy TOPSIS has been successfully applied to solve various MCDA problems, including evaluation and mitigation of supply chain risk management strategies evaluation and mitigation, supply chain risk modelling, and supplier selection and evaluation. As such, it can be used for the objective and methodical evaluation of multiple criterion alternatives by locating and selecting an alternative closer to the Fuzzy Positive Ideal Solution (FPIS) and farther away from the Fuzzy Negative Ideal Solution (FNIS).

4.4 Conclusion

In this section, this research developed a comprehensive framework for risk management in emergency supply chains. It thinks about what could go wrong and why, as well as the people who might make decisions and how they might make them, the risk management process, the supply chain strategies, and the objectives of the emergency supply chain. It is possible to use the proposed framework as a blueprint for creating a functional decision-support system, which can then be used in the disaster relief industry. An integrated model for managing risk in emergency supply chains is proposed here, with the aim of supporting effective risk factor identification and assessment, as well as logical decision-making regarding adopting emergency supply chain risk mitigation techniques. This model is based on the framework that was presented before.

CHAPTER 5 – RISK FACTORS IDENTIFICATION IN EMERGENCY SUPPLY CHAINS

5.1 Introduction

This chapter aims to identify and classify the risk factors impeding/disrupting the optimal efficiency of emergency supply chains. Fundamentally, this stage marks the commencement of any risk management process regardless of context. Diverse forms of identification and classification of supply chain risk factors exist in pre-existing literature; however, emergency supply chain risk factors remain unstructured. This study introduces a questionnaire survey to capture, validate, and structure these risk factors. The outcome provides a unique taxonomy and classification form for emergency supply chain risk factors, which provides understanding and strengthens the risk management knowledge base in emergency supply chains.

5.2 Risk Factors Identification and Classification

The goal is to develop a robust strategy that comprehensively identifies and classifies fundamental risk factors that disrupt the effectiveness and efficiency of the emergency supply chain (ESC) in disaster relief operations. Irrespective of context, managing risk in supply chains entails three critical steps: risk identification and classification, risk assessment and risk mitigation. Identifying and classifying the risk factors is the most important stage, as it provides stakeholders visibility on potential sources of disruption to their operations (Heckmann *et al.,* 2015). Risk managers gain more insights and knowledge into potential events and circumstances that can bring about risk in their operations (Harland *et al.,* 2003; Chopra and Sodhi, 2004; Christopher and Peck, 2004; Tang, 2006; Manuj and Mentzer, 2008b; Tang and Tomlin, 2008). Chapter 2 presents contributions from pre-existing studies in supply chain risk management (SCRM) that provide critical insight into the types, sources, and categories of supply chain risk present in diverse modern industries. However, there is yet to be a universal method of classifying supply chain risk regardless of context. Identifying and classifying supply chain risk is becoming increasingly complex due to the lack of consensus among academics and practitioners; thus, a unique methodology to identify, assess and mitigate risk factors that disrupt ESC activities in disaster relief operations is essential.

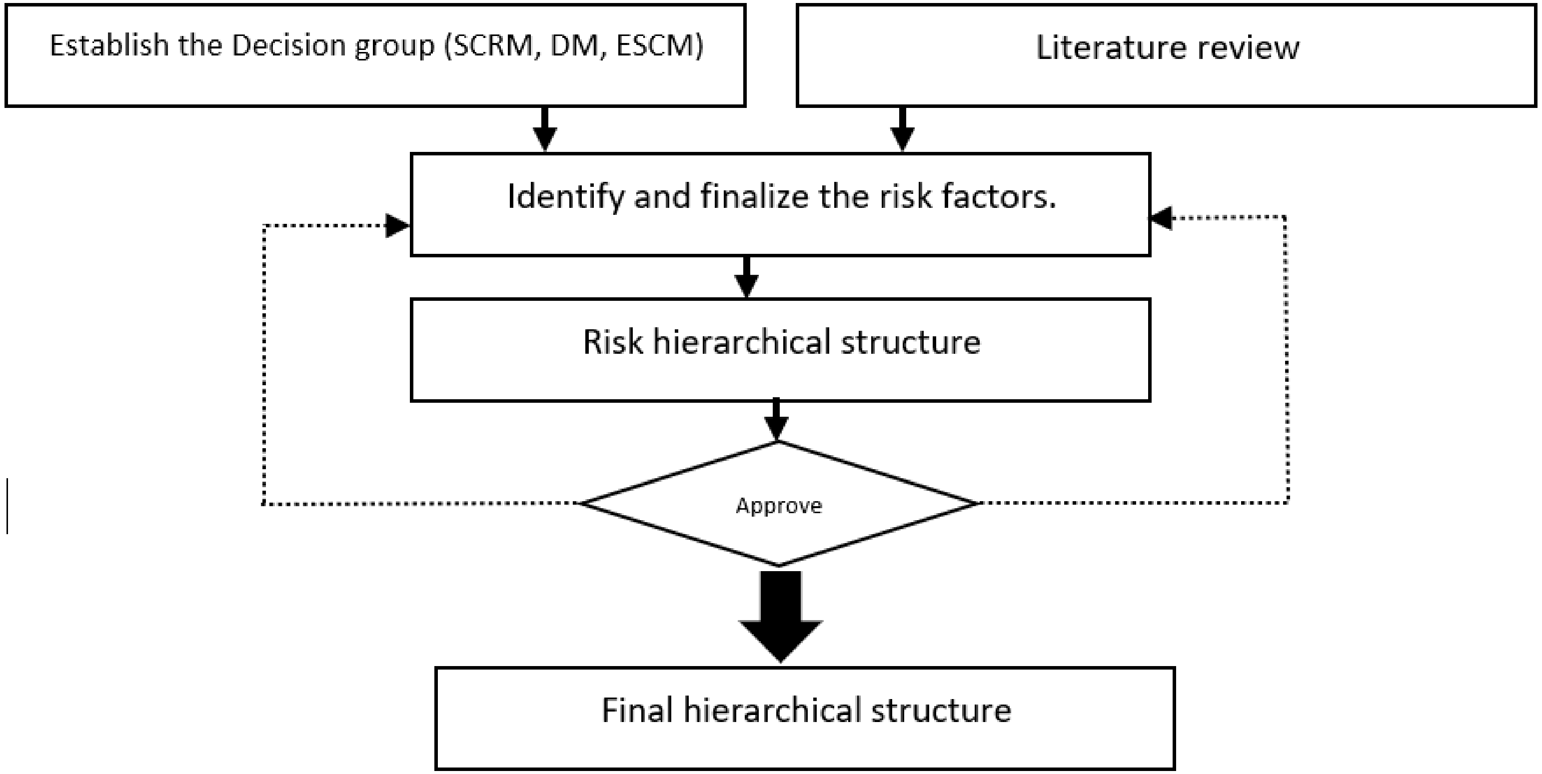

Figure 5.1 Decision model for risk identification in emergency supply chains

Emergency supply chain response is of vital importance following natural disasters and other types of crises. Despite best-laid plans, there is a high probability of the emergency supply chains failing due to various risks.

Christopher and Peck, (2004) and Wu *et al.,* (2006) presented classification models to understand better the sources of risks associated with supply chains. This study adapts these models and develops a classification model for the ESC context, which contains four risk sub-categories and twelve risk types, including demand risk, supply risk, infrastructural risk, and environmental risk. Factors likely to impede the smooth operations of the emergency supply chains are identified from the literature, and a hierarchy is developed. Table 5.1 presents a summary of these identified emergency supply chain risk factors.

5.2.1 Demand risk

Demand risk relates to potential or actual disturbances to the flow of supplies, information, and cash emanating from within the network between the focal company and the market. Specifically, it concerns processes, controls, asset, and infrastructure dependencies of the organisations downstream and adjacent to the focal company. Demand risk is associated with an organisation experiencing demand that it has not anticipated and provisioned for through its chains to enable it to satisfy its customers' demands or those of its customer's customers. Literature suggests that demand risk is the most articulated supply chain risk. This study's sub-categories of demand risks are forecast and inventory risks. Forecast risks arise from poor demand projection, distortion of information and high variation in demand. High inventory holding costs and limited life cycle of relief supplies are risk factors that drive inventory risks. Generally, in disaster relief operations, demand may be uncertain and unpredictable regarding timing, location, type, and size (Balcik and Beamon, 2008).

According to best practices, demand forecasting is integral to supply chain management and can significantly reduce operating costs by up to 7% (Van Wassenhove and Pedraza Martinez, 2012). Disaster demand forecasting is particularly challenging due to the sudden and unpredictable nature of these events and because there is often a lack of reliable historical data. As indicated by Oloruntoba and Gray, (2006), an 'agile' emergency supply chain is necessary to respond to real demand effectively, as forecast errors can result in shortages or excess critical supplies (Manuj and Mentzer, 2008b). Other sources of uncertainty include changes in population structure and economic conditions and fluctuating demands due to people returning to self-sufficiency, relocating to find relief or due to disease epidemics (De la Torre *et al.,* 2012).

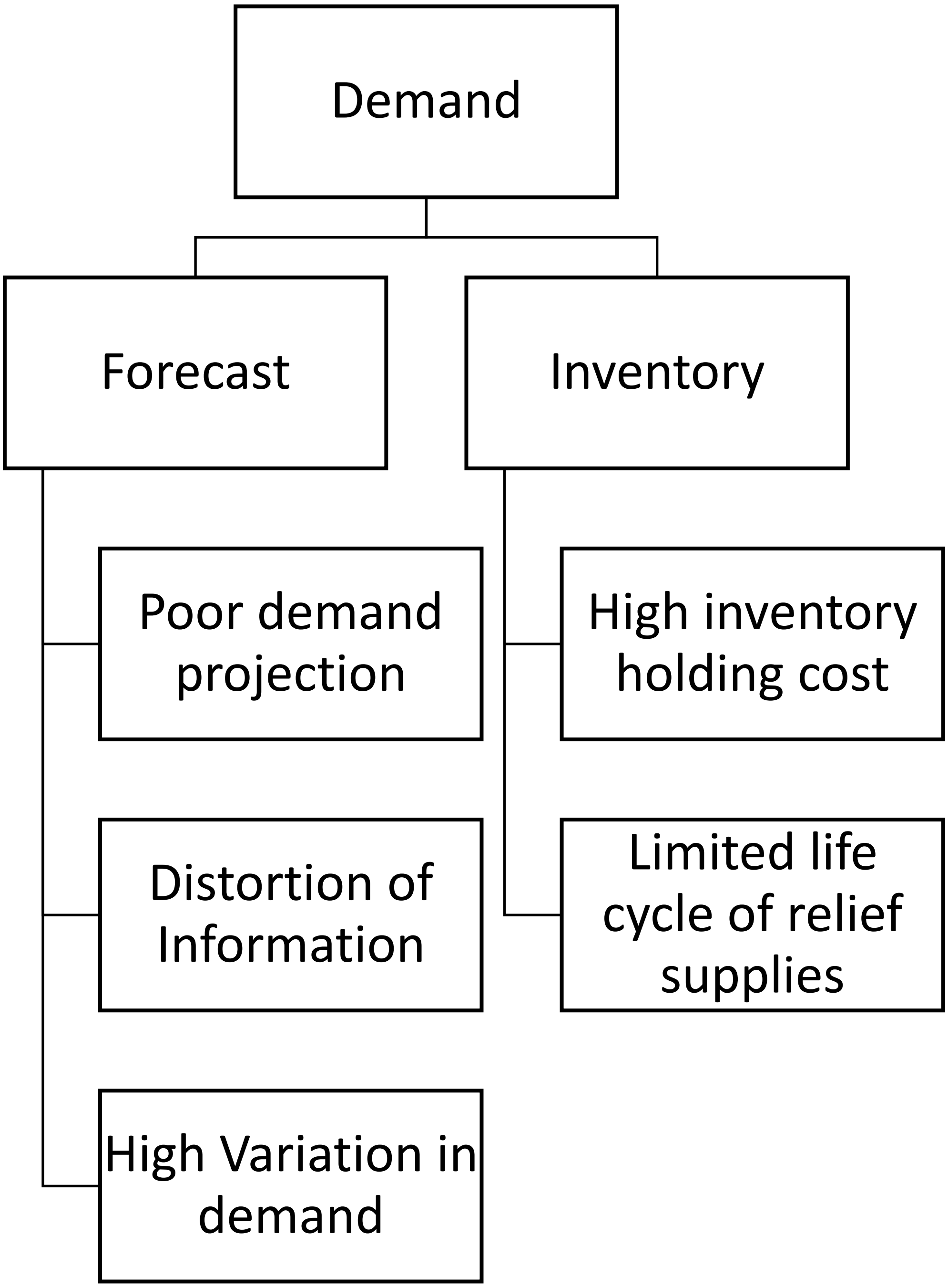

Figure 5.2 Hierarchical structure of demand risk

Table 5.1 Initial classification of emergency supply chain risk factors

Main Category	Sub-Category	Risk Type	Specific Risk Factor
Internal risk	Demand risk	Forecast risk	Poor demand projection
			Distortion of information
		Inventory risk	Inventory holding cost
			Limited life cycle of relief supplies
			Fluctuation/variation in demand
	Supply risk	Procurement risk	Non-compliance of supply contracts
			Purchasing key supplies from a single source
			Exchange rate fluctuations
		Supplier risk	Inadequate supplier capacity
			Poor level of supplier responsiveness
			Variation in transit time
			Lack of supplier flexibility
			Supplier fulfilment errors
			Wrong choice in supply partners
			Lack of competitive pricing
		Quality risk	Defective or damaged relief supplies
			Wrong or unsolicited relief supplies
			Counterfeit relief supplies
	Process risk	Transportation risk	Damaged transport infrastructure
			Absence of alternative transport modes
			Ineffective last-mile delivery
			Theft of relief supplies and resources
			Excessive handling of relief supplies during mode changes
			Damaged warehousing facilities
			Limited holding capacity of facilities

		Warehousing risk	Transit time from facility to relief site
		Systems risk	Poor i.t infrastructure
			Absence of transparency in information dissemination
			Presence of delays during information transmission
			The presence of the wrong media
	Control risk	Decision-maker risk	Restrictions on the use of donations
			Absence of transparency in funding
			Inadequate skill and expertise of relief workers
			Inadequate collaboration amongst stakeholders resulting from mistrust
		Strategic risk	Long-term vs. short-term planning
			Absence of coordination of relief activities and objectives
External risk	Environmental risk	Disruption risk	Impact of follow-up disasters
			War and terrorism
			Variations in climatic conditions
			Fire incidents
		Social risk	Poor communication
			Corrupt practices
			Presence of cultural differences
			Presence of insecurity
			Presence of poor judgement from stakeholders
			Sexual and gender abuses
		Political risk	Absence of legislative and supportive rules that influence relief operations
			Sanctions and constraints that hinder stakeholder collaboration

Inventory risk comes from demand management issues, crucial supply value, and obsolescence. Inventory holding costs and crucial supply life cycles drive this category's risk. Advance demand planning is standard in conventional supply lines, so the chain is well established. Emergency supply chain managers must make quick operational choices, among other challenges. Suppliers, manufacturing sites, and demand stability are unclear. Emergency supply lines are controlled by donors, leaving beneficiaries with few options, so there is no real market (Kovacs and Spens, 2009). Globally stored inventory provides disaster relief supplies immediately (Balcik and Beamon, 2008). Roh *et al.*, (2016) note that pre-purchase of relief supplies is influenced by cost because disasters cause crucial supplies to rise in price. Relief actors practise pre-disaster procurement and storage of crucial supplies. Inventory holding is difficult due to disaster uncertainty and position unpredictability, according to Rawls and Turnquist (2010). Thus, Balcik and Beamon (2008) noted that holding inventory has huge financial consequences, and only a few relief actors can run one. The writers advise relief actors to avoid inventory before disasters due to its complexity and cost. Long-term inventory storage fees are included. Due to disaster relief operations' uncertainty and unpredictability, crucial supplies may be held for long periods, resulting in high costs. However, pre-held inventory cannot support large-scale sudden-onset crisis relief operations. Cost is a major obstacle to pre-held goods. Therefore, the emergency supply chain and crisis relief operation will likely be disrupted without pre-held inventory.

5.2.2 Supply risk

Supplies consist of relief items, personnel/volunteers, and transportation and construction resources. Most of the supplies fall into the relief items category. Supply risk is the upstream equivalent of demand risk; it relates to potential or actual disturbances to the flow of products or information emanating within the network upstream of the primary organisation. Hence, it concerns the risk linked to an organisation's suppliers or suppliers' inability to deliver the materials the company needs to meet its production requirements/demand forecasts effectively. In this study, supply risks encompass three sub-categories, including procurement risks, suppliers' risks, and quality risks. Procurement risks are driven by non-compliance with supply contracts, purchasing key supplies from a single source, exchange rate fluctuations and contract terms (long vs. short term). Poor supplier flexibility, error in supplier fulfilment, inadequate supplier capacity, absence of competitive pricing, poor level of supplier responsiveness and variation in transit time are risk factors that bring about supplier risk. Quality risks arise from defective or damaged relief supplies, wrong or unsolicited relief supplies, and fake or counterfeit relief supplies.

Procurement of critical relief supplies is an important aspect of the disaster relief operation, and stakeholders often try to balance cost and responsiveness when planning response operations. Moreover, these stakeholders are faced with unique disasters, requiring a variety of critical supplies ranging from simple supplies (e.g., food) to complex equipment (e.g., radios, batteries, machinery, etc. (John *et al.*, 2020). Large-scale disaster response often involves receiving massive amounts of critical supplies and resources from numerous donors (governments, communities, or individuals). In some instances, these donations originate from pre-positioned inventory stocks held by organisations; often, the local community initiates donation drives to accumulate these critical supplies. The much-needed supplies are collected from donations, but a tangible portion is considered useless and creates major complications for the emergency supply chain. While it may seem counterintuitive that the donations of well-meaning individuals could have consequences, the evidence is overwhelming. Holguín-Veras *et al.*, (2012) discussed that the recent experiences in Port-au-Prince (Haiti) and Tohoku (Japan) show that the issue is still as significant as it was 60 years ago. As part of an emergency supply management system, PAHO (2001) classified the excessive supplies arriving at disaster relief sites into three: urgent or high priority (HP), non-urgent or low priority and non-priority. Urgent or high-priority critical supplies and resources are needed for immediate response, distribution, and consumption. Supplies and resources that are viewed as non-urgent or low priority are those that are not immediately required but might become relevant shortly. The non-priority supplies are those that (1) are unsolicited, i.e., inappropriate for the event, time, context, or population; (2) arrive unsorted or in a condition impossible to identify or store; (3) efficiently have limited life cycle or have surpassed expiry dates, are perishable or are in poor condition; (4) arrive without a known or appropriate site for efficient distribution; and (5) are damaged, useless or of doubtful value.

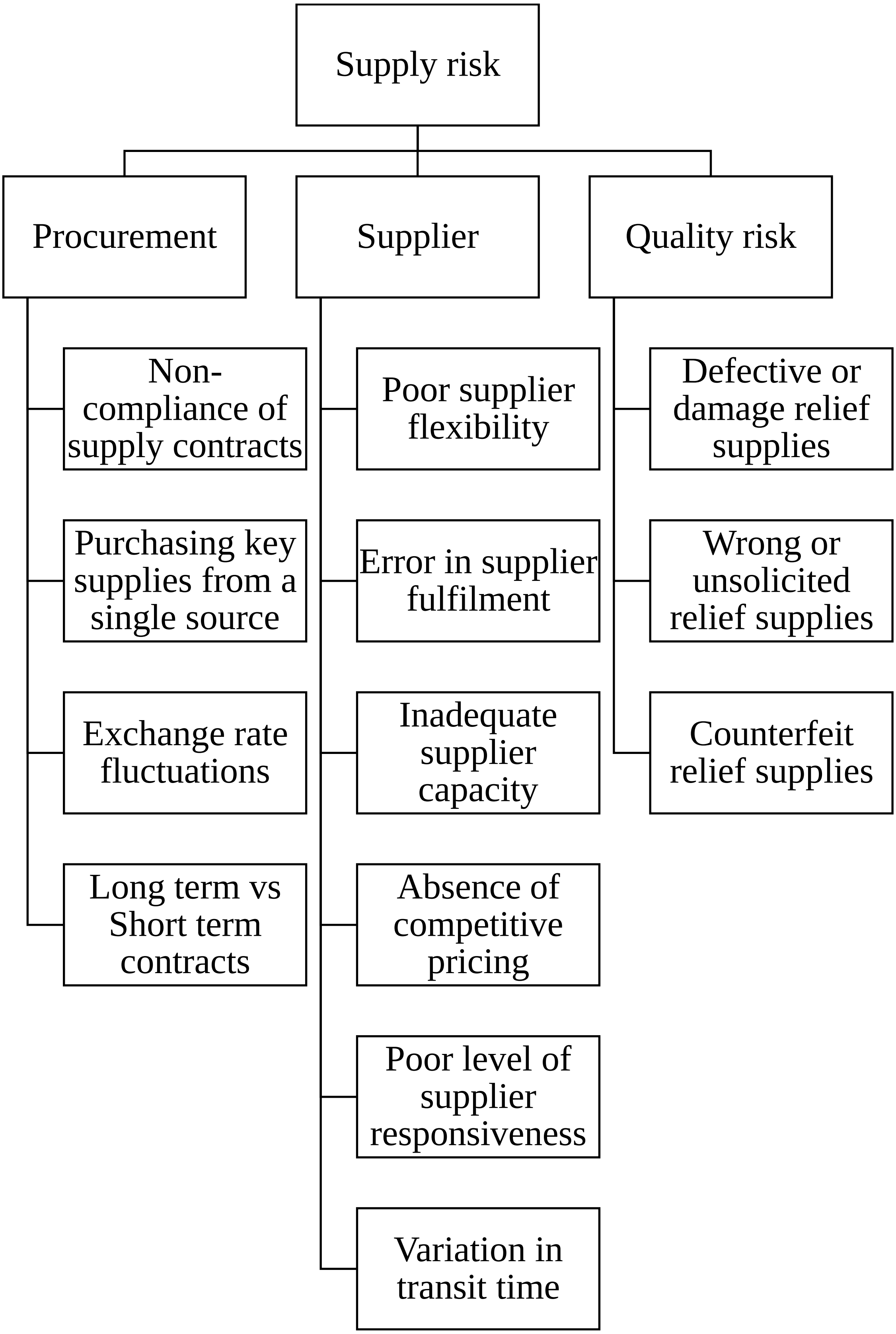

Figure 5.3 Hierarchical structure of supply risk

They may be discarded to make room for urgent and non-urgent critical supplies. Depending on their nature, these non-priority supplies may be burned, buried, or otherwise disposed of (Thomas and Kopczak, 2005). Experience has clearly shown that the flow of non-priority items can be immensely challenging and problematic. Indeed, it is so serious that stakeholders have called it “a second-tier disaster” (Holguín-Veras *et al.*, 2014). For example, delivery of the wrong or unsolicited supplies to a disaster area may congest entry points such as ports and airports and have serious repercussions for handling and warehousing capacities of critical items that are in dire need but arrive later in the pipeline (Kovacs and Falagara Sigala, 2021).

On the other hand, non-urgent or low-priority supplies can equally be challenging when they arrive in large quantities, as illustrated in the Tohoku disaster (Holguin-Veras *et al.,* 2014). In response to news reports that the earthquake victims needed blankets due to cold weather, donors rushed to send blankets to Tohoku. As a result, the volume was much larger than the actual needs. While a tiny fraction of these blankets were needed during the first week of the crisis because of the cold, once the weather warmed up, they became a disruption to the emergency supply chain as they continued to arrive from far-away countries (Holguin Veras *et al.,* 2012). Some critical supplies are regulated, such as medical supplies from the healthcare sector (Kovács and Falagara Sigala, 2021). There are specific regulations containing lists of approved drugs that can be imported and exported, relief organisations, and people permitted to handle specific critical supplies. In addition, the regulations cover temperature, humidity and hygiene requirements for the storage, movement, and materials handling of drugs in disaster relief operations (Kovács and Falagara Sigala, 2021). The World Health Organisation (WHO) frequently publishes the standard technical specifications recommended for emergencies. However, during the COVID-19 pandemic, facemasks upon delivery from global suppliers were not of the promised standard or quality, which resulted in disruption in the emergency supply chains.

5.2.3 Process risk

Processes are a series of activities executed by an organisation to add value. Christopher (2003) explains that the effectiveness of available assets and infrastructures influences the implementation of these activities. Inadequate or insufficient infrastructure is considered a critical and fundamental challenge of any immediate response operation (Kovacs and Spens, 2009). Similarly, Ozdamar *et al.,* (2004) discussed that the presence of inadequate infrastructural facilities hampers the emergency supply chain, and relief actors struggle with critical supplies distribution. Hence, Process risks are those risks that are related to disruptions to this series of activities. Under the main category, three sub-categories are identified: transportation, warehousing, and systems risks. Sudden onsets of disasters such as earthquakes, tsunamis, cyclones, and floods have a strong negative impact on physical infrastructure, including the damage and destruction of transport infrastructure such as roads, bridges and airfields, electricity, and communication infrastructure (Chari *et al.*, 2020).

Transportation risks arise because of driving factors such as damaged transport infrastructure, absence of alternative transport modes, excessive handling of relief supplies, ineffective last-mile delivery and theft of relief supplies and resources when on the move. Transport infrastructure is critical for the movement and delivery of the right quantity of relief supplies at the right time and to the right place to assist the vulnerable population (da Costa *et al.*, 2012). Road and air transport are largely used by relief organisations for response operations (Chari *et al.*, 2020), although the state and availability of transport infrastructures influence the transportation of relief supplies. In this study, transportation risks encompass damaged transport infrastructure, absence of alternative transport infrastructures, excessive handling of relief supplies, ineffective last-mile delivery, and theft of relief supplies and resources. Masaba, (2015) highlighted that disruption to transportation infrastructures during the immediate response operation can negatively impact the overall response operations and create a critical challenge for the vulnerable population and the relief actors, including the government. Along the same lines, Randrianalijaona, (2018) discussed that damage and destruction of transportation infrastructures due to sudden-onset disasters, such as cyclones, limits the accessibility to remote areas in developing nations. Thus resulting in ineffective last-mile delivery of critical relief supplies to the vulnerable population.

Warehouses provide several logistical purposes. Firstly, they protect the prepositioned supplies from physical harm caused by varied climatic conditions. These warehouses are also classified as the hub from which critical relief supplies are segregated and transported to their destination. Damaged warehousing facilities, transit time from facility location to relief sites and limited holding capacity of facilities are driving factors of warehousing risks. As earlier mentioned, the ultimate purpose of emergency logistics and supply chains is to ensure the immediate delivery of appropriate supplies in the right quantities to those affected by the disasters. Therefore, there is a critical need to establish warehouses in strategic locations to ensure relief supplies are speedily available when required (Balcik *et al.*, 2010). Some relief organisations locate these warehouses in disaster-prone locations to minimise cost and time. Stakeholders are challenged by several difficulties during the establishment of warehouses. Rawls and

Turnquist, (2010) discuss that disaster uncertainty and unpredictability is one of such challenges. Uncertainty in relation to whether a disaster will occur, and in situations where they occur, in what location and of what magnitude. The uncertainty of disasters may lead to the destruction of these warehouses and the relief supplies stored in them (Oloruntoba and Gray, 2006). As a result, relief agencies will face grave challenges in alleviating the suffering of the vulnerable population (Balcik and Beamon, 2008). In a bid to avoid the destruction of these warehouses, stakeholders and relief agencies tend to locate these warehouses farther away from disaster-prone regions, and this increases the transit time for the delivery of relief supplies to people who are in dire need.

Hence, the vulnerable population do not get the necessary help at the appropriate time, and the objectives of the emergency supply chain will not be fulfilled. Warehouses should be located as near to the point of consumption as possible (Long and Wood, 1995). Stakeholders and relief organisations must implement effective information management systems in order to ensure the effectiveness of the emergency supply chain. This includes exploring reliable communication systems, transparent information dissemination, and appropriate technology to support the integration of processes. Information concerning the handling and delivery of relief supplies should be made available to verify the effectiveness of the emergency supply chain at every stage of the disaster relief effort (Perry, 2007; Pettit and Beresford, 2009; Taniguchi et al., 2012; Chari *et al.,* 2020). Furthermore, the lack of conventional information and communication infrastructure in disaster-prone areas can disrupt the normal functioning of the emergency supply chain and must be considered in order to reduce the impact of a disaster (Long and Wood, 2005). By providing timely and accurate information, stakeholders and relief organisations can ensure that critical relief supplies are accurately identified, located, and delivered to the vulnerable population in a timely manner.

Media is a critical aspect of disaster relief operations. Van Wassenhove (2006) describes the relationship between stakeholders and the media as a love-hate that is born out of a need to highlight the sufferings of the vulnerable population. The way the media presents a disaster can exert pressure on stakeholders and donors in the emergency supply chain (Katoch, 2006). In this age of instantaneous communication, it is not uncommon for reporters to reach the scene of a big catastrophe before or at the same time as official relief organisations. Damage and human casualties are often highlighted in the earliest reports. Journalists who cover disasters often remark on the inability of aid organisations to respond adequately when the situation has not improved within a few days (Jahre and Heigh, 2008).

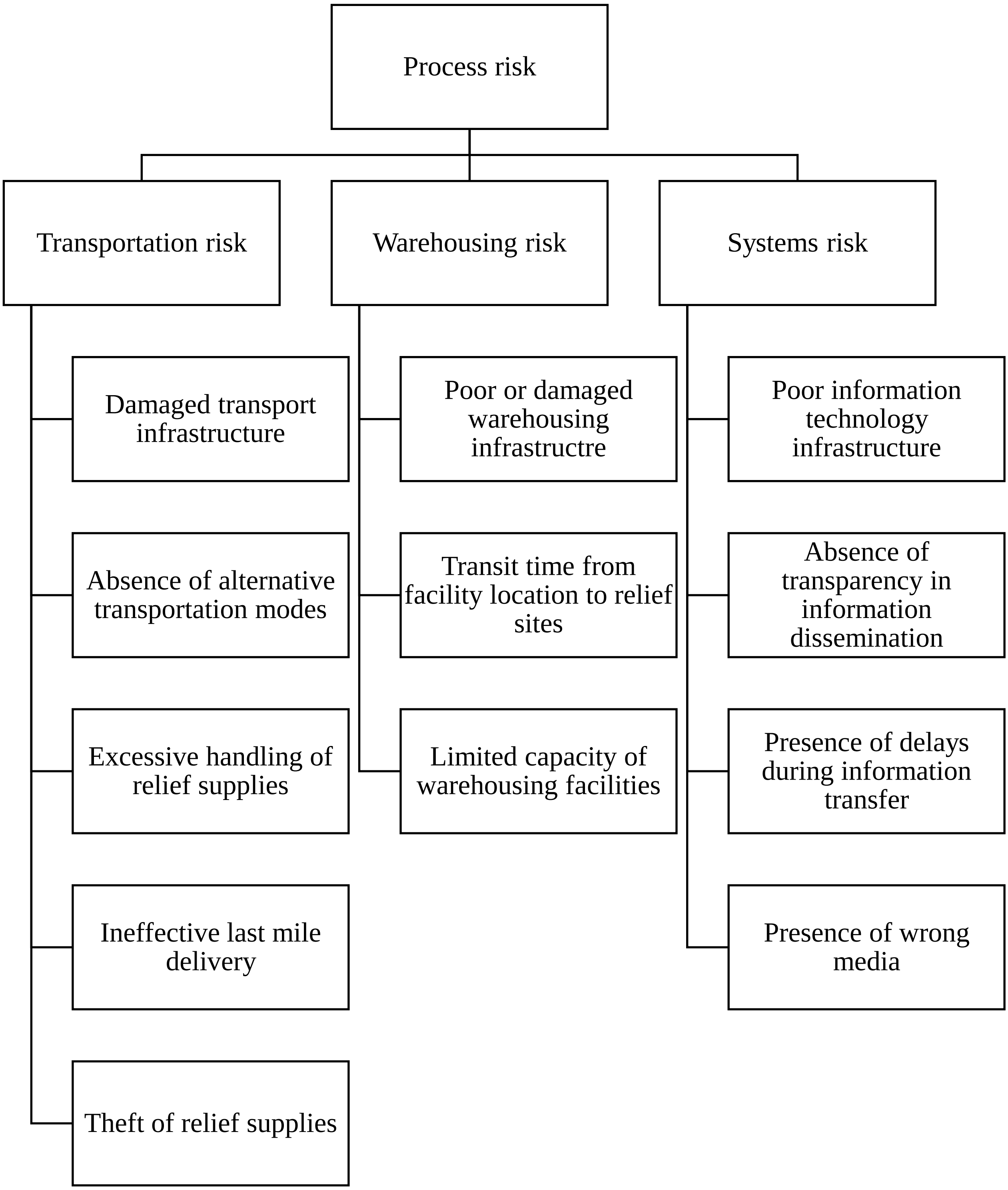

Figure 5.4 Hierarchical structure of process risk

For example, following the Pakistan earthquake in 2005, the media reports stated, '*Anger is mounting among survivors of the South Asia earthquake over the apparently slow response to a disaster that killed at least 20,000*'. When things go wrong in the emergency supply chain, it is usually the people who provide emergency relief aid who get the blame (Jahre and Heigh, 2008). Overstreet *et al.*, (2011) underline that donors provide generous contributions to well-publicised disasters but tend to pay less attention to disasters that are not captured extensively by the media. Moreover, these appeals from well-publicised disasters tend to generate numerous unsolicited donations that can disrupt the normal functioning of the emergency supply chains since resources such as personnel and transportation might be sacrificed to tackle this disruption (Van Wassenhove, 2006). Thereby preventing the chain from achieving its objectives and increasing the suffering of the affected population.

5.2.4 Control Risk

Controls are assumptions, rules, systems, and procedures that govern how an organisation exerts control over the processes. From a supply chain context, Christopher (2003) explains that controls are related to instructions on order quantities, batch sizes, safety stock policies and those policies and procedures are designed for the management of assets and transport infrastructure. Therefore, control risk can be defined as those risks that originate from the application or misapplication of these rules. In this study, control risk consists of two risk types: decision-maker risk and strategic risk.

Decision-maker risks refer to the risks incurred by an individual or decision-making group responsible for managing an organisation or project. Rao and Goldsby, (2009) highlight four common driving factors that can lead to decision-maker risk: a lack of risk awareness, risk attitude or behaviour, inadequate rules and procedures, and bounded rationality of the decision-maker. In emergency supply chains, such as disaster relief, these risks are often due to restrictions on the use of donations, absence of transparency in funding, inadequate skill and expertise of relief workers, and mistrust between stakeholders. Consequently, the purchase and last-mile delivery of relief supplies to beneficiaries is overly reliant on donors (Oloruntoba and Kovacs, 2015). Donor funding is a major contributor to emergency supply chains, yet several issues arise from it. Many countries such as India, China, Iran, and countries of Eastern Europe have emerged as new donors with varied goals and methods of delivery (Oloruntoba and Kovacs, 2015). It is hard to keep track of the funds, as donors often make pledges rather than financial contributions, providing fragmented instalments and short budgeting cycles (Acharya *et al.*, 2006).

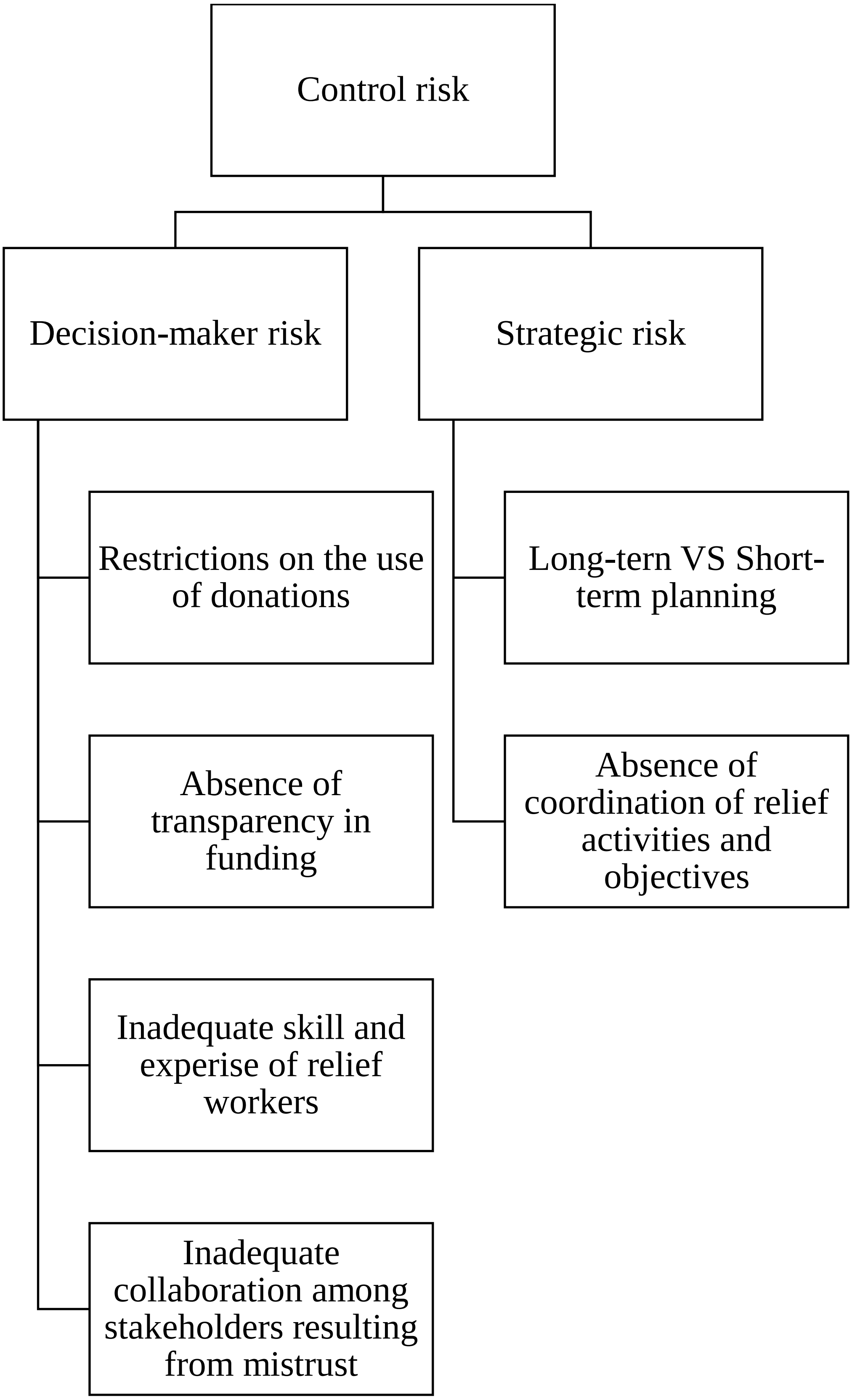

Figure 5.5 Hierarchical structure for control risks

This lack of transparency contributes to uncertainty among organisations, leading to disruptions in the supply chain. Additionally, donors often restrict funding to meet the immediate needs of the vulnerable population after the disaster, hindering a proper disaster relief plan (Murray, 2005). This lack of preparation hinders efficiency in the emergency supply chain, as observed by Whiting and Ayala-O (2009). Currently, the budget deficit for emergency response needs constitutes 40% of the required budget, further hindering the effectiveness of the response (Oloruntoba and Kovacs, 2015).
Acknowledging that logistics and supply chain activities are critical aspects of any disaster relief operation, Kovacs and Spens, (2011) underline that the delivery of adequate and appropriate relief supplies to people affected by disasters is dependent on the skills and expertise of emergency logisticians and managers. These personnel define stakeholders and relief agencies that continually work to alleviate the suffering of those affected by disasters. Thomas and Kopczak, (2004) discuss that emergency logistics and managers come from varied geographies, and the majority do not have appropriate training or possess relevant skills. Similarly, a survey conducted by the Fritz Institute involving 92 emergency logisticians to identify factors that are likely to disrupt the emergency supply chain revealed a lack of inadequate professional emergency logisticians and supply chain managers as one of the dominant issues challenging disaster relief operations. A collective suggestion indicated the need for critical forms of standardised training that will translate into more effective operations.

Trust is a critical concept in supply chain management (Mentzer *et al.,* 2001) and specifically in studies focused on collaboration (Tatham and Kovacs, 2010). Christopher *et al.,* (2006) discuss that, similar to information sharing, the development of cross-functional and inter-organisation teams is another means of building trust in supply chains. Studies on developing and managing cross-functional emergency supply chain teams are limited (Altay *et al.,* 2009). Since the activities of the emergency supply chains are usually executed in highly volatile and chaotic settings with several diverse actors converging at the same location, collaboration and coordination of these actors require immediate development of trust (Stephenson, 2005). However, Kovacs and Spens, (2009) highlighted that the involvement of several relief agencies is one of the many challenges emergency logisticians and supply chain managers face.

Moreover, these relief agencies and organisations take varied forms: from supranational aid agencies (e.g., UN agencies) and governmental organisations to big international non-governmental organisations and one-man non-governmental organisations. These varied organisations arrive with distinct mandates and differ in size and local presence. Hence, emergency logisticians and supply chain managers are faced with difficulties in identifying the right relief agency to collaborate with. The authors suggest that these respective logisticians are keen to be the first on-site; as such, these organisations operate as competitors with each other in a bid to garner public support, leading to mistrust (Altay *et al.,* 2009). Mistrust between relief organisations prevents the effective dissemination of information and poor collaboration.

Similarly, Lu *et al.,* (2018) underline that trust is a critical element that ensures collaboration and coordination between agencies since the presence of mistrust is a major barrier to inter-organisation coordination (Kabra and Ramesh, 2015). Collaboration and coordination between relief organisations in the absence of competition is rare since several constraints (organisational, legal, bureaucratic, and budgetary) do not permit it. A committed and trustworthy emergency supply chain would be helpful in meeting the necessary demands at the time of relief, recovery, and reconstruction (Altay *et al.,* 2009). The paucity of critical information during the immediate response to a disaster increases complexity and uncertainty in emergency supply chains. The presence of unknowns, such as the lack of information concerning survivors and their immediate needs, is prevalent. Whatever information is available is still scattered at various levels within the emergency supply chain, which makes it difficult to plan the relief operations (Altay *et al.,* 2009).

Strategic risks in disaster relief arise from inadequate managerial planning and failure to coordinate activities. Long-term and short-term planning must be balanced in order to manage the relief operations and reduce costs effectively. Balcik *et al.,* (2010) discuss the complexity of having multiple relief actors, each with their motives, missions, and operating challenges. Communication barriers further impede chances of coordination, as witnessed in situations where local and foreign relief agencies have difficulty sharing information (Moore et al. 2003). The lack of a common language can also be a significant constraint, as coordination meetings held in one language may shut out those who do not understand it (Van Wassenhove, 2006). Therefore, strategic planning and capacity planning are fundamental for emergency supply chain success (Blecken, 2010) and provide the best chance of mitigating strategic risks.

5.2.5 Environmental risk

Environmental risk is the risk associated with external and, from the organisation's perspective, uncontrollable events. The risks can affect the organisation directly or through its suppliers and customers. In this study, this category of risks contains three sub-categories: disruption risk, social risk, and political risk. Disruption risks arise due to the impact of follow-up disasters, variations in climatic conditions, fire incidents and war and terrorism. The extreme nature of disasters poses several difficulties for the stakeholders in emergency supply chains. Disasters are uncertain and unpredictable, and information concerning the location, time and magnitude of the next disaster is often unavailable.

In some cases, some disasters follow other disasters and exacerbate existing working conditions. The 'Great East Japan Earthquake' in 2011 was immediately followed by a tsunami and increased the complexity of the disaster response operation. Holguin and Veras, (2014) discuss that disaster response operations are dynamic; as such, emergency managers and logisticians shift from one operation to another, which may lead to the ineffectiveness of the entire operation. Therefore, emergency supply chains must be flexible and responsive to unpredictable events (McLachlin *et al.,* 2009). Presently, the globe is experiencing severe variations in climatic conditions, and their effects are continuing to devastate people, creating new complex situations and complicating those that already exist. These climate changes result in frequent disaster events that increase the risk and vulnerability levels of society and negatively affect and disrupt lives around the globe. A total of 389 climate-related disasters were recorded in 2020, resulting in the deaths of 15,080 people, affecting 98.4 million others, and inflicting $171.3 billion in economic damage. These climate-based disasters influence the nature and character of the emergency supply chain and impede its operations (Holguin-Veras *et al.,* 2012).

Social risks concern beliefs, values and attitudes of the population that are not reflected in the current government policy or business practice (Rao and Goldsby, 2009). According to Freeman (1984), the rationale for classifying political and social risk differently is that they deal with two different (but connected) stakeholders – government and society**.** In this study, social risk results from poor communication, the presence of cultural differences, corrupt practices, sexual gender abuses, and poor judgement from stakeholders**.** Following the impact of disasters, a myriad of relief actors arrive in the stricken region. It is common practice for actors to have little knowledge of other participating actors, thus making it difficult to decide who to collaborate with. These relief actors come from diverse parts of the world with varied cultures and policies that will prevent the free flow of information amongst each other. Sandwell, (2011) discusses that principles and values are the bedrock of the culture of stakeholders and relief organisations. These stakeholders are inclined to integrate properly with people of similar ideology. Thus, it is challenging to communicate with others that seem dissimilar.

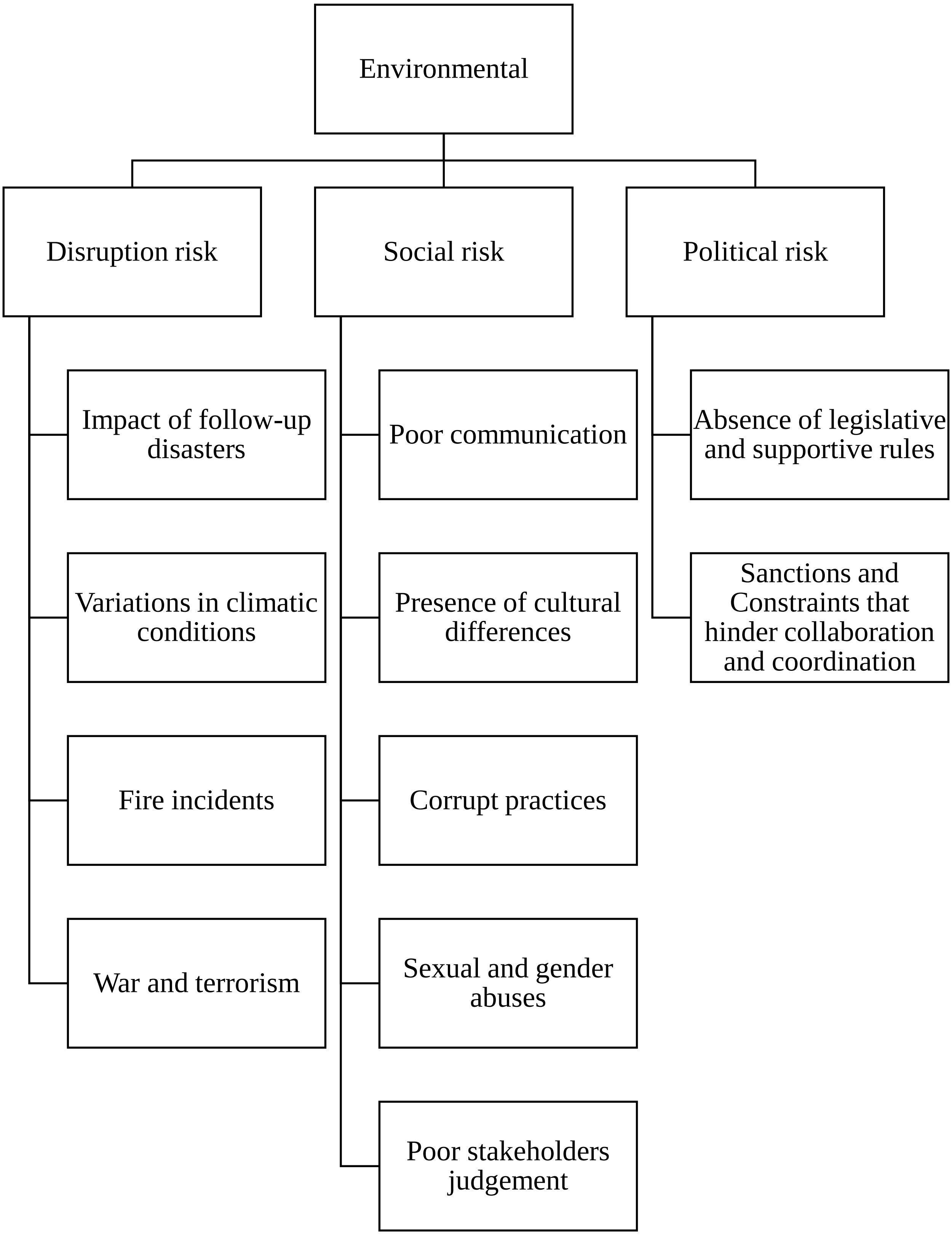

Figure 5.6 Hierarchical structure of environmental risks

Dale and Dulaimi, (2016) discuss that the effectiveness of the emergency supply chain is dependent on the development of sustainable relationships between various stakeholders from different cultural backgrounds and the affected population. Moreover, the absence of such cultural knowledge and information leads to poor communication between stakeholders and beneficiaries. Rodon *et al.,* (2012) mention that the presence of cultural differences results in poor communication and integration, affecting the effectiveness of the emergency supply chain. Therefore, possession of cultural knowledge and information about other stakeholders and beneficiaries is beneficial since it helps to understand the social codes and body language of the affected population (Azmat and Kummer, 2019). Corruption is a critical challenge in almost every disaster relief operation (Thomas and Kopczak, 2005). Disaster context and nature of relief operation influence the risk of corruption (Human interference in critical supply distribution takes several forms, including political grandstanding and dishonesty among individuals distributing supplies (McLachlin *et al.,* 2009). Officials often demand bribes from individuals, businesses, or humanitarian organizations for critical government-related authorizations. For example, bribery is requested for customs clearance of critical supplies or the creation of an imaginary tax (Kunz and Reiner, 2016). Corruption deprives the vulnerable populations and diverts relief funding to governmental officials. Thus, this negatively influences the donors (Altay, 2008; Maxwell *et al.,* 2012), which in turn disrupts the emergency supply chain.

Political risks can significantly impede the effectiveness of emergency relief operations. Host governments are the fundamental actors responsible for shaping the political and economic climate in which emergency relief operations take place. Regulations and restrictions imposed by a host government, such as bureaucratic procedures, tariffs, and non-tariff barriers, can create bottlenecks that delay the transportation and distribution of critical supplies. Furthermore, restrictions can reduce the ability of relief organisations to effectively prepare for disasters or, in extreme situations, cause certain organisations to withdraw from the country altogether (Kovacs and Spens, 2009; Richardson *et al.,* 2016; Kunz *et al.,* 2014; Kunz and Gold, 2015). Effective collaboration between stakeholders, including the local population, local government authorities and humanitarian organisations, is an important aspect of disaster relief operations (Oloruntoba, 2005; McEntire, 2002). Simatupang *et al.,* (2002) discussed that stakeholder collaboration is crucial for the improvement of processes required for immediate response to the rapidly changing conditions, but effective collaboration in emergencies can be challenging. As earlier discussed, Thomas and Kopczak, (2005) mention that the presence of a myriad of agencies can create bottlenecks in the coordination efforts at the field level.

According to Campbell and Hartnett (2005), in emergency supply chains, coordinating the efforts and activities of different stakeholders demands firm command and control. However, in practice, the various organizations normally tend to work independently (Perry 2007). According to Bealt *et al.*, (2016), a general lack of collaboration and coordination usually exists between relief organisations in the field. This often threatens the lives and safety of people affected by disasters. Balcik *et al.*, (2010) underline that host governments are responsible for the coordination of relief organisations and regulations of NGOs.

Conversely, Adem *et al.*, (2018) discussed that the collaboration and coordination of relief organisations face diverse complexities, but the most significant relates to government restrictions. Host governments do not always welcome the activities of relief organisations. Day *et al.*, (2012) suggest that "the fear of foreign influence" drives host governments to reject assistance often or ban the entry of international relief organisations into the country. Thus hindering collaboration with local NGOs. Along the same lines, often host governments are absent, and rebels control territories stricken by disasters. For example, L'hermitte *et al.*, (2014) report that during the 2011 famine, the Al-Shabaab rebel group, which controlled a large part of the Somali territory, prevented relief organisations from accessing the vulnerable population and distributing critical supplies for survival. In 2021, Haiti experienced a profound and disturbing deterioration of the socioeconomic, political and security context. Compounded by the COVID-19 pandemic and a 7.2-magnitude earthquake that affected more than 800,000 people on 14 August, these events have increased the suffering of the vulnerable population.

The activities of armed groups in the Port-au-Prince metropolitan area, which resulted in the displacement of more than 18,000 people, gained momentum with the assassination of President Jovenel Moïse on 7 July. This compromised humanitarian access, particularly on the road to southern departments affected by the earthquake, roads which are under the control of armed groups and often the site of territorial fighting. In October, transport unions and the public protested and went on due to the growing insecurity. Armed groups (with political demands, among others) blocked access to roads leading to Port-au-Prince's oil terminals and significantly hampered fuel distributions. This severely impacted the functioning of several infrastructures and services, including healthcare services, telecommunications, public transportation, bank services, and emergency relief operations (OCHA, 2021).

5.3 Emergency Supply Chain Risk Factors Identification and Classification

This section presents the first phase of the emergency supply chain risk factor analysis process, i.e., the identification and classification of risk factors that can impede the normal functioning of the emergency supply chain in disaster relief operations. This phase is vital for the development of efficient risk management in disaster relief operations. To meet the objectives of this phase, firstly, this study explored several relevant documents, including articles, reports, and government documents, to identify the risk factors that have been addressed in the field. Information concerning emergency supply chains is limited and scattered around several pertinent documents. Thus increasing the complexity of the process. Next, this study developed a survey questionnaire and distributed it to experts to ensure that all risk factors in the context are captured and validated and to test the feasibility of the identified factors. The philosophy behind this is to ensure a comprehensive and robust process. Subsequently, the study goes on to develop a preliminary hierarchical structure for the identified risk factors. Once again, subject experts are invited for the modification and validation of the final hierarchical structure.

5.3.1 Questionnaire design and sample selection

5.3.1.1 Development of questionnaire survey

This section presents details surrounding the design and development of a structured questionnaire for the exploration, identification and validation of the critical risk factors that are inclined to impede or negatively influence the working performance of emergency supply chains. To begin with, an initial questionnaire draft is developed based on the information gathered from secondary sources, including articles, organisational reports, and government documents in the field. This study based the effectiveness of identifying and classifying the risk factors on the insights and expertise of the developed groups. Hence, four experts, including one experienced consultant who is also an author with several published books and over 20 years in the field and three academic researchers with vast knowledge, were contacted and asked to assess the feasibility, content validity and questionnaire design. By subjecting the information retrieved to content validity, the questionnaire becomes clearer and more efficient. The final questionnaire adopted a five-point Likert-type scale with response options ranging from 1 (very unimportant) to 5 (very important). Subsequently, the retrieved feedback was applied, and a final draft questionnaire was developed for relevant data collection. Electronic mail was adopted for the distribution of the questionnaire. Experts were presented with a direct link attached to the email to ensure ease of accessibility and enable the instant receipt of feedback from completed questionnaires. Furthermore, to improve the robustness of the questionnaire, the study obtained ethical approval. Appendix I-II contains copies of these questionnaires.

5.3.1.2 Sample selection

In the context of disaster relief, there is a paucity of emergency logistics and supply chain experts, and accessibility to the very few can be challenging. Thus, this study adopted the purposive and snowballing sampling methods. Both sampling methods are non-probability techniques. According to Saunders *et al.,* (2019), purposive sampling suggests that the researchers utilise personal judgements for the sample selection and is sometimes termed as judgemental sampling. In snowball sampling, being part of the study is voluntary, and the researcher does not choose participants; rather, they opt to be in it. Moreover, the researcher is required to make an initial contact, which is the most difficult aspect of the process, and then these participants identify further participants. It goes on and on (Saunders *et al.,* 2012). Yang *et al.,* (2016) underline that the snowball technique is usually adopted when experts are unavailable and difficult to access.

Participants with diverse expertise and distinctive functional groups are necessary to achieve an effective study (Ramkumar 2016). In this study, several experts positioned globally from varied academic settings and industries were contacted and invited to complete the study. Two criteria were adopted for the selection of participants: work experience and academic qualifications (Wang, 2018). The relevance of these criteria confirms the participant's comprehension of the intricacies of the field in question and provides critical responses to the questionnaire. The final participants included two government officials, eight experts working in non-governmental organisations, seven academic professionals, one consultant and two humanitarian coordinators. For this research, 48 statements were made, and 19 participants were asked to answer each statement using the following 5-point Likert scale. This, as stated by Saunders *et al.,* (2012), can allow the participants to clearly express their perceptions with an adequate level of agreement with the statements given. According to Sekaran, (2000), a Likert scale is a widely accepted technique to reflect the amount of agreement or disagreement with a variety of statements about some beliefs, attitudes, persons, or objects. Based on the Likert measurement feedback received, the identification and classification of emergency supply chain risk factors are modified and confirmed. In addition, the hierarchical structure is finalised.

Accordingly, the chosen experts come from diverse backgrounds and distinctive feedback was received. These feedbacks have distinctive influences on the final decisions and results of this study. Hence, the study utilises expert weighting criteria that segregate the experts based on job positions, qualifications, and work experience, respectively. The expert weighting criteria define the level of significance attributed to data retrieved based on the expert's job role and work experience (Cooke *et al.,* 2008). Table 5.2 presents the description of the relevant weighting criteria. At the end of this process, responses were received from 24 completed surveys. Although the number of responses seems low, Saaty, (2001) mentions that a low sample size is acceptable when data is retrieved from experts in the field. Hence, the number of responses is suitable to continue the study.

Table 5.2 Description of expert weighting criteria

Weight Value	Level of Significance	Description
5.5% - 7.5%	Highly relevant	For experts who possess numerous years of working experience (>20 years) in supply chain management and disaster relief operations and hold high-ranking positions in their organisation. In academia, this weight is reserved for professors and senior lecturers who possess in-depth knowledge and have made reasonable contributions to the field.
3.0% - 5.0%	Fairly relevant	Experts with a minimum of 11 years working experience in supply chain management and disaster relief operations. From the academic side, experts who possess considerable knowledge of the field and understand the likelihood and impact of a supply chain disruption
0.5% - 2.5%	Relevant	Experts with minimal or foundational working experience (6-10 years) in supply chain management and disaster relief operations. From an academic perspective, experts who possess a generic understanding of supply chain management, emergency supply chain management and disaster management.
0	Irrelevant	Experts who possess zero experience in the field

Utilising the expert weighting criteria above, Table 5.3 illustrates the assignment of weight values to the 24 experts who completed the survey. Experts with more than 20 years of working experience in the discipline, both in academia and industry, are given the highest weight of 5.5-7.5%. The duration of working experience also reflects that the expert holds a top position in the industry and academia (Professor). Experts with more than ten years of working experience are weighted as fairly relevant (3.0-5.0%), while feedback from experts with 6-10 years of working experience weighs 0.5-2.5%. Finally, feedback received from experts who possess five or less than five years of working experience is considered irrelevant.

5.3.2 Data analysis and description

One of the primary objectives of this questionnaire survey is to determine the comprehensiveness of the identified risk factors. Moreover, the questionnaire can only be valid if it is deemed reliable. Hence, utilising the Cronbach Alpha method, a reliability and validity test was carried out to define the reliability of the data retrieved from the corresponding experts.

Cronbach's alpha, α (or coefficient alpha), was developed by Lee Cronbach in 1951. The method is the first process adopted in statistical analysis and the most common measure of internal consistency (reliability). Cronbach Alpha is a generally acceptable method utilised when a questionnaire survey contains multiple Likert questions and a grading scale. The method determines the reliability of the scale (Yin, 2014). The method is easy to comprehend, and it requires only one test administration to confirm reliability and validity. This method has been adopted in diverse forms of research that involved determining the measure of reliability of a concept with multi-criteria. Two formulas can be employed to conduct this test:

$$\alpha = \frac{k}{k-1}\left(1 - \frac{\sum_{i=1}^{k}\sigma_{Y_i}^2}{\sigma_x^2}\right) \tag{5.1}$$

$$\alpha_{standardised} = \frac{K\bar{Y}}{1+(K-1)\bar{Y}} \tag{5.2}$$

From the Eq. 5.1, K represents the total number of questions from the survey, σ_x^2 is defined as the variance of the whole sample and $\sigma_{Y_i}^2$ is the variance of a particular question. This formula is primarily used to calculate Cronbach's Alpha. In contrast, Eq. 5.2 evaluates the Alpha based on standardised items. Similarly, the K represents the number of questions in the survey and $\bar{Y}$ is the non-redundant correlation coefficient. The questionnaire encompassed 48 questions, and applying Eq. 5.1, the calculated Cronbach Alpha is 0.934. The Alpha coefficient is used to define the reliability of the data retrieved from experts, and its value ranges from 0-1. As the value of the Alpha coefficient increases, the reliability of the survey increases. According to Chomeya, (2010), a value greater than or equal to 0.9 reflects that the survey is excellently reliable.

Table 5.3 Assignment of weights to experts

Expert	**Weight**	**Organisation**	**Work experience**	**Country of operation**	**Job Title**
Expert 1	2.5%	Relief Organisation	6-10 years	Global	Operations Director
Expert 2	3.0%	Academic	11-15 years	UK and France	Professor
Expert 3	7%	Academic	>20 years	USA	Professor
Expert 4	7.5%	Other	>20 years	Global	Disaster Response and Recovery Adviser
Expert 5	4.0%	Government	11-15 years	United Kingdom	Emergency Response Project Manager
Expert 6	7%	Academic	>20 years	Australia	Professor
Expert 7	7.5%	Non-governmental organisation	>20 years	Global	Partner Portfolio Manager
Expert 8	7%	Academic	>20 years	Thailand	Asst. Professor
Expert 9	4.5%	Non-governmental organisation	11-15 years	Global	Emergency Response Director
Expert 10	7.5%	Non-governmental organisation	>20 years	Thailand	Supply Chain Specialist
Expert 11	3.5%	Non-governmental organisation	11-15 years	Singapore	Emergency Logistics Expert
Expert 12	7.5%	Other	>20 years	Global	Retired Humanitarian leader
Expert 13	7.5%	Other	>20 years	Australia	Disaster Relief Team Manager
Expert 14	2.5%	Non-governmental organisation	6-10 years	Nigeria	Humanitarian Affairs Officer Monitoring and Reporting
Expert 15	7%	Academic	>20 years	United Kingdom	Associate Professor
Expert 16	2.5%	Non-governmental organisation	6-10 years	South Sudan	Head of Programme Support
Expert 17	5%	Non-governmental organisation	16-20 years	Mexico	Regional Logistics Manager
Expert 18	3.0%	Academic	11-15 years	Finland	Professor
Expert 19	4.0%	Non-governmental organisation	11-15 years	DKI JAKARTA	Senior logistics Officer

The survey feedback is defined as good when the value of the Alpha coefficient falls between 0.8-0.89. Table 5.4 depicts the range of the Alpha coefficient and the respective description.

Table 5.4 Description of alpha coefficient value

Alpha Coefficient (α)	Level of Reliability
≥ 0.9	Excellent
0.8 – 0.89	Good
0.7 – 0.79	Acceptable
0.60 – 0.69	Questionable
0.5 – 0.59	Poor
< 0.5	Unacceptable

Furthermore, an analysis of the expert response was conducted. Firstly, the frequency and percentage of responses was calculated and is present in Table 5.5. The study calculated the sum, mean, weighted average and standard deviation of all the questions, respectively (See Table 5.6). Standard deviation can be defined as the measure of dispersion of any given data. Based on the analysis, the value of the standard deviation ranges from 0-1.3. A high value of standard deviation implies that experts attributed several values to the particular risk factor being measured. Finally, the specific risk factors are ranked based on the weighted average (see 5.7).

Table 5.5 Frequency and percentage of survey responses

IDENTIFIED RISK FACTORS		Degree of Significance				
		Very Unimportant	**Less Unimportant**	**Moderate**	**Less Important**	**Very Important**
Procurement risk	Non-compliance of supply contracts	5.26%	10.53%	5.26%	26.32%	52.63%
	Purchasing key supplies from a single source	0%	5.26%	15.78%	15.78%	63.16%
	Exchange rate fluctuations	0%	15.78%	26.32%	31.58%	26.32%
Supplier risks	Lack of supplier flexibility	0%	10.53%	42.11%	15.78%	31.58%
	Supplier fulfilment errors	0%	10.53%	21.05%	26.32%	42.11%
	Wrong choice in supply partners	0%	15.78%	5.26%	10.53%	68.42%
	Inadequate capacity from suppliers	0%	10.53%	5.26%	26.32%	57.89%
	Lack of competitive pricing	0%	0%	47.37%	31.58%	21.05%
	Poor level of responsiveness	0%	10.53%	0%	31.58%	57.89%
	Variation in transit time	0%	10.53%	15.78%	31.58%	42.11%
Quality risks	Defective or damaged supplies	0%	0%	5.26%	10.53%	84.21%
	Wrong supplies	0%	5.26%	10.53%	5.26%	78.95%
	Counterfeit supplies	0%	5.26%	5.26%	10.53%	78.95%
Forecast risks	Inadequate projection of demand due to short or zero lead time	5.26%	0%	15.78%	21.05%	57.89%
	Distortion of information	5.26%	5.26%	15.78%	10.53%	63.16%
Inventory risks	Inventory holding cost	0%	10.53%	26.32%	42.11%	21.05%
	Fluctuations/Variations in demand	0%	10.53%	26.32%	21.05%	42.11%
	Limited life cycle of supplies	0%	0%	21.05%	31.58%	47.37%
Systems risks	Inadequate I.T infrastructure	0%	0%	26.32%	31.58%	42.11%
	Absence of transparency in information dissemination	0%	5.26%	21.05%	21.05%	52.63%
	Presence of delays during information transfer	0%	0%	36.84%	15.78%	47.37%
	The presence of the wrong media	10.53%	15.78%	31.58%	15.78%	26.32%
Transportation risks	Poor or damaged transport infrastructure	5.26%	10.53%	5.26%	10.53%	68.42%

	Absence of alternative modes	0%	0%	21.05%	42.11%	36.84%
	Excessive handling of supplies during mode changes	5.26%	21.05%	21.05%	21.05%	31.58%
	Poor effectiveness during last-mile delivery	0%	10.53%	10.53%	26.32%	52.63%
	Theft of supplies and resources	5.26%	0%	15.78%	31.58%	47.37%
Warehousing risks	Poor or damaged infrastructure	5.26%	5.26%	21.05%	15.78%	52.63%
	Transit time from facility to relief site	0%	10.53%	21.05%	31.58%	36.84%
	Limited holding capacity of the facility	0%	5.26%	21.05%	31.58%	42.11%
Decision-maker risks	Restriction on the use of donations	10.53%	0%	26.32%	21.05%	42.11%
	Absence of transparency in funding	0%	5.26%	21.05%	42.11%	31.58%
	Inadequate skill and expertise of relief workers	5.26%	15.78%	10.53%	42.11%	26.32%
	Inadequate collaboration among stakeholders resulting from mistrust	0%	5.26%	26.32%	10.53%	57.89%
Strategic risks	Long-term vs. Short-term planning	0%	0%	21.05%	15.78%	63.16%
	Absence of coordination of relief activities and objectives	0%	0%	21.05%	15.78%	63.16%
Disruption risks	Impact of follow-up disasters	0%	5.26%	21.05%	10.53%	63.16%
	Variation of climatic conditions	5.26%	5.26%	42.11%	21.05%	26.32%
	Fire incidents	10.53%	26.32%	21.05%	31.58%	10.53%
	War and terrorism	0%	0%	31.58%	26.32%	42.11%
Social risks	Difficulty in communicating with beneficiaries and other stakeholders	0%	10.53%	10.53%	15.78%	63.16%
	Presence of cultural differences	0%	5.26%	26.32%	36.84%	31.58%
	Presence of corruption practices from upstream to downstream along the chain	0%	5.26%	15.78%	26.32%	52.63%
	Sexual and gender abuses	10.53%	0%	15.78%	10.53%	63.16%
	Presence of insecurity affecting relief workers and beneficiaries	0%	5.26%	15.78%	15.78%	63.16%
	Presence of poor judgement from stakeholders	5.26%	5.26%	15.78%	52.63%	21.05%
Political risks	Absence of legislative and supportive rules that influence disaster relief operations	0%	0%	26.32%	26.32%	36.84%
	Sanctions and Constraints that hinder stakeholder collaboration and coordination	0%	5.26%	15.78%	21.05%	68.42%

Table 5.6 Statistical analysis of questionnaire survey

IDENTIFIED RISK FACTORS		Degree of Relevance			
		Sum	**Mean**	**Weighted Average**	**Standard Deviation**
Procurement risk	Non-compliance of supply contracts (S1)	78	4.11	4.155	1.21
	Purchasing key supplies from a single source (S2)	83	4.37	4.24	0.93
	Exchange rate fluctuations (S3)	70	3.68	3.64	1.03
Supplier risks	Lack of supplier flexibility (S4)	70	3.68	3.655	1.03
	Supplier fulfilment errors (S5)	76	4	3.94	1.03
	Wrong choice in supply partners (S6)	82	4.32	4.355	1.13
	Inadequate capacity from suppliers (S7)	82	4.32	4.275	0.98
	Lack of competitive pricing (S8)	71	3.74	3.755	0.78
	Poor level of responsiveness (S9)	83	4.37	4.395	0.93
	Variation in transit time (S10)	77	4.05	4.1	1
Quality risks	Defective or damaged supplies (S11)	91	4.79	4.805	0.52
	Wrong supplies (S12)	87	4.58	4.705	0.88
	Counterfeit supplies (S13)	88	4.63	4.735	0.81
Forecast risks	Inadequate projection of demand due to short or zero lead time (S14)	81	4.26	4.285	1.07
	Distortion of information (S15)	70	4.21	4.035	1.2
Inventory risks	Inventory holding cost (S16)	71	3.74	3.78	0.91
	Fluctuations/Variations in demand (S17)	75	3.95	3.855	1.05
	Limited life cycle of supplies (S18)	81	4.26	4.18	0.78
Systems risks	Inadequate I.T infrastructure (S19)	79	4.16	4.085	0.81
	Absence of transparency in information dissemination (S20)	80	4.21	4.27	0.95
	Presence of delays during information transfer (S21)	78	4.11	4.145	0.91
	Presence of wrong media (S22)	63	3.32	3.36	1.3
Transportation risks	Poor or damaged transport infrastructure (S23)	81	4.26	4.3	1.25
	Absence of alternative modes (S24)	79	4.16	4.165	0.74

	Excessive handling of supplies during mode changes (S25)	67	3.53	3.655	1.27
	Poor effectiveness during last-mile delivery (S26)	80	4.21	4.335	1
	Theft of supplies and resources (S27)	79	4.16	4.145	1.04
Warehousing risks	Poor or damaged infrastructure (S28)	77	4.05	4	1.19
	Transit time from facility to relief site (S29)	75	3.95	4.01	1
	Limited holding capacity of facility (S30)	78	4.11	4.11	0.91
Decision-maker risks	Restriction on the use of donations (S31)	73	3.84	3.77	1.27
	Absence of transparency in funding (S32)	76	4	3.93	0.86
	Inadequate skill and expertise of relief workers (S33)	70	3.68	3.68	1.17
	Inadequate collaboration among stakeholders resulting from mistrust (S34)	80	4.21	4.2	1
Strategic risks	Long term Vs Short term planning (S35)	84	4.42	4.365	0.82
	Absence of coordination of relief activities and objectives (S36)	84	4.42	4.45	0.82
Disruption risks	Impact of follow-up disasters (S37)	82	4.32	4.355	0.98
	Variation of climatic conditions (S38)	68	3.58	3.48	1.09
	Fire incidents (S39)	58	3.05	3.02	1.19
	War and terrorism (S40)	78	4.11	4.145	0.85
Social risks	Difficulty in communicating with beneficiaries and other stakeholders (S41)	82	4.32	4.37	1.03
	Presence of cultural differences (S42)	75	3.95	4.03	0.89
	Presence of corruption practices from upstream to downstream along the chain (S43)	81	4.26	4.325	0.91
	Sexual and gender abuses (S44)	79	4.16	4.145	1.31
	Presence of insecurity affecting relief workers and beneficiaries (S45)	83	4.37	4.39	0.93
	Presence of poor judgement from stakeholders (S46)	72	3.79	3.785	1
Political risks	Absence of legislative and supportive rules that influence disaster relief operations (S47)	77	4.05	4.145	0.83
	Sanctions and Constraints that hinder stakeholder collaboration and coordination (S48)	82	4.32	4.415	0.92

Table 5.7 Ranking of risk factors by mean and weighted average.

Risk Factors	Weighted Average	Mean
S11	4.805	4.79
S13	4.735	4.63
S12	4.705	4.58
S36	4.45	4.42
S48	4.415	4.32
S9	4.395	4.37
S45	4.39	4.37
S41	4.37	4.32
S35	4.365	4.42
S6	4.355	4.32
S37	4.355	4.32
S26	4.335	4.21
S43	4.325	4.26
S23	4.3	4.26
S14	4.285	4.26
S7	4.275	4.32
S20	4.27	4.21
S2	4.24	4.37
S34	4.2	4.21
S18	4.18	4.26
S24	4.165	4.16
S1	4.155	4.11
S21	4.145	4.11
S40	4.145	4.11
S44	4.145	4.16
S47	4.145	4.05
S27	4.145	4.16
S30	4.11	4.11
S10	4.1	4.05
S19	4.085	4.16
S15	4.035	4.21
S42	4.03	3.95
S29	4.01	3.95
S28	4	4.05
S5	3.94	4
S32	3.93	4
S17	3.855	3.95
S46	3.785	3.79
S16	3.78	3.74
S31	3.77	3.84
S8	3.755	3.74
S33	3.68	3.68

S25	3.655	3.53
S4	3.655	3.68
S3	3.64	3.68
S38	3.48	3.58
S22	3.36	3.32
S39	3.02	3.05

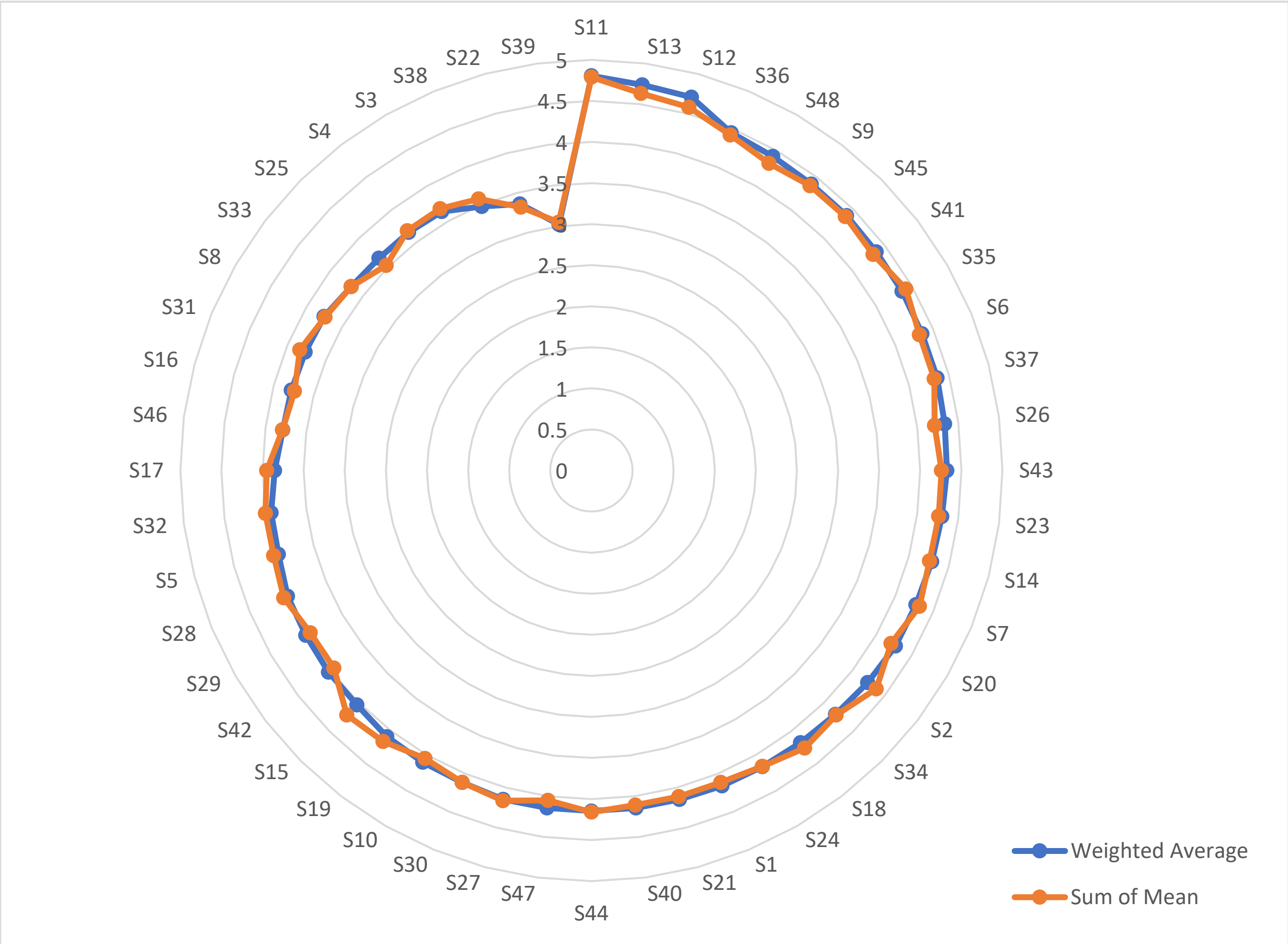

Figure 5.7 Mean value vs Weighted average

Figure 5.7 presents the difference between the mean and weighted average of the respective risk factors. From the chart, the study observed that both results are almost identical. Hence, the weighting criteria adopted are dependable. Based on the questionnaire survey, experts were mandated to rate the level of importance of the respective risk factors using a five-point Likert scale (i.e., 1 = very unimportant, 2 = less unimportant, 3 = moderate, 4 = less important and 5 = very important). The mean of the Likert scale is 3, so respective factors that obtain values above the mean value (3) are suggested to be very important and have a great influence on the emergency supply chain. However, experts from diverse backgrounds participated in the survey. Each expert was assigned weights based on their respective job position and work experience (Number of years). Therefore, the study calculated the weighted average of each question and only risk factors that obtained mean and weighted average values ≥4 were chosen for further study. This is illustrated in Figures 5.8 to 5.12

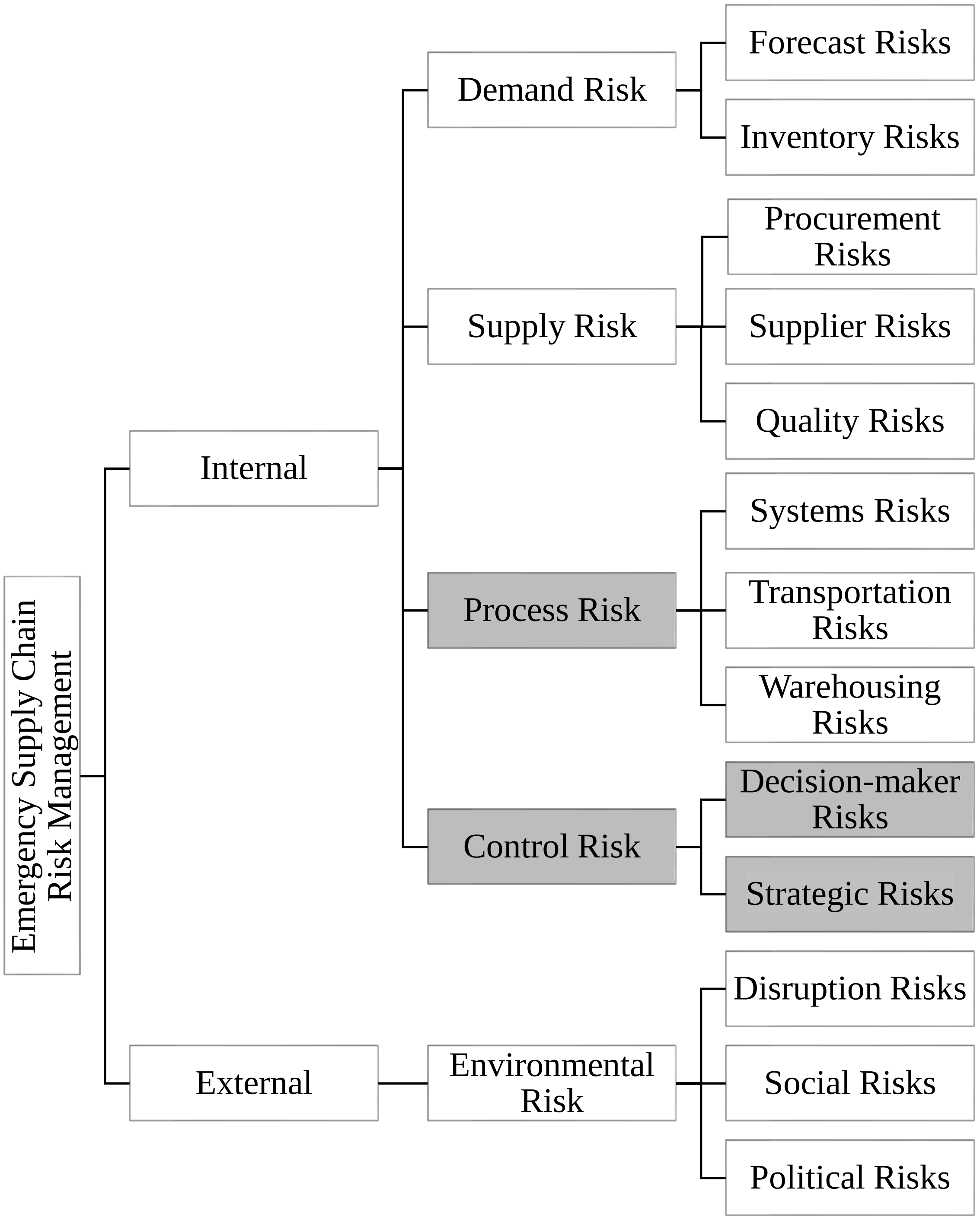

Figure 5.8 Modified hierarchical structure.

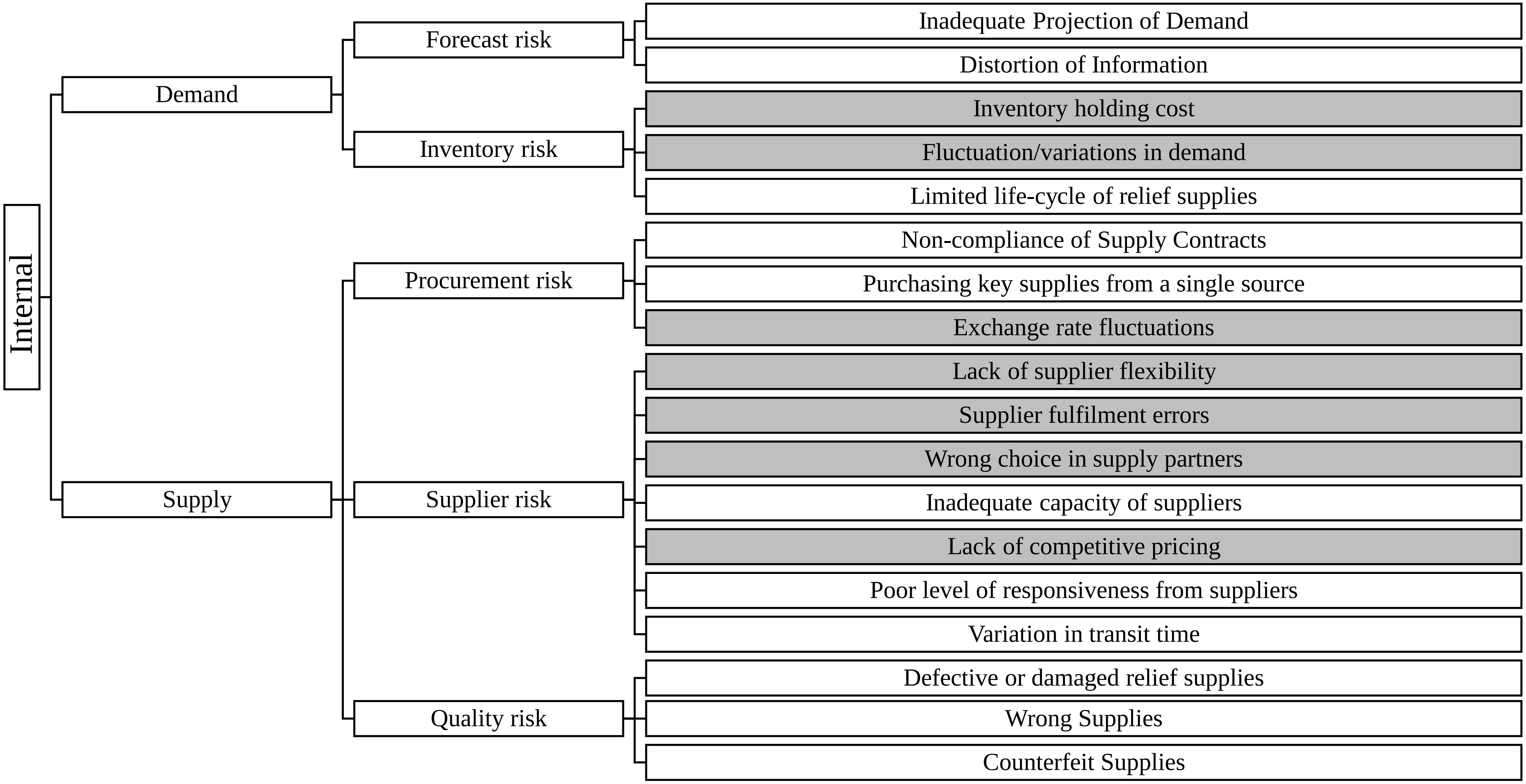

Figure 5.9 Modified hierarchical structure (internal risks)

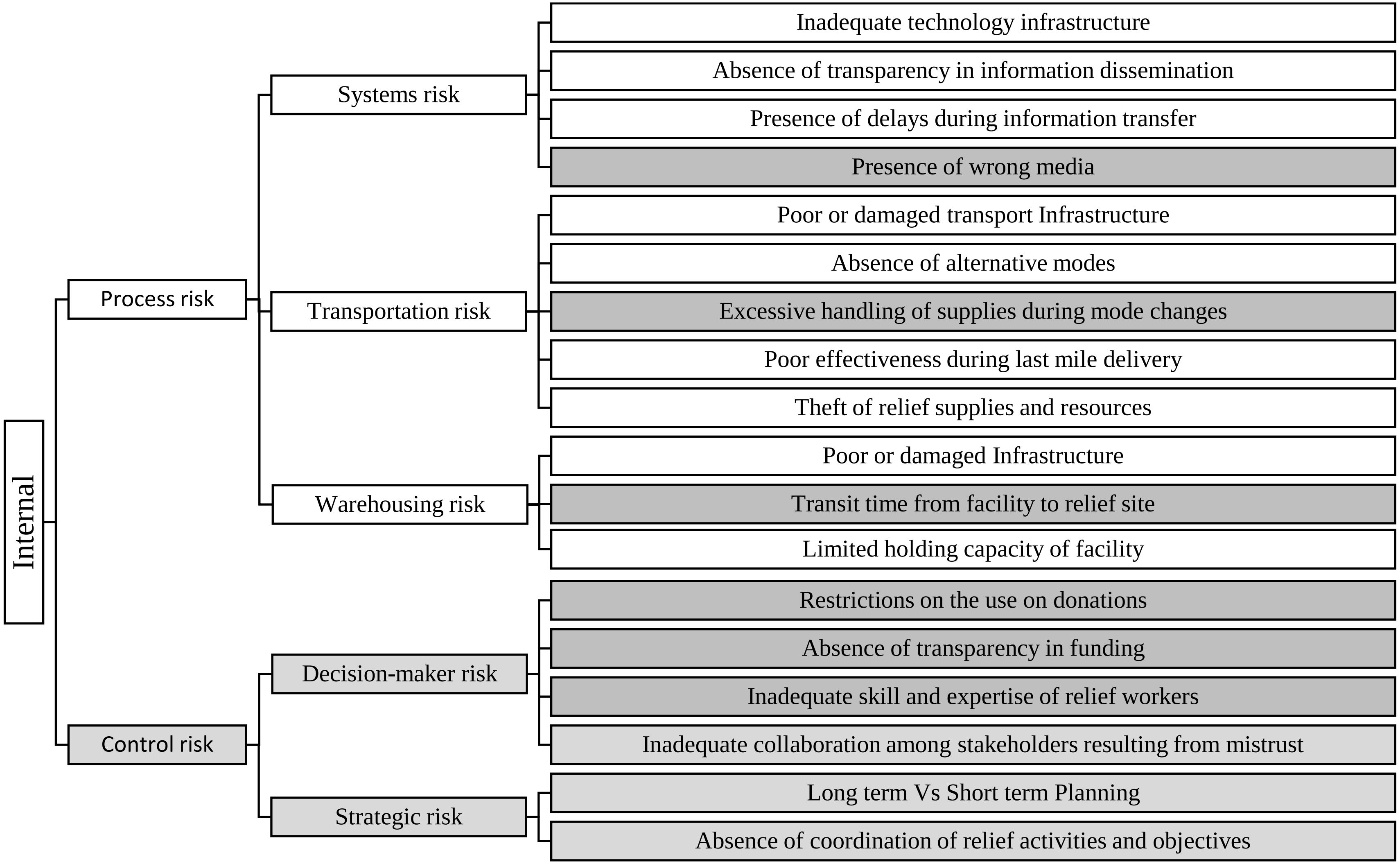

Figure 5.10 Modified hierarchical structure (internal risks)

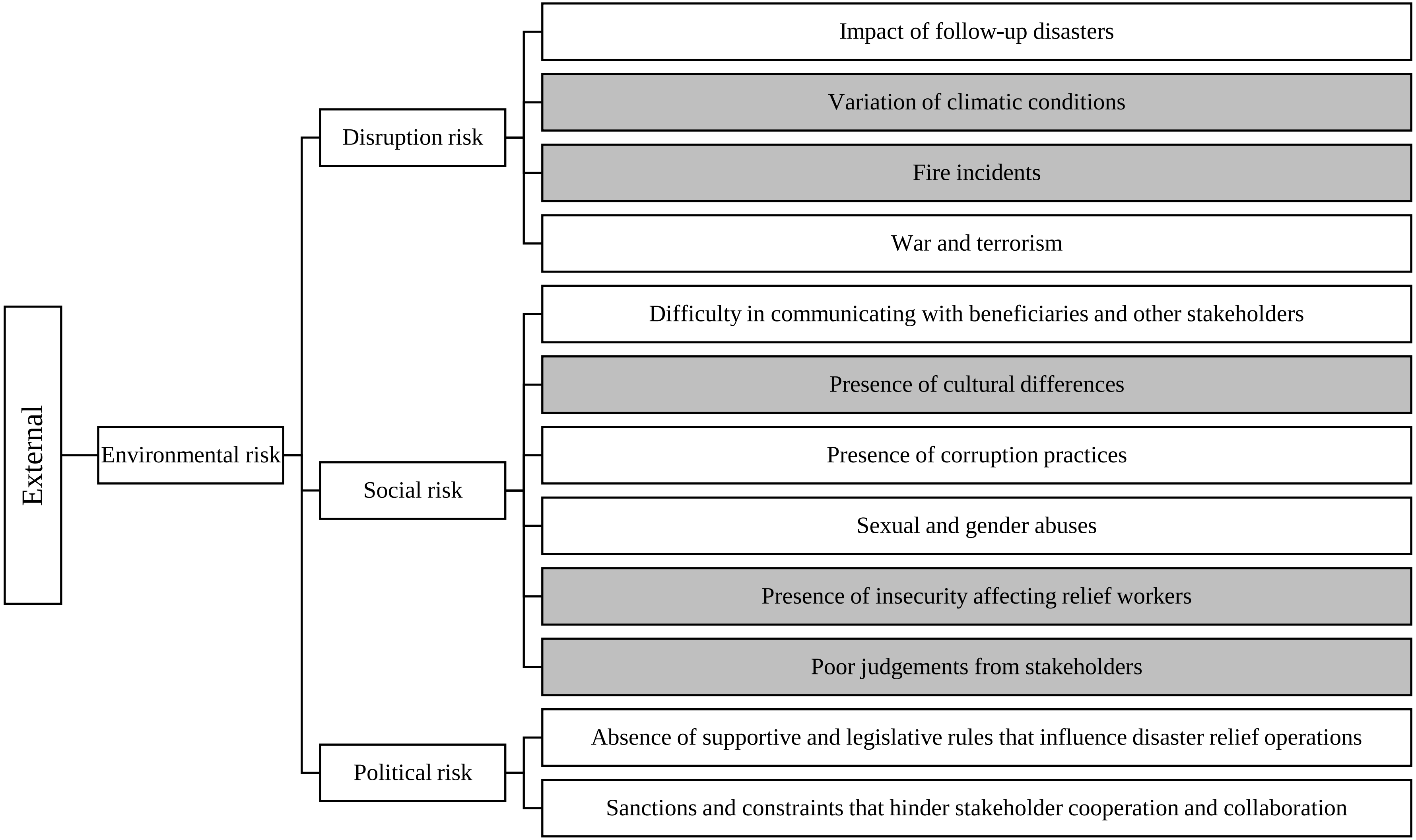

Figure 5.11 Modified hierarchical structure (external risks)

From the feedback analysis, results indicate that quality-related risks, including defective or damaged relief supplies (4.805), counterfeit relief supplies (4.735) and wrong relief supplies (4.705), strategic-related risks, including the absence of coordination of relief activities and objectives (4.45), politically related risks including sanctions and constraints that hinder stakeholder collaboration and coordination (4.415) and, supplier-related risks including poor level of responsiveness (4.395) is of more importance to decision-makers and stakeholders of the emergency supply chain in disaster relief operations. These risk factors are more likely to impede the normal functioning of the emergency supply chain, which might lead to grave consequences such as loss of human lives. Although the questionnaire survey was completed by different experts with diverse backgrounds and operating in varied regions, the result from the analysis presents a relative consensus of the feedback received. Based on these results, the study developed an updated hierarchical structure for the risk factors that are likely to disrupt the normal operation of the emergency supply chain. The ultimate hierarchical structure consists of two fundamental categorizations, four lower-level categorizations, eleven varieties of hazards, and twenty-eight risk elements. The fusion of the sub-categories of process and control risks gave rise to a new sub-category, which is referred to as infrastructural risks.

Additionally, it was observed that specific risk factors displayed overlapping connotations, resulting in the elimination of one to avoid duplication. The research team and experts offered more insights into the categorisation of the emergency supply chain risk factors and the final development of the hierarchical structure. Subsequently, the final hierarchical structure was presented to only experts who indicated that they were willing to participate further in the study to ensure the final structure was valid and reliable. No further modification was required for the hierarchical structure.

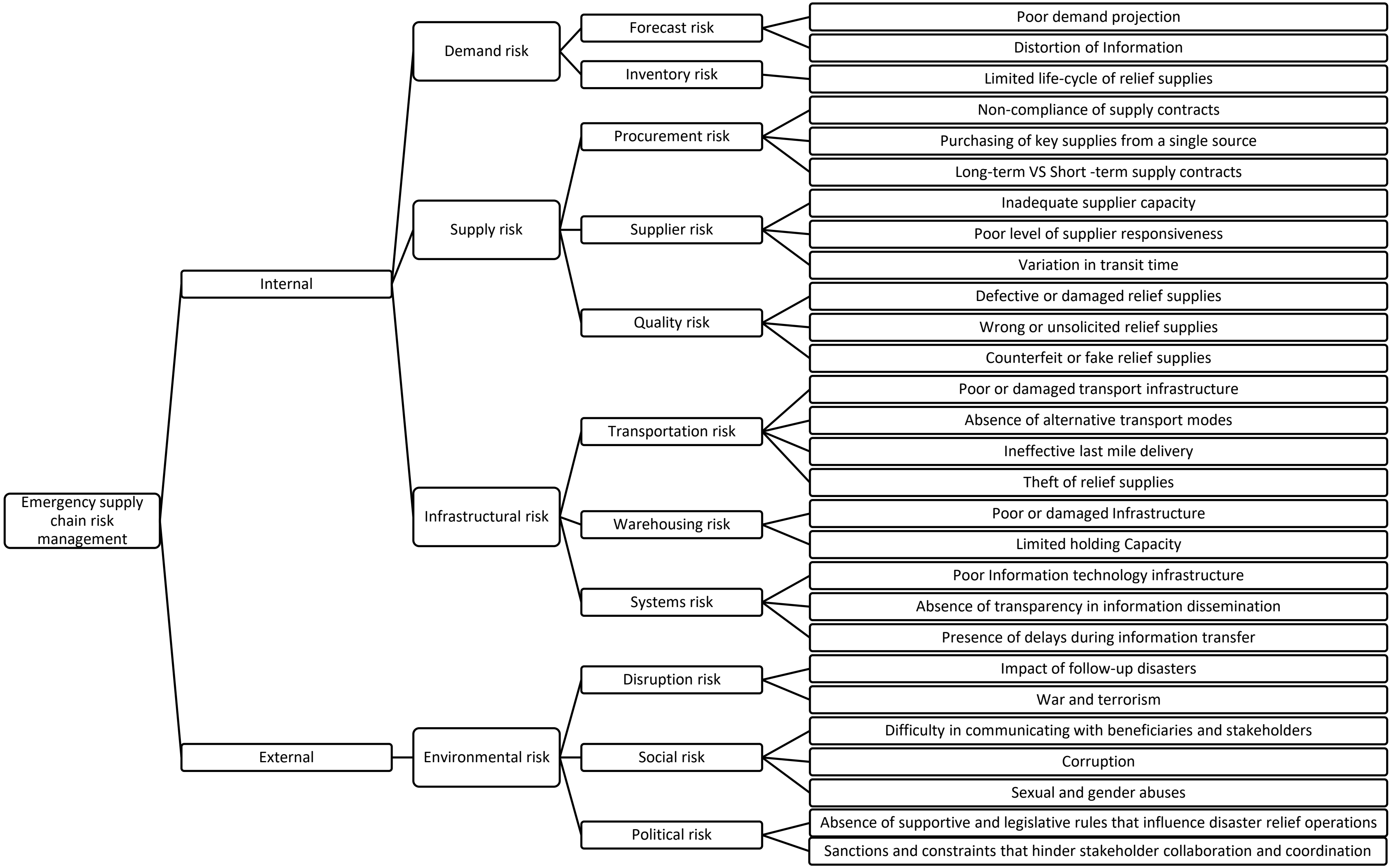

Figure 5.12 Final hierarchical structure for emergency supply chain risk factors

5.4 Conclusion

The goal of this chapter was to identify and classify the specific risk factors that are prevalent in the emergency supply chain. This is a fundamental step of the risk management process, and this research utilized the insights and knowledge gathered during the literature review (Chapter 2) as a foundational base. Several risk factors that are likely to disrupt the normal activities of the emergency supply chain during immediate disaster response operations were retrieved from scattered pertinent documents. In addition, information on various risk classification methods from previous commercial studies was collected. Next, a series of questionnaire surveys, emails, and face-to-face discussions resulted in the validation of twenty-eight specific risk factors and the development of a hierarchical structure. Accordingly, the hierarchical structure classified the specific risk factors into two main categories: internal and external risks. The internal risk was further decomposed into three sub-categories: demand, supply, and infrastructural risks, and eight different risk types: forecast, inventory, procurement, supplier, quality, transportation, warehousing, and systems risk types. The external risk consisted of one sub-category, environmental risk, and three risk types: social, disruption, and political risk types. A generic and comprehensive emergency supply chain risk portfolio was developed for practitioners in the field to gain a better understanding of the nature of risks that are likely to be encountered during immediate response operations.

CHAPTER 6 – RISK FACTORS ASSESSMENT IN EMERGENCY SUPPLY CHAINS

6.1 Introduction

The goal of this chapter is to conduct the second stage of the risk management process: Risk assessment. This stage of the study adopted various steps. Firstly, empirical studies, the retrieval of primary data from experts in the field by means of a pairwise comparison survey. Secondly, the application of the Fuzzy-AHP methodology for analysis of the retrieved subjective data. The primary purpose of the methodology is to evaluate and prioritize the risk factors that can disrupt the effective operation of emergency supply chains. Based on the results, effective decision-making in subsequent stages (risk mitigation) of the risk management process is more feasible.

6.2 Fuzzy-AHP Methodology for Risk Factor Assessment in Emergency Supply Chains

The proposed integrated risk management model encompasses the whole process. Based on the developed model, risk factor assessment adopts the generic Fuzzy-AHP model for evaluating the significance of and prioritizing the identified risk factors. Fig 6.1 presents the schematic diagram of the model. This model is a fundamental part of the comprehensive risk management model proposed for implementation in emergency supply chains.

6.3 An Empirical Study

Risks in emergency supply chains are detrimental to their overall effectiveness, so the need to identify and assess these risks remains crucial. Considering this, a fuzzy-AHP method has been developed to examine the level of significance of the identified risk factors inherent in an emergency supply chain. This process will encompass four different stages, including:

1. Development and dissemination of a pairwise comparison questionnaire to the relevant population sample.
2. Data Collection and Analysis.
3. Investigating the robustness of the proposed method.
4. Discussion of findings.

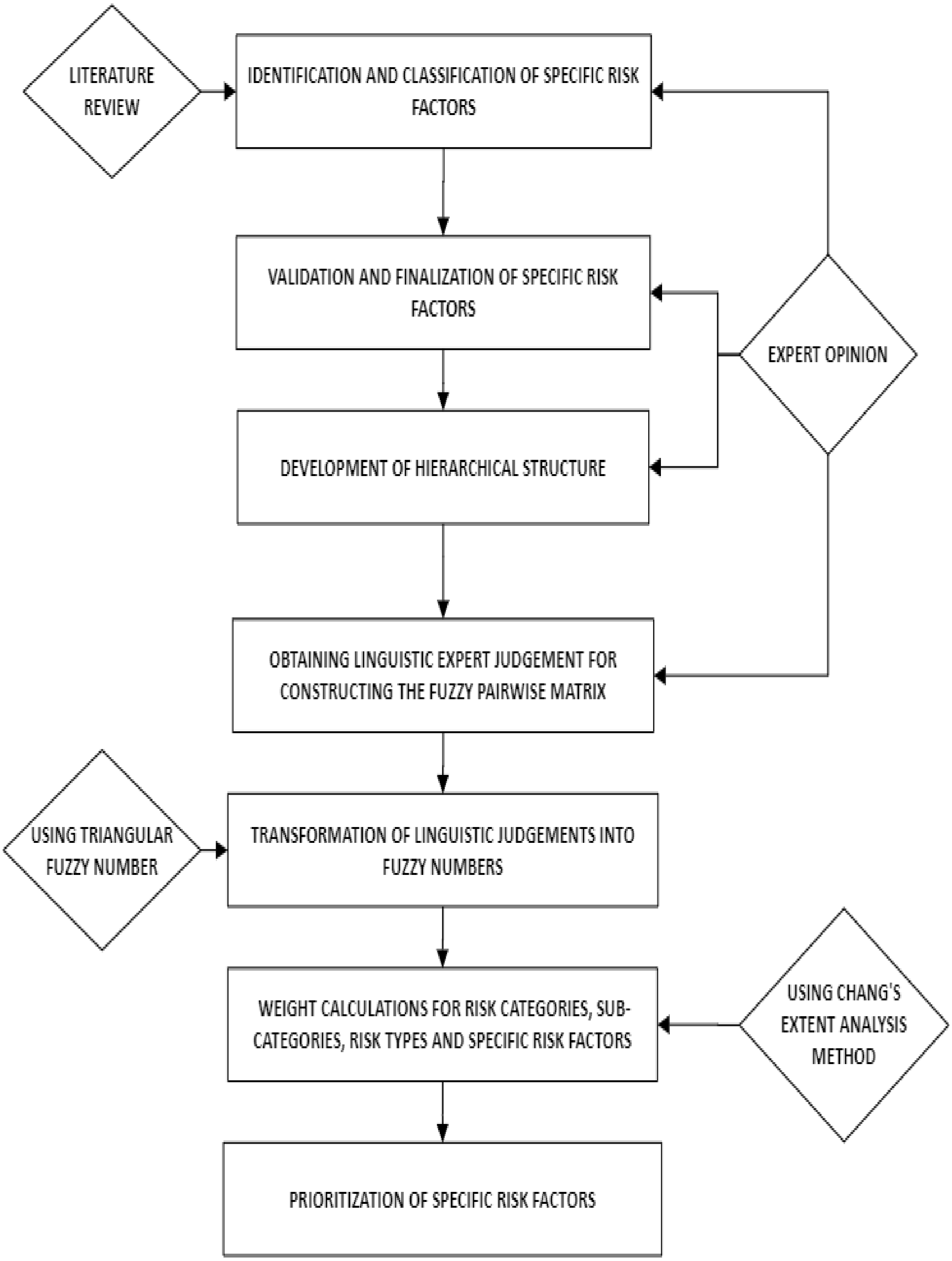

Figure 6.1 Fuzzy AHP model for risk assessment of ESC risk factors

6.3.1 The questionnaire survey

Before the dissemination of the final questionnaire for data collection, this study conducted content validity to ensure relevance, simplicity, and clarity (Yaghmaie 2003). Initially, the developed questionnaire was sent to the supervisory team to review and make necessary comments. Based on the comments received, the questionnaire was adjusted and approved. Subsequently, this study performed a pilot study to ensure the necessary robustness of the questionnaire. In addition, the study obtained ethical approval to ensure the full validity of the questionnaire contents and appropriate expert consent. Based on this, the final pairwise comparison questionnaire (see Appendix III) was developed and sent out to the relevant sample.

The developed questionnaire contained four distinct parts. The first, "Part 1", contained an introductory note informing the participants of the relevant details of the researcher, research focus and research institution. The second, "Part 2", contained questions related to the participants. Questions including type of organization, job title, and years of experience in the industry were asked to ensure the participant's expertise. "Part 3" explains how to answer the pairwise comparison questions. The F-AHP technique utilizes predefined linguistic terms to reduce vagueness and uncertainty in decision-making. In this part, experts were instructed to use predefined linguistic terms to define the level of importance of one risk factor over another. "Part 4" presented the questions comprising eighteen matrices that required completion as per experts' judgement as per their knowledge and expertise.

Table 6.1 Details of survey responses

Questionnaires		**Invalid Response**	**Valid Responses**
Mails	130		
HLA	55		
RO	20	1	19
LinkedIn	98		
Total	303		

Table 6.2 Survey respondents' profile

Experts	Type of organisation	Job title	Years of experience
1	Non-governmental Organisation	Operations Director	6-10 years
2	Academic	Professor	20+ years
3	Other	Former UN humanitarian Coordinator	20+ years
4	Other	Logistics Director	20+ years
5	Academic	Senior Lecturer	20+ years
6	Non-governmental Organisation	Project Coordinator	6-10 years
7	Academic	Professor	20+ years
8	Non-governmental Organisation	Operations Manager	16-19 years
9	Non-governmental Organisation	Supply Chain Specialist	11-15 years
10	Other	Logistics Associate	16-19 years
11	Relief Organisation	Supply Chain Manager	20+ years
12	Non-governmental Organisation	N/A	20+ years
13	Non-governmental Organisation	Country Director	20+ years
14	Non-governmental Organisation	Director Public Health	16-19 years
15	Academic	Professor	20+ years
16	Other	N/A	20+ years
17	Non-governmental Organisation	Regional Emergencies Supply Chain Officer	11-15 years
18	Non-governmental Organisation	Regional Supply Chain Manager	11-15 years
19	Non-governmental Organisation	Emergency Logistics Officer	6-10 years

6.3.2 Numerical Illustration

Step 1. Developing the hierarchical structure of the decision problem.

This is the first step of the analysis. Here, a hierarchy is developed to illustrate the problem. The hierarchy consists of a goal, a set of criteria, sub-criteria, and sub-sub criteria. Based on findings from the previous chapter, a final hierarchical structure is built (see Fig 6.2).

Step 2. Establishing a group of decision-makers

The target sample is selected globally without limiting the scope to a specific region. Firstly, organizations involved in global disaster response operations are chosen from ReliefWeb's website, a humanitarian information service provided by the United Nations Office for the Coordination of Humanitarian Affairs (OCHA). The ReliefWeb's editorial team monitors and collects information from more than 4,000 key sources, including humanitarian agencies at the international and local levels, governments, think tanks and research institutions and the media. In addition, the study utilized private and public directories to retrieve contact details of experts in the field. The Humanitarian Logistics Association contains a private directory of humanitarian and emergency experts only accessible to registered members. Public directories, including Facebook and LinkedIn, were also utilized to retrieve additional contact details.

A total of 20 relief organizations and 283 emergency response experts comprising both academic and practitioner experts were selected and sent the questionnaire. Job positions held by the experts include operations director, professor, former UN humanitarian coordinator, logistics director, emergency logistics officer, logistics and supply chain specialist and regional emergencies supply chain officer. During this stage of the study, the world was still facing the COVID-19 pandemic and restrictions such as the social distancing rule were still in effect. Thus, Email was used as a means of contacting the respondents to register an intent to participate and sending the link to the online-based questionnaire for completion. In total, 20 questionnaires were returned, with only one incomplete questionnaire (see Table 6.1). The accepted questionnaire return rate is 6%. The rate seems low but acceptable because the AHP is a subjective technique, and a high return is not warranted if the relevant information is gathered from experts with sufficient knowledge and expertise (Saaty, 2001).

Table 6.2 presents the profiles of the experts reported in Part A of the questionnaire. From the results, 13 experts, accounting for 68.4% of all respondents, reportedly have worked in the field for more than 20+ years, and another three experts (15.8%) have worked for more than 10+ years. This indicates the high level of professionalism and expertise of the questionnaire respondents. In addition, it portrays a high validity and reliability of findings. With regards to the type of organization, only four experts (21%) are from academia, and 79% are industry practitioners from global relief operations who are constantly operating in the field.

In many cases, an indication of an unbalanced sample will cause some form of bias, but due to the criticality of the emergency supply chain and its complex working environment, more information is needed from experts who work in the scene of operations to retrieve more informed and dynamic data. In terms of job positions, the experts reported vast and distinct professional roles. The results constituted three academic professors and one senior lecturer from academia. Others reported holding positions such as operations director, operations manager, logistics director, regional emergency supplies officer, emergency supplies officer, project coordinator, and supply chain specialist. One expert is a retired United Nations humanitarian coordinator; another two experts did not reveal their job position; however, one mentioned the type of organization. These experts have reported from diverse organizations with different structures. Most of the job positions reported may entail similar duties and responsibilities. It is noteworthy to state that only logistics and supply chain experts who have specific qualifications and experience in emergency response were included in the target sample.

Step 3. Determining the linguistic variables and fuzzy conversion scale.

The triangular fuzzy conversion scales and linguistic scales, which are proposed by Patil and Kant, (2014), are used to convert such linguistic values into fuzzy scales, as demonstrated in Figure 3.4 and Table 3.4.

Step 4. Establishing comparison matrices

At this stage of the analysis, the degree of importance of each risk factor has been subjectively measured. The decision-makers are advised to make relevant comparisons between two risk factors in the same class. Experts' judgement has been presented in linguistic terms and is not suitable for analysis. In this phase of the analysis, the subjective terms will be transformed into triangular fuzzy numbers using the linguistic scale presented in Table 3.4. For illustration purposes, a part of an expert's response is presented in Table 6.3.

Table 6.3 Fuzzy pair-wise comparison matrix for supply risk (one expert)

Attribute	Procurement	Supplier	Quality
Procurement	(1, 1, 1)	(2/5, 1/2, 2/3)	(2/7, 1/3, 2/5)
Supplier	(3/2, 2, 5/2)	(1, 1, 1)	(1/3, 2/5, 1/2)
Quality	(5/2, 3, 7/2)	(1, 5/2, 3)	(1, 1, 1)

Step 5. Constructing the aggregated matrix of all decision-makers.

This study utilizes the AIJ approach for the aggregation of group decisions. Table 6.4 illustrates the aggregated matrix for supply risks.

Table 6.4 Aggregated matrix of supply risks (Geometric mean)

Attribute	Procurement	Supplier	Quality
Procurement	(1.000, 1.000,1.000)	(0.286, 1.066, 3.500)	(0.286, 0.945, 3.000)
Supplier	(0.286, 0.938, 3.497)	(1.000, 1.000, 1.000)	(0.286, 1.108, 3.000)
Quality	(0.333, 1.058, 3.497)	(0.333, 0.903, 3.497)	(1.000, 1.000, 1.000)

Step 6. Calculating the consistency index and consistency ratio of the aggregated comparison matrix

To validate the results and ensure that pairwise comparison is consistent overall, the AHP utilizes a consistency ratio. The findings from the aggregated pairwise comparison are validated and termed reliable when the consistency ratio is less than or equal to 0.1

Step 7. Calculating the priority weights of the risk factors

Following the aggregation of expert judgements for a consensus decision, the weight of each attribute and sub-attribute is calculated. In this study, the extent analysis method is utilised to compute the priority weights of the attributes with respect to the goal of the study. The aggregated fuzzy comparison matrix is shown in Table 6.5

Table 6.5 Aggregated pairwise comparison of criteria with respect to the goal.

Attribute	Internal	External
Internal	(1.000, 1.000, 1.000)	(0.286, 1.021, 3.500)
External	(0.286, 0.979, 3.497)	(1.000, 1.000, 1.000)

To calculate the synthetic extent, use the formula below:

$$Si = \sum_{j=1}^{N} a_{ij} \left\{ \sum_{i=1}^{n} \sum_{j=1}^{n} \hat{a}_{ij} \right\}^{-1}$$

Firstly, calculate $\sum_{j=1}^{N} a_{ij}$, which is the summation of the fuzzy numbers across the rows,

To add two fuzzy numbers, use the formula,

$A_1 + A_2 = (l_1, m_1, u_1) + (l_2, m_2, u_2) = (l_1 + l_2, m_1 + m_2, u_1 + u_2$

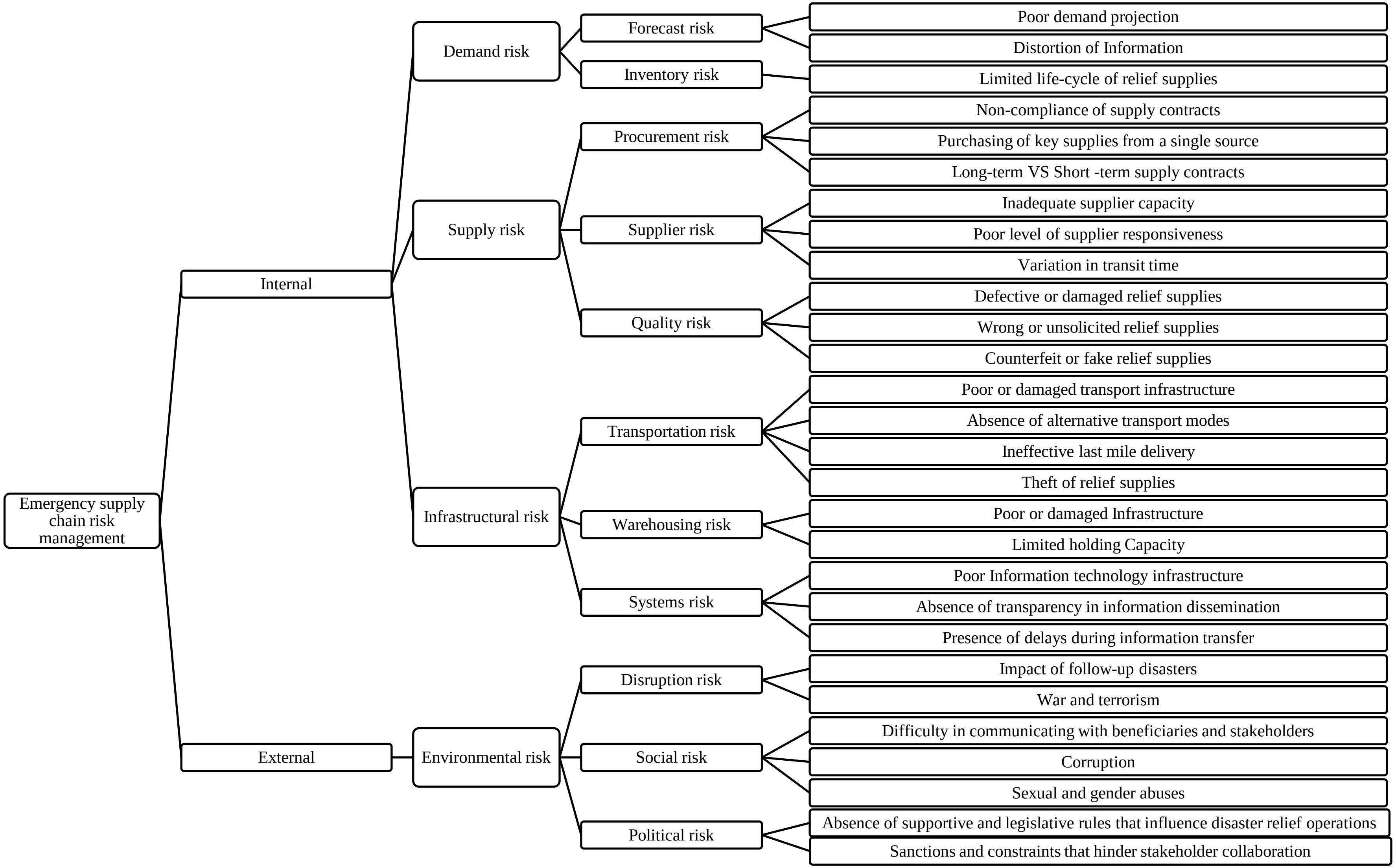

Figure 6. 2 Final Hierarchical Structure

Table 6.6 Sum of Fuzzy numbers across the rows

Attribute	Internal	External	Sum
Internal	(1.000, 1.000, 1.000)	(0.286, 1.021, 3.500)	(1.286, 2.021, 4.500)
External	(0.286, 0.979, 3.497)	(1.000, 1.000, 1.000)	(1.286, 1.979, 4.497)

Next, calculate the summation of the summed fuzzy numbers down each column using the formula:

$$\left\{\sum_{i=1}^{n}\sum_{j=1}^{n}\hat{a}_{ij}\right\}^{-1}$$

Again, we use the formula:

$$A_1 + A_2 = (l_1, m_1, u_1) + (l_2, m_2, u_2) = (l_1 + l_2, m_1 + m_2, u_1 + u_2)$$

Table 6.7 Sum of fuzzy numbers down columns

Attribute	Sum
Internal	(1.286, 2.021, 4.500)
External	(1.286, 1.979, 4.497)
Sum	(2.572, 4.000, 8.997)

Then, calculate the inverse of the sum using the inverse formula:

$$(l, m, u)^{-1} = (1/u, 1/m, 1/l)$$

Thus, $(2.572, 4.000, 8.997)^{-1} = (1/8.997, 1/4.000, 1/2.572)$

Next, calculate the synthetic extent.

$$Si = \sum_{j=1}^{N} a_{ij} \{\textstyle\sum_{i=1}^{n}\sum_{j=1}^{n}\hat{a}_{ij}\}^{-1}$$

To calculate, both results are multiplied using the formula:

Sum
(1.286, 2.021, 4.500)
(1.286, 1.979, 4.497)

$\times \quad (1/8.997, 1/4.000, 1/2.572)$

$S_1 = (1.286, 2.021, 4.500) \times (^1/_{8.997}, ^1/_{4.000}, ^1/_{2.572})$ = (0.1429, 0.5053, 1.7496)

$S_2 = (1.286, 1.979, 4.497) \times (^1/_{8.997}, ^1/_{4.000}, ^1/_{2.572})$ = (0.1429, 0.4948, 1.7484)

Next, the degree of possibility is calculated by comparing the synthetic values using the Eq of extent analysis.

V ($S_1 \geq S_2$) = 1

V ($S_2 \geq S_1$) = $\frac{(0.1429 - 1.7484)}{(0.4948 - 1.74848) - (0.5053 - 0.1429)} = \frac{-1.6055}{-1.616}$ = 0.9935

Next, calculate the weight vector and normalize the non-fuzzy weights.

d' (S_1) = min V ($S_1 \geq S_2$) = min (1) = 1,

Similarly, d' (S_2) = min V ($S_2 \geq S_1$) = min (0.9935) = 0.9935

Hence, the weight vector is,

W' = $(1, 0.9935)^T$

The final step is the normalization of the weight vectors by dividing the weights by the sum of the total weights.

$W_{total} = W_1 + W_2$

W_{total} = 1 + 0.9935 = 1.9935

Table 6.8 Priority weights with respect to the goal

Attribute	Internal	External	Weights
Internal	(1.000, 1.000, 1.000)	(0.286, 1.021, 3.500)	0.5016
External	(0.286, 0.979, 3.497)	(1.000, 1.000, 1.000)	0.4984

Following the weight calculation, a comparison of all attributes and sub-attributes takes place. Weight normalization must take place whenever the values in the matrix are greater than zero. Global weight calculations should be calculated by multiplying the local weights of attributes with respective sub-attributes. The calculated values are shown in Table 6.9

Table 6.9 Global ranking of risk factors

MAIN CATEGORY	MAIN CATEGORY WEIGHT	SUB-CATEGORY	SUB-CATEGORY RATIO WEIGHT	RISK TYPE	RISK TYPE RATIO WEIGHT	SPECIFIC RISK FACTORS	RISK FACTOR RATIO WEIGHT	FINAL WEIGHT	Rank
						POOR DEMAND PROJECTION	0.507	0.041742332	9
				FORECAST	0.494	DISTORTION OF INFORMATION	0.493	0.040589684	10
		DEMAND	0.332						
				INVENTORY	0.506	LIMITED LIFE-CYCLE OF RELIEF SUPPLIES	1	0.084331984	4
						INADEQUATE SUPPLIER CAPACITY	0.356	0.020652674	15
				SUPPLIER	0.334	POOR LEVEL OF SUPPLIER RESPONSIVENESS	0.334	0.019376385	17
INTERNAL	0.502					VARIATION IN TRANSIT TIME	0.31	0.01798407	19
		SUPPLY	0.346			NON COMPLIANCE OF SUPPLY CONTRACTS	0.341	0.019723248	13
				PROCUREMENT	0.333	PURCHASING KEY SUPPLIES FROM SINGLE SOURCE	0.334	0.019318372	16
						LONG-TERM VS SHORT-TERM CONTRACTS	0.325	0.018797817	22
						DEFECTIVE OR DAMAGED RELIEF SUPPLIES	0.347	0.020010013	14
				QUALITY	0.332	WRONG OR UNSOLICITED RELIEF SUPPLIES	0.329	0.01897203	18
						COUNTERFEIT RELIEF SUPPLIES	0.324	0.018683701	20
						DAMAGED TRANSPORT INFRASTRUCTURE	0.253	0.014231784	25
						ABSENCE OF ALTERNATIVE TRANSPORT MODES	0.251	0.01411928	26
				TRANSPORTATION	0.348	INEFFECTIVE LAST MILE DELIVERY	0.251	0.01411928	26
						THEFT OF RELIEF SUPPLIES AND RESOURCES	0.245	0.013781767	27
		INFRASTRUCTURAL	0.322						
						DAMAGED WAREHOUSING FACILITIES	0.515	0.026888671	11
				WAREHOUSING	0.323	LIMITED HOLDING CAPACITY OF FACILITIES	0.485	0.025322341	12
						POOR I.T INFRASTRUCTURE	0.331	0.017549366	23
				SYSTEMS	0.328	ABSENCE OF TRANSPARENCY IN INFROMATION DISSEMINATION	0.347	0.018397674	21
						PRESENCE OF DELAYS DURING INFORMATION TRANSMISSION	0.321	0.017019173	24
				DISRUPTION	0.354	IMPACT OF FOLLOW-UP DISASTERS	0.486	0.085677912	3
						WAR AND TERRORISM	0.514	0.090614088	1
						POOR COMMUNICATION	0.337	0.05454345	6
EXTERNAL	0.498	ENVIRONMNETAL	1	SOCIAL	0.325	CORRUPT PRACTICES	0.333	0.05389605	7
						SEXUAL AND GENDER ABUSES	0.33	0.0534105	8
				POLITICAL	0.321	ABSENCE OF LEGISLATIVE AND SUPPORTIVE RULES THAT INFLUENCE RELIEF OPERATIONS	0.537	0.085843746	2
						SANCTIONS AND CONSTRAINTS THAT HINDER STAKEHOLDER COLLABORATION	0.463	0.074014254	5

6.3.3 Sensitivity Analysis

This research performed a sensitivity analysis to examine the effects of changes in the final ranking of the specific risk factors of the emergency supply chain. The results are presented in Table 6.10. In the process of assessing the risk prevalent in the emergency supply chain, not all sub-categories of risk were involved in the pairwise comparison process with other categories at the same level. For example, environmental risk is the only sub-category of the main category of external risk. Therefore, there may be concerns in relation to the larger weights of this sub-category and other forms of risks associated with it. The fuzzy-AHP methodology in this research utilized subjective judgements from diverse experts for the calculation of respective weights and prioritization of the specific risk factors. Thus, it is important to check the validity of the final ranking by altering the respective weights attained (Govindan *et al.*, 2014). To illustrate the sensitivity analysis, for easy comprehension, the process will be conducted using the specific risk factors. The process involves multiplying each risk factor by the number of risk factors in its respective risk type. For example, forecast risk consists of poor demand projection and distortion of information. The weight of each risk factor will be multiplied by 2. Findings from the analysis indicate that the top 10 risk factors remain the same, which justifies the robustness of the research model.

6.3.4 Results and Discussion

Determining the most important risk factor that will most likely impede the smooth operation of the emergency supply chain can be challenging, but utilising the fuzzy-AHP methodology to prioritise the risk factors will ensure the process is comprehensive and systematic. Adopting the fuzzy AHP will improve the management of risk in the emergency supply chain, which will most definitely enhance its effectiveness and efficiency in disaster relief operations. Risk sources associated with the emergency supply chain are categorised into two main categories, internal and external risk, with four sub-categories: demand, supply, infrastructural and environmental risks, eleven risk types and twenty-eight specific risk factors.

With respect to the main categories of risk, Internal risks are risks that are within the control of the stakeholders in the emergency supply chain, and external risks are risks that arise from factors that stakeholders have no primary influence on. The order of priority reveals that internal risks (50.6%) are more important than external risks (49.4%). This indicates that stakeholders should pay more attention to the effectiveness of their processes and actions within the supply chain. For example, during an immediate response operation, a myriad of actors differing in local presence, size, mandate, and structure are present.

Table 6.10 Sensitivity analysis

SPECIFIC RISK FACTORS	INITIAL WEIGHT	INITIAL RANK	WEIGHT AFTER MULTIPLICATION	RANK AFTER MULTIPLICATION
POOR DEMAND PROJECTION	0.041742332	9	0.083484664	9
DISTORTION OF INFORMATION	0.040589684	10	0.081179368	10
LIMITED LIFE-CYCLE OF RELIEF SUPPLIES	0.084331984	4	0.084331984	8
INADEQUATE SUPPLIER CAPACITY	0.020652674	13	0.061958022	11
POOR LEVEL OF SUPPLIER RESPONSIVENESS	0.019376385	16	0.058129155	14
VARIATION IN TRANSIT TIME	0.01798407	22	0.05395221	23
NON COMPLIANCE OF SUPPLY CONTRACTS	0.019723248	15	0.059169743	13
PURCHASING KEY SUPPLIES FROM SINGLE SOURCE	0.019318372	17	0.057955115	15
LONG-TERM VS SHORT-TERM CONTRACTS	0.018797817	19	0.05639345	19
DEFECTIVE OR DAMAGED RELIEF SUPPLIES	0.020010013	14	0.060030039	12
WRONG OR UNSOLICITED RELIEF SUPPLIES	0.01897203	18	0.05691609	17
COUNTERFEIT RELIEF SUPPLIES	0.018683701	20	0.056051103	20
DAMAGED TRANSPORT INFRASTRUCTURE	0.014231784	25	0.056927136	16
ABSENCE OF ALTERNATIVE TRANSPORT MODES	0.01411928	26	0.05647712	18
INEFFECTIVE LAST MILE DELIVERY	0.01411928	26	0.05647712	18
THEFT OF RELIEF SUPPLIES AND RESOURCES	0.013781767	27	0.055127068	22
DAMAGED WAREHOUSING FACILITIES	0.026888671	11	0.053777342	24
LIMITED HOLDING CAPACITY OF FACILITIES	0.025322341	12	0.050644682	27
POOR I.T INFRASTRUCTURE	0.017549366	23	0.052648098	25
ABSENCE OF TRANSPARENCY IN INFROMATION DISSEMINATION	0.018397674	21	0.055193022	21
PRESENCE OF DELAYS DURING INFORMATION TRANSMISSION	0.017019173	24	0.051057519	26
IMPACT OF FOLLOW-UP DISASTERS	0.085677912	3	0.171355824	3
WAR AND TERRORISM	0.090614088	1	0.181228176	1
POOR COMMUNICATION	0.05454345	6	0.16363035	4
CORRUPT PRACTICES	0.05389605	7	0.16168815	5
SEXUAL AND GENDER ABUSES	0.0534105	8	0.1602315	6
ABSENCE OF LEGISLATIVE AND SUPPORTIVE RULES THAT INFLUENCE RELIEF OPERATIONS	0.085843746	2	0.171687492	2
SANCTIONS AND CONSTRAINTS THAT HINDER STAKEHOLDER COLLABORATION	0.074014254	5	0.148028508	7

These differences can affect response times, delimit operational possibilities, and hinder collaboration since these actors are not familiar with or have little knowledge of one another. As a result, aid delivery might be delayed, and the effectiveness of the emergency supply chain hampered. Environment risk (100% of 0.494) is the only sub-category of the external risk. These adverse events are beyond the control of organisations. However, stakeholders are urged to develop strategies that are inclined to reduce the consequences of these risks in the emergency supply chain.

On the other hand, three sub-categories of risk make up the internal risk: demand risk (33.2%), supply risk (34.6%) and infrastructural risk (32.2%). Supply risk is ranked first and occupies the highest priority in reference to other sub-categories in this group. Supply risk is the upstream equivalent of demand risk; it relates to potential or actual disturbances to the flow of products or information emanating within the network upstream of the primary organisation. This sub-category concerns the risk linked to an organisation's suppliers or suppliers' suppliers being unable to deliver the relief supplies needed to meet production requirements/demand forecasts. Critical supplies are the backbone of any disaster response operation, and the emergency supply chain will be non-existent without these supplies. No assistance can be provided for the vulnerable population in dire need in the absence of critical supplies. The presence of culturally inappropriate supplies can make stakeholders struggle during emergency response operations. Therefore, stakeholders should focus their efforts on ensuring the availability of relief supplies for the vulnerable population. Demand risks are next in line in this category. Demand risk relates to potential or actual disturbances to the flow of supplies, information, and cash emanating from within the network between the focal company and the market. Specifically, this form of risk is associated with an organization experiencing demand that it has not anticipated and provisioned for through its chain to enable the satisfaction of those in dire need.

Following the impact of disasters, need assessment is determined to identify the needs of the vulnerable population. Not meeting the demands of the population affected may lead to loss of lives, so stakeholders must ensure that effective assessment of the needs of the vulnerable population for optimal performance of the emergency supply chain. Infrastructural risk comes third and receives the lowest priority in this group. Inadequate infrastructure or the absence of proper infrastructure is viewed as a critical and fundamental challenge to any immediate response operation (Kovács and Spens, 2009; Chari *et al.*, 2019). This suggests that stakeholders need to make targeted endeavours to lessen the consequences of this manner of risk and its associated concerns about the effectiveness and efficiency of the emergency supply chain. The difference between these results is minimal, which reflects the importance of all risk factors.

6.4.4.1 Supply risks

Specifically, supply risk consists of three risk types: procurement, supplier, and quality risks. From the analysis, a risk emerges first, weighing 33.4% of 0.346 and has the highest priority. Quality risks come second, weighing 33.3% of 0.346 and then procurement risks, weighing 33.2% of 0.346. These results confirm the fundamental relevance of suppliers in the immediate response to any disaster. Stakeholders must ensure they maintain valuable relationships with suppliers to support the immediate provision of critical relief items in uncertain emergencies. (Kovács *et al.,* 2012; Rajakaruna *et al.*, 2017). This will ensure a better strategic partnership and enable the emergency supply chain to achieve its objectives. The supplier risk type consists of three specific factors: inadequate supplier capacity, poor level of supplier responsiveness and variation in transit time. Based on the analysis, inadequate supplier capacity ranks as the most important factor, with a weightage of 35.6% of 0.334. Disasters bring about a huge order of diverse supplies necessary to support the needs of the vulnerable population. Not all suppliers have sufficient reserve capacities and are able to adapt swiftly to changes in demand, particularly in the areas of delivery, volume, and modification (Chirra and Kumar, 2018). Therefore, stakeholders are advised to carefully choose suppliers that can appropriately meet the ever-changing vast demands of beneficiaries and incorporate multiple suppliers into the network to essentially satisfy these diverse demands (Olanrewaju *et al.,* 2020). Quality risks comprise defective or damaged relief supplies, wrong or unsolicited relief supplies and counterfeit relief supplies. Defective or damaged relief supplies emerged as the most important risk factor, with a weighting of 34.7% of 0.333. Wrong or unsolicited relief supplies are the next important risk factor, weighing 32.9% of 0.333. Counterfeit relief supplies come last in this group with a weighting of 32.4% of 0.333. This result reveals that for stakeholders to alleviate the suffering of people affected by disasters, only relief items in the right form should be received and distributed to the affected population (Bölsche *et al.,* 2013; Maghsoudi and Moshtari, 2021). For example, in regulated sectors such as health, the World Health Organization (WHO) recommends quality and standard specifications for the development of critical supplies. Production standards across regions or continents may vary since manufacturers are diverse. However, the quality of critical relief supplies must never be altered (Kovács and Falagara Sigala, 2021).

Moreover, these results suggest that appropriate needs assessment should be conducted, and stakeholders are encouraged to integrate pull principles to prevent the delivery of unwanted relief supplies to people in dire need. Furthermore, procurement risks can result from non-compliance with supply contracts, purchasing critical supplies from a single source, and long-term vs. short-term contracts. Results from the analysis reveal that non-compliance with supply contracts is the most significant risk factor, with a weighting of 34.1% of 0.332. Stakeholders and relief actors purchasing key supplies from a single source is the next most important risk factor in this group, with a weighting of 33.4% of 0.332. Long-term vs. short-term contracts come third with a weighting of 32.5%, respectively. This result reveals the necessity for stakeholders and suppliers to adhere to the terms of contracts. However, the uncertainty and unpredictability surrounding disasters and their relief operations might negatively influence contractual agreements for the provision of relief supplies. For example, the contracts might not be initiated due to high expenses related to the non-usage of critical supplies committed in contracts. Thus, stakeholders that constitute the emergency supply chain are usually advised to carefully examine procurement contracts before entering one (Olanrewaju, Dong and Hu, 2020).

Moreover, dependence on single suppliers for the critical needs of the vulnerable population is now outdated, and stakeholders preferably share resources where possible (Haque and Islam 2018). For example, the COVID-19 pandemic re-emphasized the need for and benefits of multiple sourcing and the integration of several alternative suppliers at hand (Kovács and Falagara Sigala, 2021). Also, the incessant demand for critical supplies in disaster-struck environments mandates stakeholders to establish long-term purchase contracts with suppliers to enable an overall achievement of the supply chain objectives (Zhang *et al.*, 2019).

6.4.4.2 Demand risks

Next in line is demand risk. This sub-category of risk includes two types of risk: forecast and inventory risks. In this group, inventory risk comes first and attains the highest priority with a weighting of 50.6% of 0.332. Positioning inventory at strategic locations before the impact of a disaster is crucial to emergency response since the goal of the emergency supply chain is to manage eventualities caused by disasters, not certainties. Hence, Stakeholders are urged to ensure the availability of strategically placed sufficient inventory for the provision of aid, the absence of which will lead to loss of lives or great difficulties for the vulnerable population. Limited life cycle of critical supplies (100% of 0.506) is the only specific risk factor that makes up the inventory risk. Uncertainty and unpredictability in disaster relief operations reflect that there is a high chance of critical supplies being held for long periods before a disaster strikes, and they can be distributed to the affected population. Some of these supplies may have already expired or near the expiry date. Hence, stakeholders are advised to adopt supply chain strategies such as postponement or vendor-managed inventory to eliminate these risks and ensure appropriate supplies are distributed when necessary. Forecast risks are second in this sub-category with a weighting of 49.4% of 0.332 and receive the lowest priority. This type of risk encompasses two specific risk factors: poor demand projection and distortion of information. Poor demand projection is the risk factor, with the highest weighting of 50.7% of 0.494. Errors in estimating the needs of the vulnerable population must be avoided, unlike the commercial supply chain, where these errors translate into lost sales or excess inventory. Poor demand projection in the emergency supply chain relates to the vulnerable population not receiving the critical supplies they need at the appropriate time, which can result in human suffering or loss of lives. Consequently, stakeholders are encouraged to adopt novel and appropriate models for projecting demands to ensure the effective delivery of the critical needs of the vulnerable population.

6.4.4.3 Infrastructural risks

The infrastructural risks include transportation risk, warehousing risk, and systems risk. From the analysis, transportation risks have the highest priority, with a weighting of 34.8% of 0.322. Systems and warehousing risks follow, respectively, with a weighting of 32.8% and 32.3%. These results indicate that transportation is more significant and challenging in any disaster relief operation (Balcik *et al.*, 2010; Azmat *et al.*, 2019). Transport activities mainly include but are not limited to transporting staff, relief items, and material to the affected area (Pedraza Martinez *et al.*, 2011). Timely transportation of people and relief supplies is essential for the success of relief operations, as they play a primary role in providing relief and assistance to the vulnerable population. The supply system deployed in disaster relief operations is dependent on transportation-related infrastructure, which is often destroyed (Balcik *et al.*, 2010). Thus, relief organisations are urged to develop advanced transportation and logistics networks to obtain more flexible access to disaster-struck environments. Transportation is the link in the emergency supply chain that makes it possible for critical relief supplies to reach their destination. Transportation risks encompass four risk factors: poor or damaged transport infrastructure, with a weighting of 25.3% of 0.3489, ranks as the most significant in this group. The absence of alternative transport modes and ineffective last-mile delivery come second and third, weighing 25.1%, respectively, while theft of supplies and resources (24.5%) comes last in this group. This result shows that when designing an emergency supply transport strategy, it is not enough to consider in the abstract the best means of transport or resources needed to mobilize supplies from point A to point B. In addition, relief organisations must consider alternative transport means as a matter of course. It is critical to deliver relief supplies to the right place and at the right time. Moreover, stakeholders must consider utilizing a variety of means of transport, including land, air, or water, to deliver these supplies from the point of origin to the destination (Azmat and Kummer, 2020). Warehousing risks include limited holding capacities and damaged warehousing facilities. Based on the analysis, poor or damaged warehousing facilities, with a weighting of 51.5% of 0.323 is, ranked as the most important risk factor, and limited holding capacities come next with a weighting of 48.5%. One of the main factors that can increase the speed of critical supplies delivery to beneficiaries is to locate the emergency relief warehouse near the region where disasters frequently occur. However, relief organisations struggle to locate warehouses out of the reach of the demolishing impact of the disaster while at the same time close enough to the disaster to deliver aid quickly and effectively (Balcik and Beamon, 2008).

Moreover, time is a critical factor in any disaster relief operation. Critical supplies need to arrive in the right area at the right time to assist the vulnerable population (Tatham and Kovács, 2007). Thus, this result indicates that the emergency relief network should be carefully constructed to meet the needs of every disaster (Pettit and Beresford, 2009). In addition, capacity in disaster relief operations has been defined as "the ability of the organization to conduct operations of different volumes, in various areas, at different times and to provide a diverse range of services and relief supplies". Hence, relief organisations are advised to develop their capabilities and capacities, including expanding the current warehouse networks (Azmat and Kummer, 2020). System risks include poor IT infrastructure, absence of transparency in information dissemination, and presence of delays during information transmission. From the analysis, the absence of transparency in information dissemination, with a weighting of 34.7%, is ranked as the most important in the group. Next in line is poor IT infrastructure, with a weighting of 33.1% and the presence of delays during information transmission (32.1%). In complex environments like disaster relief operations, information sharing amongst relief actors is often considered critical for better collaboration (Altay and Labonte, 2014). Information plays a crucial role in disaster management. The faster critical information is retrieved, analyzed, and distributed by participating agencies, the more effective the response (Perry, 2007). Information sharing among actors creates transparency, i.e., relief actors sharing information about their available capabilities and resources helps everyone understand their role in a coordinated response (Dubey *et al.*, 2019). First-hand reliable, adequate, and timely information about the disaster location, its intensity, and the level of damage is vital for the success of the relief operation (Moshtari and Gonçalves, 2017). Accurate information flow could dramatically increase not only the productivity of the supply chain but also help in the proper allocation of resources (Day and Silva, 2009). Relief organisations that have high levels of transparency and effective information capabilities are significantly well-positioned to develop and deploy systems and processes for successful relief operations (Dubey *et al.*, 2021). Technology provides a platform to relay this information up and downstream, assures the delivery of correct and reliable information up and downstream, and assures the delivery of correct and reliable information faster than traditional ways of communication. In addition, specific decision support systems and communications and information systems are vital in controlling relief operations. The United Nations (UN) developed a system to improve coordination between humanitarian organisations, attempting to facilitate information exchange, improve coordination and build capacity (Kovács and Spens, 2007). Therefore, relief organisations are advised to make available and properly utilize effective communication tools, information technology and equipment for the success of any relief operation since the management of information in disaster response "is the single greatest determinant of success" (Long and Wood, 1995).

6.4.4.4 Environmental risk

Environmental risk comprises disruption risk, social risk, and political risks. Disruption risk is ranked as the most significant, with a weighting of 35.4%. Social risks rank second with a weighting of 32.5%, and political risk is the least important in this group with a weighting of 32.1%. According to McLachlin *et al.,* (2009), disruption risk arises because of natural disasters (earthquakes, hurricanes, tornados, tsunamis, volcanoes), terrorism and political instability, and managerial issues (strikes, material shortages, supplier bankruptcy). This result indicates that the emergency supply chain must be flexible and responsive to unpredictable events. Relief organisations must develop supply chain strategies under a set of principles capable of establishing a swift and effective response since time saved means lives saved *(Cozzolino et al.,* 2012). Disruption risks encompass several factors, including the impact of follow-up disasters (48.6%) and war and terrorism (51.4%). Disasters happen anywhere in the world at any time, often in undeveloped regions with poor infrastructure or political instability and may necessitate a combination of military and commercial applications. This result indicates that regions with civil unrest are most likely to create difficulties for the emergency supply chain. Therefore, stakeholders are encouraged to design fully flexible emergency supply chains that can respond to unplanned events and utilise strategic approaches to get satisfactory results (Scholten *et al.,* 2010). Social risk covers poor communication, corrupt practices, and sexual and gender abuse. Based on the analysis, poor communication, with a weighting of 33.7%, is the most important risk factor in this group. Next in line are corrupt practices and sex and gender abuses, with a weighting of 33.3% and 33%, respectively. This result informs the need for stakeholders to make concerted efforts towards effectively collaborating with other stakeholders and local communities. The integration of local groups in decision-making and the logistics of relief operations will also ease the effects of sociocultural differences (Altay, 2008). Political risks include two risk factors: the absence of legislative and supportive rules that influence relief operations and sanctions and constraints that hinder collaboration. The absence of legislative and supportive rules that influence relief operations has the highest priority, with a weighting of 53.7% and sanctions and constraints that hinder collaboration are the least important factor, with a weighting of 46.3%. This result shows that host governments play an important and positive role in emergency supply chains, including coordination activities (Balcik *et al.,* 2010). Thus, stakeholders are encouraged to work with host governments to develop policies and trustful relationships that will ultimately improve collaboration. This improved collaboration will speed up certain activities, including needs assessment and distribution capacity.

6.4.4.5 Summary of Fuzzy-AHP Results

This research assessed 28 specific risk factors that are likely to impede the normal functioning of the emergency supply chain and prevent it from achieving its goal: to save lives. Based on the findings, the top ten specific risk factors are detailed. The presence of war and terrorism in the face of disaster relief operations is more likely to hamper the activities of the emergency supply chain. Weighing 0.09016, war and terrorism create a very hostile working environment for stakeholders and relief organisations working together to save the lives of the affected population. The absence of legislative and supportive rules that can influence disaster relief operations ranks second with a weighting of 0.08584; this specific risk factor is followed by the impact of follow-up disasters with a weighting of 0.08568. This risk factor suggests that the presence of cascading disasters makes an already challenging working environment more complex. Limited life cycle of relief supplies ranks fourth with a weighting of 0.08433; next to this is sanctions and constraints that hinder stakeholder collaboration, weighting 0.07401; poor communication, 0.05454; corrupt practices, 0.05389; sexual and gender abuses, 0.05341; poor demand projection, 0.04174 and distortion of information, 0.04058. These respective specific factors can significantly impact the activities of the emergency supply chain and increase its complexity. Decision-makers and stakeholders are urged to pay more attention to supply chain strategies that can help mitigate these risk factors and improve the resilience of the emergency supply chain.

6.4 Conclusion

Disaster relief operations are conducted in highly volatile conditions, and the emergency supply chain encounters multiple risks and uncertainties. Managing risk in emergency supply chains has become an integral part of disaster relief operations. The topic is gaining more attention and continues to be discussed in literature. However, the volume of research on emergency supply chain risk management is limited, and clear categories of risks and uncertainties encountered along the emergency supply chain remain to be empirically determined and analyzed. In this respect, this chapter contributes to the literature by presenting a systematic framework for prioritizing the specific risk factors that can negatively influence the successful accomplishments of the emergency supply chain by using the fuzzy-AHP technique. Disasters are unique and require distinct emergency supply chains, and the specific risk factors that might disrupt the supply chain may differ depending on various factors associated with the disaster. However, knowledge of the most significant global emergency supply chain risks will support the effectiveness of the overall disaster relief operation. Experts provide subjective judgements and, most often, are uncertain when it comes to providing evaluation scores. Hence, performing the AHP technique in a fuzzy environment aided in reducing the bias. The result indicates that War and terrorism, the absence of legislative and supportive rules that influence relief operations, the impact of follow-up disasters, the limited life cycle of relief supplies and sanctions and constraints that hinder stakeholder collaboration are the most important risk factors that are likely to disrupt the effectiveness of the emergency supply chain. Though internal risk emerged as the most important risk category, most of the significant specific risk factors are external risks, and stakeholders have limited control over them. However, stakeholders are urged to develop emergency supply chains that are agile and work closely with the government to develop policies and trustful relationships to ensure the smooth operation of the emergency supply chain. This ranking will support stakeholders in improving decision-making when selecting the necessary strategies that will minimize the negative influences of the relevant risk factors that will most likely prevent the emergency supply chain from meeting its objectives, which is to provide critical supplies to the vulnerable population in dire need. This ranking helps to enhance the efficiency and effectiveness of relief activities. To conclude the analysis, the research conducts a sensitivity analysis.

CHAPTER 7 - RISK FACTORS MITIGATION IN EMERGENCY SUPPLY CHAINS

7.1 Introduction

This chapter focuses on the final stage of the emergency supply chain risk management process, which is the identification, validation, and evaluation of the risk mitigation strategies that are currently being implemented. Empirical research is utilised to determine the risk-mitigation strategies that are already being put into practice (i.e., official documentation review, questionnaires, and semi-structured interviews). The risk mitigation strategies that have been found are validated with the use of semi-structured interviews, and additional risk mitigation strategies will be uncovered where possible. A Fuzzy TOPSIS approach is employed to identify the order of relevance of the identified strategies in comparison to the risk variables that were discovered earlier in the process.

7.2 Methodology for Risk Factors Mitigation Identification and Evaluation

A generic risk mitigation model is proposed for the purpose of assessing and evaluating the risk mitigation strategies that have been put into action, and it is based on the integrated risk management model that has been established. It is an essential component of the comprehensive risk management model that has been advocated for emergency supply chains in disaster relief operations. Figure 7.1 presents a diagrammatic representation of the generic model for the reduction of risk.

The following procedures will be used to implement the suggested risk mitigation model for emergency supply chains:

Phase 1: Using existing risk reduction methods and empirical risk factors to reduce risk.

Phase 2: Develop a questionnaire for experts to appraise the risk mitigation techniques. Fuzzy TOPSIS is used to rank the importance of risk mitigation strategies.

7.3 Identification and Validation of Risk Mitigation Strategies for Emergency Supply Chains

For the purpose of investigating the risk mitigation strategies implemented in emergency supply chains during immediate disaster response operations, an empirical approach was utilised. This empirical technique involves the use of in-depth interviews, questionnaire surveys, and documentation reviews, all of which are referred to as qualitative and quantitative studies, respectively (Creswell and Creswell, 2018). Empirical research is conducted to confirm or refute hypotheses or hypotheses that have been offered but not yet tested. According to Long (2014), an empirical study is based on 'field' experiences or direct observation, allowing for in-depth, natural context-based analyses of contemporary phenomena. Yin, (2013) claims that the research design (including reliability, construct validity, internal validity, and external validity) is the criterion by which the quality of empirical investigations is determined. In this section, construct validity is established using corroborative evidence through several channels. For this study, a combination of semi-structured interviews, high-level questionnaire surveys, and a review of official documents to obtain our data was employed (Wang, 2018).

Before moving on to further in-depth analysis, the study conducts empirical investigations to discover and validate the various risk mitigation strategies. The investigations were carried out in three stages: (1) an analysis of existing risk mitigation strategies published in journals and official paperwork, (2) high-level surveys, and (3) semi-structured interviewing. Following is a discussion of each of the phases.

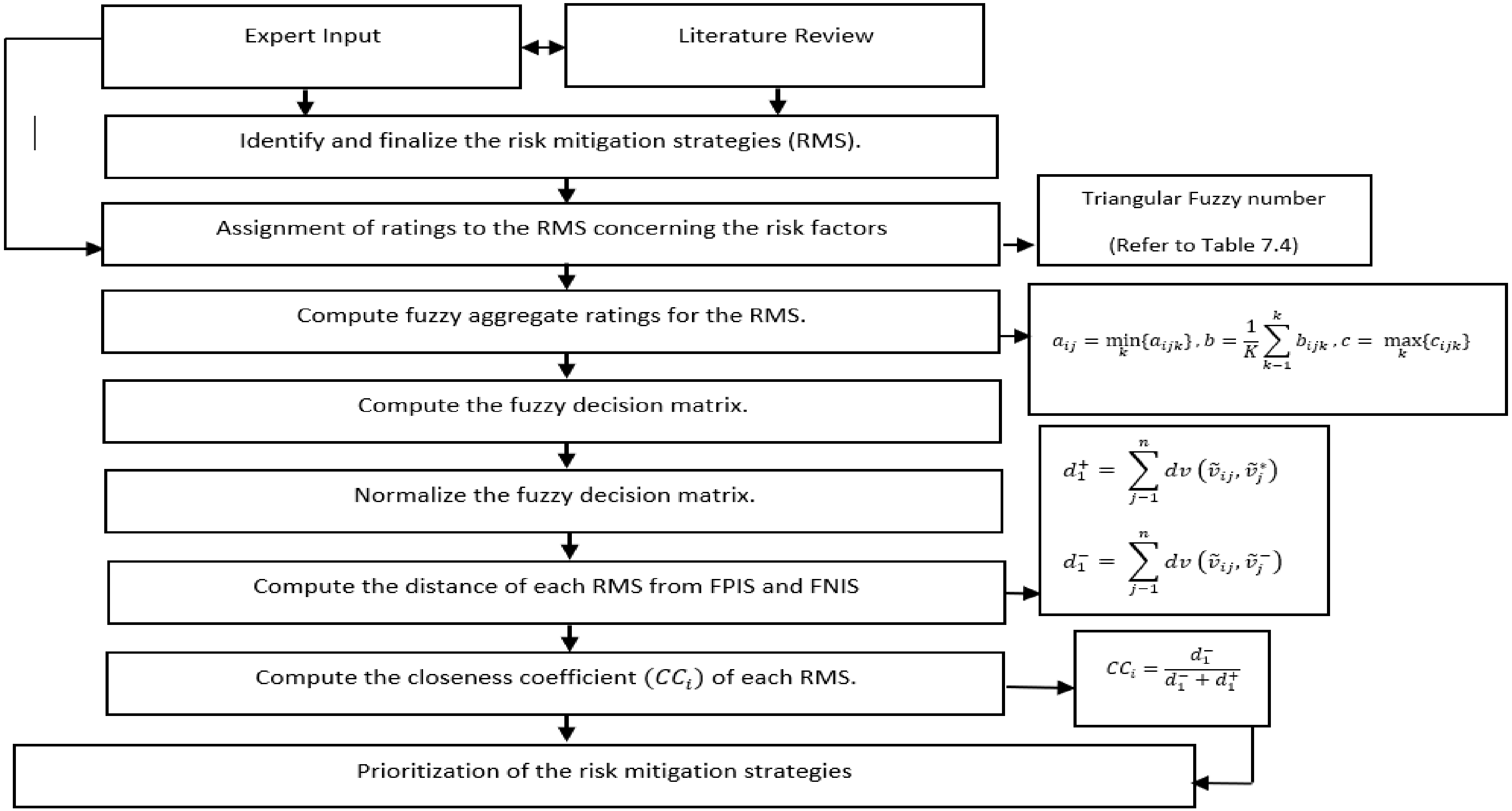

Figure 7.1 Fuzzy-TOPSIS model for risk factor mitigation in emergency supply chains

To begin, a detailed and meticulous literature analysis was conducted to locate current supply chain strategies for mitigating risk was conducted. In particular, and building off Jahre's (2017) work, the review focused on articles that detailed in-depth case studies of relief organisations. This collection of case studies provided an overview of the empirical emergency relief research and supply chain strategies that aid organisations appear to be focused on at present. Next, the study moved to review several official documents from various bodies, including *"Global Humanitarian Overview 2022", "DG ECHO Thematic Policy Document", "Evaluation of Humanitarian Logistics within EU Civil Protection, 2013-2017", "Supply Chain Expenditure & Preparedness Investment Opportunities in the Humanitarian Context, 2017", "Emergency Supply Prepositioning Strategy, ESUPS, NEPAL, Country-Wide Analysis of Prepositioned Relief Items, 2020", "Global Logistics Cluster, Delivery in a Moving World, 2016",* etc. The primary benefit of documentary research is that it allows researchers to gain access to data that would be difficult to acquire through more traditional methods, such as interviews with subjects who are hard to locate or who are hesitant to participate in a formal study. Reviewing existing documentation is usually a reliable method for keeping tabs on developments over time. Since papers may be accessible without any effort, the cost savings are further accentuated. At the end of the first phase of empirical investigations, the study uncovered various risk mitigation strategies implemented in the disaster relief context.

Next, using the identified risk mitigation strategies, a high-level survey is developed and disseminated to five experts, including academics and practitioners, to validate the strategies and further uncover others omitted. Although surveys appear and sound authoritative, the mode of investigation is easy to explain and comprehend. At the end of this process, the study retrieved only two valid responses, which make up 40% of the entire sample. Finally, the study conducted semi-structured interviews over 60 days. Several experts were contacted, but only three experts accepted and participated in this stage of the process. The interviews were conducted remotely using different video conferencing apps, including Skype and Microsoft Teams, at a time favourable to the participant. The sample included two field practitioners and one academic. All participants have over 15 years of experience in disaster relief operations and emergency supply chain management. Table 7.1 presents each expert's details for both the questionnaire survey and the interview. To ascertain whether the respondents believed the retrieved strategies to be unsuitable, interview talks were held, and the respondents were asked to discuss and validate the strategies that had been discovered in the previous steps. See Appendix V for interview questions. To a greater extent, by offering their judgements regarding whether or not certain techniques had been handled well. Before the end of the empirical research, twelve risk mitigation strategies were identified that can remove or minimise the effects of the main risk elements of emergency supply chains in quick reaction operations. After conducting additional research, four of the risk mitigation strategies were deemed generally ineffective and removed.

Table 7.1 Experts' Profile

Participant	Position	Method
Expert 1	Senior operations consultant	Face-to-Face interview (Ms-Teams)
Expert 2	Director of Logistics	Face-to-Face interview (Ms-Teams)
Expert 3	Professor	Face-to-Face interview (Skype)
Expert 4	Professor	Questionnaire
Expert 5	Emergency supply chain consultant	Questionnaire

7.3.1 Overview of Risk Mitigation Strategies for Emergency Supply Chains

A summary of the identified risk mitigation strategies being implemented in emergency relief operations is presented in Fig. 7.2.

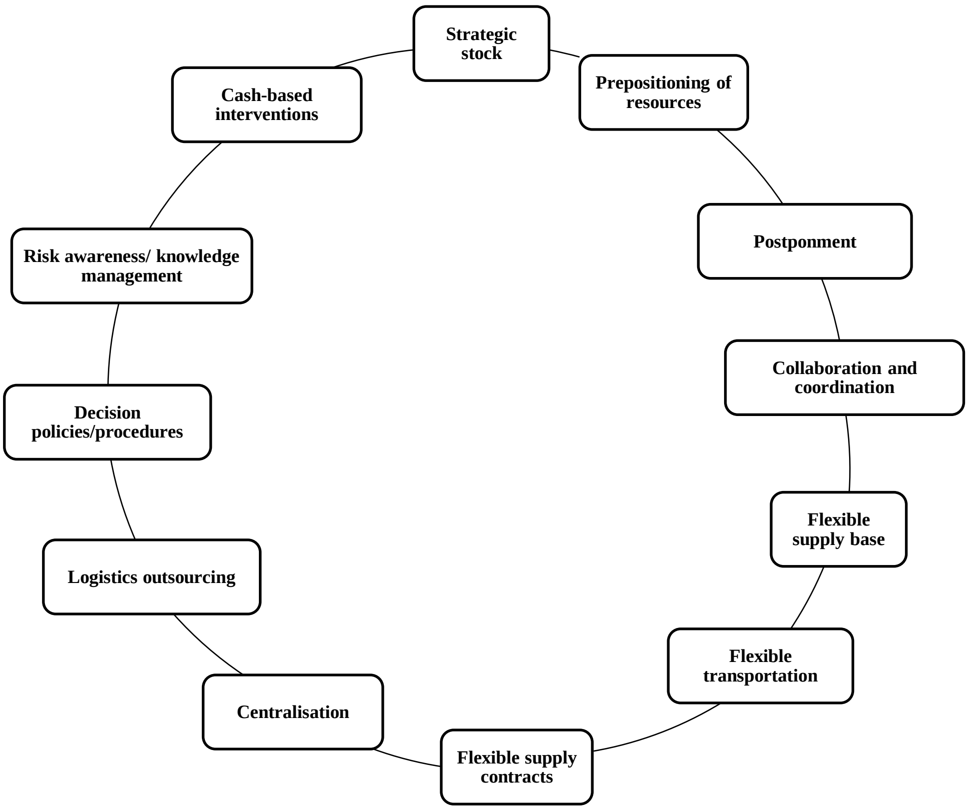

Figure 7.2 Summary of supply chain strategies for risk mitigation in emergency supply chains

7.3.1.1 Prepositioning of relief supplies (strategic stock) and resources

To ensure the supply chain can continue to run smoothly during pre-Just-in-Time periods, one may consider retaining additional safety stock stockpiles of essential components. If the product's life cycle is shortened, and there is a greater variety of products available, the costs associated with retaining inventory and avoiding obsolescence for extra safety stocks may become too expensive. Instead, organisations may opt to store inventories at strategic locations, such as warehouses, logistics hubs and distribution centres, which may be shared by various supply chain participants such as retailers and repair centres (Tang, 2006). As an example, Toyota and Sears have strategic inventories of automobiles and home goods at specific sites, so local merchants within their vicinity can benefit from sharing these stocks. When it comes to coping with normal demand changes, organisations such as Toyota and Sears can provide excellent customer service without drastically increasing their inventory expenses by constructing shared inventories located in key regions. In volatile contexts, relief organisations' strategies must be able to address risks and uncertainties in terms of demand, supply, and operations (Balcik and Beamon, 2008). To do this, it is important to be well-prepared, quickly deploy the required resources, and be able to rapidly adjust to various local settings (Jahre and Fabbe-Costes, 2015). With such proactive measures, organisations are better equipped to adapt to potential demand shifts and provide better customer service. The operational success of emergency supply chains depends on their capacity to adapt to external interruptions and engage in dynamic operations rapidly (L'Hermitte *et al.*, 2015). Supply chains must demonstrate both responsiveness (Blecken et al., 2009; Oloruntoba and Gray, 2009; Merminod et al., 2014) and cost efficiency (McLachlin *et al.*, 2009; Pettit and Beresford, 2009) to address any unpredictable disasters that may occur effectively. If necessary, supplies or resources are unavailable or delayed, it could potentially result in increased human suffering and fatalities (Long, 1997). Logistics, as highlighted by Thomas (2003), acts as a connection between disaster preparedness and response. Supply chain success is largely attributed to the capability to fulfil customer needs while adjusting to sudden market shifts (Kim and Lee, 2010; Kim *et al.*, 2013) and the quality of both internal operations and external partnerships (Ghosh *et al.*, 2014). To handle irregularity and unpredictability, relief organisations must rely on prepositioning, or stockpiling inventories, as a vital strategy for emergency preparedness (Caunhye *et al.*, 2012).

Many different relief organizations, either individually or collectively, carry such supplies. The UN Humanitarian Depot (UNHRD) mechanism, for instance, facilitates the sharing of resources among aid groups (Toyasaki *et al.*, 2017). Many people in need would be unable to cope without certain critical supplies that relief organisations cannot provide. Hence, prepositioning will ensure the deployment of critical supplies and resources close to where they will be needed (Oloruntoba and Gray, 2006). Panic buying and price spikes in the aftermath of a disaster or the onset of a pandemic are tempered by this mechanism. Implementing systems for prepositioning essential relief goods on a regional or national scale can improve the efficiency of disaster response operations and lessen the impact of disruptions to the supply chain (Kovacs and Sigala, 2021). Similarly, Sabbaghtorkan *et al.*, (2020) underline that the objective of prepositioning stocks in strategic locations is to reduce the complexities of the emergency supply chain and speed up the immediate response operations.

According to one expert,

"*Prepositioning inventory is also called strategic stock. Firstly, one needs to know the areas prone to frequent disasters. Sometimes, we have an idea of the kind of disaster that affects a location. For example, Japan and Turkey are prone to frequent floods and earthquakes. Therefore, one can plan and identify important locations to maintain critical relief supplies such as medical supplies, food, and other important supplies to help the potentially vulnerable population in advance. This strategy is very relevant when you know areas and locations prone to frequent disasters*."

Relief organisations would benefit greatly from having an established prepositioning network to better respond to sudden-onset natural disasters such as earthquakes, which do not go through a transitional phase. If they had such a network, the procurement phase of the response would be eliminated (Duran *et al.*, 2013; Salmeron and Apte, 2010). For instance, CARE International was able to respond to the earthquake in Haiti in 2010 by delivering water purification kits within a single day because of the prepositioning network that the organisation had in place (Duran *et al.*, 2013). According to Duran *et al.*, (2011), the scale, timing, and location of catastrophes can be very unexpected, which makes it difficult to structure a prepositioning network to enable emergency response during sudden-onset disasters. Several studies agree that prepositioning regular supplies at strategic sites is an effective way to bridge early increases in demand during the emergency response (Jahre and Heigh, 2008; Altay *et al.*, 2009; Comes *et al.*, 2020; Kovacs and Spens, 2009; Tang, 2006; Toyasaki *et al.*, 2017; Sigala *et al.*, 2022). Prepositioning of goods and resources, as stated by Jahre and Heigh, (2008), not only facilitates the speedy distribution of relief supplies to individuals in need but also aids in reducing transportation costs by allowing for the use of more economical and efficient modes of transport (Kovacs and Sigala, 2021). Considering the high frequency with which certain supplies are required in the aftermath of natural disasters, relief organisations generally establish robust ties with the suppliers from whom they source their supplies and enter into long-term purchasing agreements. As a result, the UNICEF disaster management distribution centre in Copenhagen regularly collects the most widely needed products (Dignan, 2005). To reduce risk, it is possible to preposition stock (Thomas, 2003). Basic relief materials (like shelter, cooking sets, and mosquito nets), support items (like trucks and generators), and kits (including administration and emergency team survival) are some examples of critical supplies and resources that are commonly prepositioned (Jahre and Heigh, 2008).

Another expert explains.

"Strategic stocks are important, and many different organizations use them. You can see there are stocks in various locations around the world. For example, WFP has strategic stocks in five locations. We also consider many of our stocks for strategic stock. At all times, we have about 50 ships on the ocean which do not arrive at the destination port. We consider those as, even though they are programmed to go to one specific country, we consider them as well, as strategic stocks, because in an emergency we can change the destination".

Typically, acquiring and transporting appropriate relief goods from local and foreign sources is time-consuming and costly (Balcik and Beamon, 2008). Hence, a necessity for prepositioned stocks and resources. Although prepositioning improves the capacity of assistance agencies to deploy critical relief supplies and distribute help rapidly, it can be relatively expensive. As a result, only some relief groups can afford to operate worldwide distribution centres to store and distribute relief materials. In 2000, World Vision International (WVI) launched a worldwide prepositioning network (Beamon and Kotleba, 2006). Prepositioned in the United States, Italy, Germany, and Dubai, these modules of relief supplies are ready to be transported anywhere in the globe as soon as the need arises (Beamon and Kotleba, 2006). The United Nations Humanitarian Response Depot (UNHRD) in Italy is managed by the World Food Programme (WFP) in collaboration with other partners (including NGOs and the Office for the Coordination of Humanitarian Affairs, governments). Within 24 to 48 hours after receiving a request, UNHRD may ship aid to any location in the world to help those in need after natural disasters or complicated events (Balcik and Beamon, 2008).

One expert stated that.

"The strategic stock has been in various locations for about 20 years. The challenge of having a large and valuable volume of critical relief locations like Dubai, Panama, Kuala Lumpur, Ghana, and the Canary Islands is the cost of moving these items quickly. This movement entails chartering aircraft to uplift the relief items to a primary hub and even from the primary hub to the last mile. Disasters are unpredictable since knowledge of when and where they are likely to occur, the number of people affected, or stocking critical supplies is a bit of a "guessing game." Although predictions can be made since history tells us countries that are much more likely to be affected, the presence of climatic change makes prediction difficult. For example, south-eastern Africa was not previously affected by cyclones; it is now being affected. Therefore, there is a need to look at strategic stock more strategically. i.e., localizing strategic stock. Although there are risks associated with this strategy, it makes more sense to utilize this strategy. Stakeholders are encouraged to look at clusters of countries or individual countries to preposition strategic stock".

According to the European Commission, (2022), the activities requiring a quick response come with their difficulties. In the case of prepositioning, it can be difficult to strike a fair balance between the stocks and resources that are stored locally and the ones that are stored regionally or to quickly assess what is available in the country to scale the call on foreign stocks and resources. Prepositioned inventory turnover is an additional difficulty. Prepositioning is most effective when it aims for continual replenishment and takes the shelf life of products into account to avoid wasting perishable goods. Funding should be made available regularly to ensure that country-specific local capacity assessments are kept current. To respond effectively, it is essential to have detailed knowledge of local market capacity, a map of critical roads and infrastructures, the availability and supply of housing, fuel, communications networks, the internet, and transportation markets (European Commission, 2022).

7.3.1.2 Postponement

The term "postponement" refers to the practice of postponing the processing or distribution operations (for example, regarding the form and the location of products) until more specific information regarding the client order is made available (Yang and Yang, 2010). Tang, (2006) explains that postponement is a method that delays the moment at which product differentiation occurs. The utilisation of product or process design ideas such as standardization, commonality, modular design, and operations reversal accomplishes this. Several papers have made the connection between the decoupling points of supply chains and the idea of postponement, which may be thought of as the reverse of prepositioning in certain ways (Jahre and Heigh, 2008). The purpose of postponement is to lower the "anticipatory risk" of logistics by delaying the commitment of inventory (both in form and in time) until after client orders have been received (Oloruntoba and Gray, 2006). This is done so that the postponement can occur (Cozzolino *et al.*, 2012). Using good demand-led inventory management through the principle of postponement may prove to be a cost-effective replacement for prepositioning, allowing the distribution of relief supplies to be as quick as necessary.

One expert describes,

"*This strategy is about holding a supply chain at a point known as the pull and push interface. This strategy has proven to be very successful in the commercial supply chain in responding to uncertainty in demand and minimizing obsolete inventory. In the context of disaster relief, the postponement does not perform well because it can be challenging since stakeholders and relief rely majorly on donors' contributions. Postponement strategy looks simple, but it is difficult to replicate in the disaster relief context*".

The postponement strategy allows organisations to initially develop generic products based on the overall aggregate demand for all items, and, after being stored as a general "strategic inventory," these goods are then allocated in accordance with the ever-changing requirements of the end users. Because the commitment of inventory to ultimate delivery is delayed, more precise data may be used, and the knowledge that is obtained on the current requirements of receivers can be relied upon. The upkeep of generic inventories may also assist in overcoming possible security issues, such as the danger of aid being diverted away from its intended beneficiaries or the possibility of violent acts. The generic merchandise needs to be quickly turned into supplies that are geared specifically toward the receiver. In the commercial sector, organisations like Xilinx, Hewlett-Packard (HP), and Benetton have found success using the postponement strategy as a cost-effective tool for mass customisation of products, allowing them to meet frequent variations in customer demand under normal conditions (Tang, 2006).

According to one expert,

"I do not think that is generally used in the humanitarian context. There are some scenarios where you can do it, so we do something called kitting, right? You take a variety of

commodities, a lot to do with medical. So, you will have many health supplies; they could be anything from, I do not know, paracetamol, family planning, different types of drugs, and syringes. Moreover, they have those kits. Now, of course, what happens in a kit is that that kit can be adaptable depending on what the type of medical or health outbreak is going to be. However, in general, those kits are pre-kitted for a specific emergency. They can be utilized if needed. You must re-kit them. Yeah, you can do it right by taking from one kit and putting them into another one. However, it is far from ideal".

The planning and decision-making processes for site selection are informed by the information provided by local people considering, among other things, accessibility, topography, weather, and available facilities. It is expected that the implementation of the postponement principle as a field-level supply chain strategy would have a good influence on the speed of reaction and flexibility and, consequently, on the agility required to satisfy the ever-evolving requirements of end users.

One expert argues.

"*Postponement is viewed as keeping semi-finished supplies to adapt them to the need that arises. It is considered a good option - looking at what can be sourced, manufactured, and locally available that can be adapted to match the demands of those affected. More attention is being paid to consulting the vulnerable population to extract what they need. Since the storage of general kits in a global centre- like Dubai, while this is helpful, it is a costly way of preparation in terms of production and transportation*".

7.3.1.3 Flexible supply base

Natural and man-made disasters alike can cause significant harm to local communities (e.g., destruction of infrastructure, transportation networks, buildings, etc.), as well as injuries, deaths, and influxes of refugees (Van Wassenhove, 2006; Tomasini and Van Wassenhove, 2009; Kovács and Spens, 2007; Tatham and Houghton, 2011). Given that there has been an average of 385 catastrophic occurrences each year over the past decade, with over 200 million people needing help, there must be a good understanding of the effects of these disasters (Duran *et al.,* 2013). In addition, environmental degradation, rapid urbanisation, and the spread of HIV/AIDS in the developing world are predicted to increase the frequency and severity of natural and man-made disasters by a factor of five over the next 50 years (Thomas and Kopczak, 2005), with a cumulative global economic impact of roughly $960 billion. Therefore, improved disaster management methods and higher operational efficiency have emerged as a major issue for the global economy, with emergency supply chain management playing a clearly essential role in this regard (Van Wassenhove, 2006). More than two-thirds of the money spent on disaster assistance goes toward logistics-related tasks (Trunick, 2005), the majority of which is spent on purchasing supplies. (Falasca and Zobel, 2011; Iakovou *et al.,* 2014).

Suppliers are crucial to a rapid and effective emergency response. The considerable variability in disaster location and demand size makes it difficult for relief agencies to evaluate potential suppliers. For instance, a supplier's proximity to an impacted area affects both the supplier's ability to quickly deliver relief supplies and the supplier's availability to do so. Disaster response efficiency can also be affected by a supplier's capacity, geographical coverage, commitment requirements, and pricing schedule. With the support of multiple sourcing strategies (i.e., choosing two or more providers), the effects of supply chain disruptions in emergency relief can be lessened or even eliminated (Torabi *et al.*, 2018). Although an organisation can cut expenses by purchasing from a single supplier (lower supply management cost, lower unit cost owing to quantity discount, etc.), doing so may make it more difficult to handle intrinsic demand swings or catastrophic interruptions (Tang, 2006). To overcome shortages from one site or supplier, multiple sourcing strategies, both across multiple suppliers and multiple geographic regions, are also recommended as mitigation strategies for disruptions (Yang *et al.*, 2019; Berger and Zeng, 2006). Pre-qualifications of suppliers and framework agreements for quicker scaling up to meet surge demand are used in the disaster relief context as a mitigation strategy to ensure the availability of items when needed (Gossler *et al.*, 2019). Multiple sourcing with flexible supply bases enables companies to shift production among suppliers promptly (Yang *et al.*, 2019). This is not only to find alternative suppliers but also specifically for geographical diversification of the supply chain to ensure that critical relief supplies are produced in different countries (i.e., not only in China) and even on different continents (Sigala *et al.*, 2022). In the preparation phase, Kovács and Spens, (2007) emphasise the importance of risk management for regional actors as well as the strategic planning of disaster relief activities for extra-regional actors. Local sourcing can play a positive role in boosting the local economy while offering quicker and more affordable delivery.

Additionally, local suppliers have been acknowledged by numerous scholars and relief organisations as essential partners in an emergency supply chain (Duran *et al.*, 2013; Falasca and Zobel, 2011). On the other side, international (often far-off) suppliers play a significant role in the framework for relief procurement (Blecken, 2010), typically offering affordable pricing, excellent quality, and enough unaffected capacity. Alternative suppliers are required in this situation to properly plan for and respond to a disaster (Van Wassenhove, 2006; Iakovou *et al.,* 2014)

According to one expert,

"you always need to have a diverse supplier base. This was experienced during COVID-19. If a government is concerned that they do not have enough supplies for their market, they will normally go for exports; It could be for several different items. In a situation where you only have one supplier in one location, and suddenly there is an export ban, or there is some situation that could be a strike, that could be a natural disaster. If any reason upsets the supply chain, you will be stuck and need a diverse supplier base. Localization, of course, is also very important. One should purchase as much as one can as locally as possible".

7.3.1.4 Collaboration and Coordination

International relief organizations, host governments, the military, local and regional relief organizations, and private sector enterprises are all involved in disaster relief contexts. Each of these groups may have varying interests, missions, capacities, and skills in logistics. In most cases, no single actor possesses adequate resources to properly respond to a disaster (Bui *et al.,* 2000; Leiras *et al.,* 2014). For example, in the aftermath of the Asian Tsunami in 2004, more than 40 nations and 700 non-governmental organisations (NGOs) gave aid to victims of the disaster (Chia, 2007; Balcik *et al.,* 2010). Only a responsive supply chain can match the demands of its customers. Ghosh *et al.,* (2014), described responsiveness as "the capacity to react to abrupt or rapid changes in the marketplace."

Additionally, responsiveness is defined as the ability to respond to the demands of customers in a dependable and timely manner. According to Kim and Lee, (2010), one of the most important ways for businesses and supply chains to achieve a competitive advantage is to be able to respond quickly and effectively to shifting market needs and competitive environments. As a result, responsiveness is commonly understood to refer to the speed with which the supply chain reacts to changing market needs and competitive environments (Holweg, 2005; Reichhart and Holweg, 2007; Singh, 2015). Most studies done in the past have agreed that the network of entities running the supply chain contains the greatest potential for responsiveness (Reichhart and Holweg, 2007; Ghosh *et al.,* 2014). According to Kim and Lee (2010), "the competence of a business to deploy resources available along the supply chain to recognise and respond to market developments" is what supply chain responsiveness refers to. The capacity of a company to stay responsive comes from the company itself, the partners in its supply chain, and the joint efforts of those partners (Jahre and Fabbe-Costes, 2015; Squire *et al.,* 2009; Kim and Lee, 2010). It is about the "coordination of the activities of the chain members and the seamless integration of the relevant business processes" both within firms and between firms (Ghosh *et al.,* 2014), and there is a "lack of close collaboration and integration between relations throughout the supply chain" (Jahre and Fabbe-Costes, 2015).

Collaboration and coordination are two concepts that are frequently used interchangeably in the context of relief organisations (Balcik *et al.,* 2010; Cozzolino *et al.*, 2017). The definitions of these terms are differentiated in some of the research on supply chains based on the quality of the interpersonal connections between the many actors involved. However, the borders between these words are blurred, and the unique definition of each remains unclear (Cozzolino *et al.,* 2017). In the context of disaster relief, the concept of coordination can be interpreted in a number of different ways. For instance, coordination may refer to the sharing of resources and information, the conduct of joint projects, the regional division of tasks, or a cluster-based system in which each cluster represents a different sector area. Centralized decision-making may also fall under the umbrella of coordination (e.g., food, water and sanitation, and information technology) (Balcik *et al.,* 2010). According to the research of Mittu *et al.,* (2008), basic aid and relief efforts may be substantially hampered if there is no way to coordinate groups across the relief chain efficiently. Therefore, building up the indigenous capability to secure and provide basic services should be a long-term objective. Many people and organisations have a stake in emergency response. Emergency relief groups, along with organizations and agencies, donors, logistics service providers, governments, the armed forces, NGOs, and vendors, make up this group. As a result, failure to communicate among key players often leads to last-minute chaos when resources are wasted because of unnecessary repetition (Sheu and Pan, 2015). Increased costs have been noted in relief situations where cooperation was lacking. As noted by Diedrichs *et al.*, (2016), effective communication is crucial for coordinating the efforts of all relevant parties.

According to One expert,

"Coordination is a massive issue, and it is very challenging to apply these strategies. However, recently, the activation of cluster systems. For example, Malawi has set up a national cluster system like the global supply system. With the help of the UN, agencies have adopted a

mechanism that can help them coordinate during a crisis. It is the government's responsibility to ensure that citizens are supported during crises".

Customers in the relief activities are the donors. In the absence of any overarching leadership, the various organizations must now compete with one another for the same funding. Donors are more likely to provide money for the relief operation if it focuses on the short term. This is the root cause of the disparity between the resources allocated to short-term objectives and those allocated to long-term aid. As a result, inter-organizational cooperation is crucial.

Another expert discusses.

"*Coordination and collaboration are usually important in an emergency, right, and stakeholders are forced to do it in an emergency. We saw that during COVID, when organizations, including my own, were normally competing. Suddenly, everybody knew that they were in this kind of major emergency and things had to be done differently. Upstream coordination and cooperation are less visible to me, especially with suppliers. There is sometimes a competition for access to those supplies, especially when they are limited*".

By combining their skills, teams can create new knowledge that contributes to their quest for constant growth and development. The media serves as both a watchdog over the establishment and a source of information for the public (Balcik *et al.*, 2010). It is necessary to work with the media to get the word out about the situation, solicit donations and follow through on instructions. Therefore, it is believed that the supply chain can be differentiated by collaboration and coordination between assistance organisations, suppliers, and local and regional players (Haavisto and Kovács, 2014), integrating several processes into one streamlined supply chain. However, difficulties in inter-organizational cooperation arise due to the widespread diversity in culture, language, and goal. After the storm Hudhud hit the eastern coast of India, emergency workers and the administration worked closely together to expedite recovery (www.Reliefweb.com). Whereas, in the 2015 Chennai (India) floods, the relief work was slowed down due to a lack of coordination. Excessive aid was distributed in some parts of Chennai while the hardest stricken neighbourhoods still lacked necessities (Singh *et al.*, 2018).

One expert explains,

"Collaboration and coordination may sound similar, but they hold different meanings. One needs to understand some important elements, such as building trust among all partners (relief

actors) involved in the operation. This kind of trust is known as swift trust. Building this swift trust is challenging because of several factors, including background, culture, language, and beliefs. Several efforts have been made to build coordination. Nowadays, technology is playing an important role. For example, using blockchain technology, big data analytics, and artificial intelligence can be used in building coordination in disaster relief operations, thus improving the agility and resilience of the relief supply chain".

7.3.1.5 Flexible transportation

Major disasters can strike at any time and in any part of the world. They are more likely to occur in underdeveloped areas with inadequate infrastructure or political unrest, which may require a combination of military and commercial applications. Because it is difficult to accurately anticipate demand and supply requirements (Van Wassenhove, 2006), significant degrees of flexibility are required to set up distribution networks as rapidly as possible (Scholten *et al.,* 2010). Following the disaster outbreak, the situation is appraised, and resources are mobilized for transit to the disaster location. If necessary, relief aid is obtained, and transportation activities are organized. Transportation activities include but are not limited to bringing personnel, relief supplies, and material to the impacted area (Day *et al.,* 2012; Martinez *et al.,* 2011). To effectively provide aid and relief to the recipients, timely transportation of personnel and relief goods is crucial (Azmat and Kummer, 2020).

Furthermore, Ngwenya and Naude, (2016) argue that transportation is one of disaster relief operations' most critical and challenging aspects. When a disaster strikes, it damages or thoroughly washes away infrastructure; most supply lines become closed, transportation resources become scarce, and conveying a bulk cargo of supplies to recipients in the afflicted area complicates an already tricky process. These topographical constraints limit the usage of already scarce resources. They also stated that the complex topographical qualities of the afflicted locations, such as steep terrain or exceptionally harsh weather, could significantly impact the relief operation. This causes a delay in not just providing relief and supplies (for example, isolated places may only be accessible by tiny trucks or helicopters, whilst larger vehicles may only be used for adjacent areas) but also in assessing the extent of the disaster (Balcik *et al.,* 2010). Natural disasters have the potential to cause significant damage to transportation networks. Transportation networks (including roads, air, and seaports, and the likelihood of accidents along the way) evolve through time. Damaged distribution networks, including roads and railways, as well as the availability of air and seaports, may be challenging to identify in the aftermath of a disaster since their impacts cannot be predicted. Many modes of transportation may be inaccessible after a disaster (Long and Wood, 1995; Maghfiroh and Hanaoka, 2020). Damage to transportation infrastructure may prevent access to some impacted locations via specific means of transportation. This influences the number of relief supplies that can be moved using a particular mode of transportation in the allotted amount of time for the response activities (Barbarosoglu and Arda, 2004). This may be the case for parts of the affected area (Tariq *et al.*, 2017).

Since speed is crucial, especially during the response phase, numerous alternatives should be explored to deliver relief supplies as rapidly as possible within the available funds and resources. This can be achieved by utilizing several means of transportation (e.g., road, rail, air, and water), which can broaden the range of options for decision-makers. In times of emergency, supply chains typically involve the transfer of supplies across multiple tiers. Through the many stages of the emergency supply chain, things make their way from internationally dispersed warehouses stocked with prepositioned items that are ready to be deployed in the event of severe calamities. The term "transport" refers to any delivery made inside the network of the relief organisation, including the transport's last leg ("last-mile distribution"). Transport in this context encompasses not only domestic but also international, single mode as well as multi-modal travel. However, It can be difficult for relief organizations to arrange transportation after a disaster, especially over the "last mile." (Balcik and Beamon, 2008) since they usually operate in highly volatile environments. There is a need to adopt a flexible strategy that improves their capacity to react to risk and uncertainty.

According to one expert,

"*Agility comprises three dimensions: flexibility, speed, and dynamic sensing capability. Flexibility comprises structural flexibility and flexibility from all perspectives, including transportation, structural flexibility, organizational structure, etc. Sometimes, we build flexibility, but our organizational structures need to embrace flexibility. The Decision-making capability should also be flexible. Hence, it is not only about manufacturing or transportation, but the organizational structure must also be flexible to adapt and accommodate any rapid changes that are taking place in the external environment. This is a part of agile supply chain design*".

For instance, with the earthquake that struck Haiti in 2010, the country's airports and ports suffered damage. It was necessary to bring in portable equipment for air traffic control in order to make the airport operational. However, due to the destruction of the piers and two cranes, the ports could not restore normal operations for several weeks. To re-establish the flow of relief supplies and medical teams, alternative logistical arrangements and emergency equipment were brought into play (Holguin-Veras *et al.,* 2012). One of the reasons for the adoption of alternative means of transportation in disaster operations is the interruption of the logistics infrastructure caused by the disaster. Furthermore, depending on the nature of the disaster, other forms of transportation may be the only choice to reach affected people due to the level of damage to the transportation system (Ertem *et al.,* 2017)**.**

Another expert discussed,

"Alternative modes of transportation. Yes, it is always important to look at it. I mean some examples we had in Mozambique in 2017. We have air operations, which, of course, you want to minimize because they are so expensive compared to relatively cheap road operations. We also had operations going on the river. The combination of those three types of operations is those three types of transport. Alternative Modalities was very helpful as well because you can serve a lot of the different requirements".

This will allow them to serve their beneficiaries better (Charles *et al.,* 2010). Optimal distribution routes are determined in emergency supply chain planning networks with the goal of reducing human suffering (Klose and Drexel, 2005; Stauffer *et al.,* 2016). Human suffering must be alleviated, and disaster relief efforts are crucial to this end (Ertem *et al.,* 2010). Planning for emergency supply chains must consider both potential risks and available means. This means that many different options for transportation and evacuation must be considered throughout the planning stages. Effective preparation should yield a robust yet flexible relief distribution strategy that addresses the specific needs of the disaster-stricken communities (Maghfiroh and Hanaoka, 2020). Each transportation option has some advantages over the others, whether it be in terms of price, capacity, or time. So, the chosen mode of transportation should be suitable for the disaster areas, and it should be possible under the given conditions and cost. The manner of transport, amount of time, and delivery timetable may all influence the route chosen (Yadav and Barve, 2015).

7.3.1.6 Flexible Supply Contracts

In recent decades, there has been an increase in the number of people affected by natural disasters, highlighting the need for timely and sufficient relief supplies to be sent to affected areas. Therefore, logistical planning is crucial to the effectiveness of relief operations (Thomas and Kopczak, 2005). Procurement planning is a crucial part of disaster relief logistics, as it guarantees that the relief organization has the necessary relief resources to meet operational needs in the aftermath of a disaster. A relief organization's ideal choices for the transport, storage, and distribution of relief goods are impacted by its decisions regarding its procurement processes. In addition, the procurement process might affect the effectiveness of emergency supply chains and the delivery of relief goods. According to Blecken and Hellingrath (2008), 65 per cent of disaster relief logistics budgets are spent on procurement activities (Aghajani and Torabi, 2019). Following a disaster, relief goods such as water, shelter, and medical supplies should be made accessible at the appropriate time and in the proper quantity. Relief organizations provide these supplies through several channels, such as prepositioned supplies, in-kind donations, and procured supplies (Balcik and Ak, 2014). One of the primary causes of the ineffectiveness of the emergency response is the paucity of supplies and the delay in receiving them (Duran *et al.,* 2011). Because of this, it is necessary for organizations that provide relief, such as the Red Crescent Societies, to develop suitable relief supply decision models that can generate reasonable supply plans in order to lessen the impact that natural disasters have and to keep social order (Aghajani *et al.,* 2020).

Inventory shortage/surplus issues can affect relief organisations if they fail to manage their relief supplies properly. Therefore, most large governmental relief organisations purchase supplies in bulk at low unit costs and store them in advance to speed up their response (Galindo and Batta, 2013). However, prepositioning of relief items could be very costly since this relief approach is susceptible to inventory shortage/surplus concerns due to a high level of demand unpredictability (Wang *et al.,* 2015; Aghajani *et al.,* 2020). Most prepositioned relief items are not used within their durability/expiry term if predicted disasters do not occur or demand is minimal, resulting in waste and financial loss. Many relief organisations lack the resources and capacity to preposition huge amounts of relief materials. If demand surges, it may be ineffective and risk stock-out. The vast bulk of critical relief supplies is procured from international and local vendors in the aftermath of a disaster. However, meeting the needs of the affected population in a timely and effective manner in the aftermath of a disaster may present a few difficulties (Balcik and Ak, 2014). Procurement is not a typical procedure for relief groups because the timing, location, and impact of disasters are very unpredictable.

Additionally, each disaster may bring specific requirements; thus, relief organisations must be prepared for anything. For example, depending on the location of the disaster and the date of it, there may not be enough relief supplies available in local or worldwide marketplaces for rapid purchase and quick delivery. This could be the case even if there are enough. Moreover, after a disaster, there is sometimes competition between relief organisations for the purchase of specific products, which can lead to market shortages. Even worse, the unexpected surge in demand could lead to large price increases. Ultimately, most organisations adopt a competitive bidding system, which requires producing and announcing appeals, waiting for supplier bids, and analysing bids after a disaster (Ertem *et al.,* 2010; Balcik and Ak, 2014). So, in order to speed up the buying process and make sure that critical relief items are available, delivered quickly, and bought at a low cost after a disaster, relief organisations are getting closer to their suppliers and making contracts with them during the disaster preparation stage.

In the context of disaster relief, supply contracts come in a wide variety, but they all serve the same purpose: to improve supply chain performance by mitigating the most common types of procurement-related risk and settling any associated incentive conflicts that may arise between buyers and sellers (Cachon and Lariviere, 2005). There are many different types of contracts, from the traditional long-term agreements (Balcik and Ak, 2014) with quantity flexibility (Torabi *et al.,* 2018; Nikkhoo *et al.,* 2018) and quantity discount (Shin and Benton, 2007) to the more contemporary option agreements (Liang et al., 2012; Wang *et al.*, 2015) and revenue-sharing agreements (Cachon and Lariviere, 2005). The adoption of long-term contracts prior to a disaster impact would reduce inventory-related risks and boost the flexibility and efficacy of relief organisations in disaster response (Aghajani *et al.,* 2020). Suppliers agree to hold inventory for the relief organisation and ship orders in accordance with the conditions of the framework agreements (including pricing, packaging, etc.). Following a disaster, relief agencies weigh whether to issue directives based on pre-existing contracts. Orders may be shipped straight to the disaster zone or to other logistical hubs, depending on the situation and requirements after the tragedy (e.g., depots, transhipment areas). Framework agreements can be thought of as a subset of stock prepositioning; in fact, "virtual stocks" are the stocks obtained from suppliers through framework agreements (Schulz, 2009). Relief agencies maintain physical inventories in prepositioning to deal with demand uncertainties and quicken the response to disasters, but the expenses of warehousing and inventory can be very high (Balcik and Beamon 2008). Thus, adopting a mix of relief prepositioning and proper supply contracts (between relief groups and suppliers) in the pre-disaster phase would reduce inventory-related risks by enabling a flexible supply base for relief organisations. Framework agreements enable aid agencies to hold onto essential supplies and equipment that would be too costly to stockpile in warehouses.

Additionally, framework agreements are beneficial to suppliers since they guarantee revenue for a set time frame. Interestingly, many relief organisations, like the International Federation of Red Cross (IFRC) and Red Crescent Societies, do their procurement of relief supplies through pre-established supply contracts before a disaster strikes. This can improve their flexibility, response capacity and timeliness while reducing procurement costs (Balcik and Ak, 2014; Aghajani *et al.*, 2020). In order to secure the availability of relief supplies at affordable costs and to mitigate the risk associated with demand unpredictability, option contracts can be used by relief agencies. In addition, an option contract allows the relief organisation to determine the precise purchase amounts of essential relief items as more demand information becomes available post-disaster, increasing the ordering window and allowing for greater flexibility. Suppliers may be enticed to participate since, unlike the relief organisation, they stand to gain financially from the start of an option contract (in the form of the option price) even if they do not initially supply any goods (Chen *et al.*, 2014). The supplier, on the other side, benefits from the HO's early commitment, which allows for more precise capacity and material planning. Thus, an option contract creates win-win circumstances for both the HO and the supplier (Aghajani *et al.*, 2020).

Although they have several advantages, creating these supply contracts with suitable suppliers can be difficult for relief organisations due to the complexity and unpredictability of emergency supply chains (Balcik *et al.*, 2010). In a situation marked by a high degree of unpredictability, relief groups could be hesitant to make legally enforceable pre-purchasing agreements. Due to the unpredictability of disaster demands (in terms of timing, location, amount, and type), there is a possibility that the agreements will not be activated in certain circumstances, and the costs associated with not making use of the products that are attached to the agreements may be significant. As a result, it is necessary for relief organisations that procure supplies to thoroughly evaluate the implications of the agreement conditions that are being given by potential suppliers (Balcik and Ak, 2014).

According to one expert,

"*Several organisations try to put together flexible contracts, but at the end of the day, the problem is to do things quickly. So, stakeholders try to identify suppliers that they can have long-term agreements and framework agreements with. These frameworks can be more flexible. However, several criteria need to be assessed through a tendering process, where suppliers are vetted to check for due diligence; their process must go through a procurement* *mechanism to ensure compliance with laws and regulations. These elements must be put in place before flexible contracts are designed*".

7.3.1.7 Centralisation

The centralised system consists of one organisation or group that is responsible for controlling and commanding all operations related to logistics, accumulating the necessary information, executing a decision, and expecting all the parties involved to follow the decision. This organisation or group may be a government agency, a private company, or a non-profit organisation (Dolinskaya *et al.,* 2011). The agencies of the United Nations are a good illustration of this because they have a centralised authority that allows them to act on decisions pertaining to the coordination of logistical tasks. As was mentioned in their article, one example would be the floods that occurred in Mozambique in the year 2000. The World Food Program and the United Nations High Commissioner for Refugees were the main centralised actors during this time, and they were responsible for making logistical decisions, arranging vehicles, and delivering supplies to the affected area (Dolinskaya *et al.,* 2011). Another example of a centralised approach to logistics would be the method that the International Federation for the Red Cross and Red Crescent Societies (IFRC) used in 2006 to coordinate the organization's responses to natural disasters by first centralising information at its headquarters in Geneva and then transmitting it to the relevant suppliers (Gatignon *et al.,* 2010). One of the most influential factors in the work done during a relief operation is the presence of a local authority or body that is willing to play the role of central coordinator and thus advocate a command-and-control method of coordinating efforts (Charles *et al.,* 2010).

One expert explains,

"This strategy is only effective in small-scale disasters. When dealing with large-scale disasters, there is a need to spread over a long geographical distance. Thus, this strategy can act as a barrier to the emergency supply chain since relief actors with different organizational cultures come from various global locations. Therefore, coordinating and cooperating in disaster relief will be challenging".

Some relief actors refuse to partner up with each other despite sharing the same beliefs and values, which is another reason to lead a centralized strategy (Charles *et al.,* 2010). At this time, there is no widespread agreement that a centralised system is the most effective way to conduct relief operations, nor is there agreement over whether or not the United Nations ought to play the role of a central coordinator in the environment of emergency relief (Dolinskaya *et al.,* 2011).

Another expert discusses.

"It depends on what level you are going to. Are you talking at the country level? For instance, looking at warehouses, If you are looking at the country level, I mean, I would say, on average, we have probably between 15 and 30 different warehouses in most of our countries of operation. So, we would have one which is bigger, probably depending on its location. However, we would never have one that is centralized. Perhaps it does not make any sense to us because we are dealing with a variety of different populations around the country, from a risk strategy to an access strategy or even as a liability. You know, if there was a fire anywhere and you only had one warehouse, and everything would be burned down, that would leave you in a very vulnerable position for a multitude of different reasons. I would not recommend going on the single centralized".

7.3.1.8 Logistics outsourcing

Undoubtedly, efficient management of emergency supply chains is one of the most critical aspects of disaster relief operations. There is a lot at risk in disaster relief, and a well-managed supply chain is necessary to accomplish aid organizations' objectives (Van Wassenhove,2006). It is a commonly held belief that emergency supply chains face several obstacles, some of which include inadequate logistics infrastructures (Liu *et al.*, 2010), sluggish coordination and response times (Chandes and Paché, 2010), disjointed technology and information systems (Tatham and Spens, 2011), and high employee turnover rates (Beamon and Kotleba, 2006; Van Wassenhove, 2006; Tomasini and Van Wassenhove, 2009). On the other hand, it has been suggested that emergency supply networks are among the supply chains that are the most adaptable currently in operation (Van Wassenhove, 2006). According to Whiting and Ayala-Ostrom, (2009) and Van Wassenhove, (2006), the logistics function in disaster relief is vital to the success of various operations. It is generally believed that logistical operations account for up to 80 per cent of the entire investment in disaster relief activities (Trunick, 2005). In addition, it is estimated that more than forty per cent of the money spent on these activities is lost. Several factors cause this, including the repetition of efforts and a lack of time to conduct an accurate analysis (Day *et al.,* 2012; Van Wassenhove, 2006; Bealt *et al.,* 2016). The word "outsourcing," which was coined from the expression "outside resourcing" (Stevenson, 2010), denotes the strategy that businesses adopt to make use of resources that lie outside the confines of their organizational structures (Gossler *et al.*, 2020). Outsourcing can also mean providing logistics functions as services through a contract (Razzaque and Sheng, 1998). It includes strategic, tactical, and operational tasks, such as deciding whether to build or buy, choosing a provider, negotiating a contract, putting outsourcing into action, and evaluating performance (Gossler *et al.*, 2020). Emergency logistics and supply chains are critical areas for outsourcing. Logistical service providers are integral to any disaster relief operation, and aid organizations spend several billion dollars annually on logistics services (Binder and Witte, 2007). They are crucial at the national or local level (Sanchez Gil and McNeil, 2015; Vega and Roussat, 2015; Cozzolino *et al.*, 2017; Baharmand *et al.*, 2017).

According to OCHA, (2022)

"The private sector continues to prove its capacity to quickly mobilize resources on the ground and strengthen emergency preparedness and recovery. In 2021, as the number of people affected by humanitarian crises continued to increase, the private sector has once again shown that it can contribute to stakeholders' coordinated action within complex emergencies. After a 7.2-magnitude earthquake hit Haiti in August 2021, the Alliance for Risk Management and Business Continuity, a local private sector network, played a key role in the response. Support was received from the Connecting Business initiative (CBi), a joint OCHA-UNDP project engaging the private sector in disaster management. The private sector has been a key ally during the COVID-19 pandemic. In 2021, UNICEF, leader of the COVAX procurement and logistics operation, partnered with Microsoft's Disaster Response Team to improve the security and infrastructure of the COVAX information hub. The hub provides key stakeholders with up-to-date information on the allocations and delivery of COVID-19 vaccines. Microsoft experts worked with UNICEF to track and monitor the distribution of vaccines from manufacturers through to local market delivery, increasing efficiencies and sharing real-time data with key stakeholders to help make critical decisions. Following the hub's success, the project has expanded to include all COVAX partners and new types of vaccine product and service delivery information".

However, many workers consider their logistical service provider involvement not fruitful (Bealt *et al.*, 2016). Frequently, relief organizations are unhappy with the results they see for the money they spend (Schulz, 2009; Gossler *et al.*, 2020). Emergency relief outsourcing is fraught with unique difficulties. Relationship building with logistics service providers might be difficult, for instance, due to the significant personnel turnover and unstable funding experienced by relief organizations (Thomas, 2003; Van Wassenhove, 2006). Similarly, conflicts may arise from team members' dissimilar cultural backgrounds and working habits (Nurmala *et al.,* 2017). Services that logistics service providers offer relief organizations need to reveal the relevance of logistics outsourcing (Bealt *et al.,* 2016).

According to one expert,

"It depends on what is outsourced. Stakeholders must ensure adequate information on what is needed from each player".

Another expert highlight,

"Commercial supply chains play an important role in disaster relief operations, but let us understand that the objective of disaster relief is different. However, remember that 3PL organizations will not play important roles out of interest. Hence, the military plays a more significant role in most cases since they are more prepared. In extreme cases, I do not think these commercial organizations are prepared to handle such situations".

In situations with no pre-existing operational presence, logistics service providers can generally ramp up quickly and grow because they can subcontract and manage multiple projects simultaneously inside massive initiatives (Stoddard, 2009). Due to their technical expertise, data access, responsiveness, and financial resources, NGOs can be an invaluable asset in the emergency relief sector (Scholten *et al.,* 2010; Kovács and Spens, 2007; Van Wassenhove, 2006). LSPs may be inexperienced with the local environment and emergency relief operations. Furthermore, there are discrepancies in resource availability, levels of uncertainty, complexity, and stakeholders that make cooperation between the two sectors difficult (Falagara Sigala and Wakolbinger, 2019).

OCHA (2022) underlines

"Despite the demonstrated value of private sector contributions to humanitarian emergencies and achieving the SDGs, the private sector, particularly local businesses, are frequently overlooked. The private sector is still not systematically included in humanitarian coordination systems. More must be done to fully leverage its expertise and contribution to principled and accountable disaster response and recovery in sudden-onset and complex emergencies, whether in natural hazards or human-made conflicts and pandemics".

When you outsource, you save money on "capital investment in premises, equipment, IT, and labour" (Razzaque and Sheng, 1998). Due to limited resources and heavy reliance on donor funding, this is especially important in disaster relief.

According to another expert,

"As an organisation, WFP is the largest humanitarian organization. We have a budget this year of over $10 billion. We do not own any of our assets. We do not own any planes. We do not own any ships. We own about 800 trucks, which is about 5% of our total requirement. Moreover, that is only for emergencies, right? We use that in cases where there are no suppliers or in some cases where we feel they act as a cartel and the market rates are just so high that we cannot pay them. We always try and use the private sector. We never want to replace the private sector, and we always want to use third parties. What we do differently, though, is that you know they have what they call 3PL and 4PL, right? So 3PL will be a transporter and a shipping company, and a 4PL will offer you an end-to-end service. We do not use four PLs. We prefer to control all the different parts of the transportation legs ourselves. So, when we procure, we buy FOB, then we will contract the ships, and we will contract the ports and unload them. The warehouses and the trucks to transport. Rather than ask any organization or any private sector to provide an end-to-end service again because we need to have the flexibility that that we require, especially in the countries where we are working".

7.3.1.9 Decision policies/procedures

The emergency supply chain is backed by many different groups (government, military, NGOs, donors, etc.), and it begins with determining what is needed and continues all the way through to the provision of aid to the victims. The government is also essential in both the pre- and post-disaster phases. To a large extent, and for the better, host governments help facilitate emergency supply chains. They may, for instance, regulate non-governmental organisations (NGOs) in order to improve their professionalism (Tomasini and Van Wassenhove, 2003; Balcik *et al.*, 2010), provide military support for the emergency relief effort (Kovács and Spens, 2007), or coordinate the activities of relief organisations (Mac Abbey, 2008). When a government declares a state of emergency, lengthy customs clearance procedures are sometimes suspended to allow for the expedited import of disaster response supplies (Kunz and Gold, 2015).

Furthermore, governments can control the influx of ad hoc and frequently unprofessional organisations into a catastrophe zone (Day *et al.*, 2012). Finally, governments can restrict the influx of un-asked-for donations, which significantly disrupt emergency supply networks by causing unnecessary bottlenecks (Holguin-Veras *et al.*, 2012). The government is the primary decision-maker in relief efforts. To that end, the host government's enabling services could greatly improve the efficiency and efficacy of the relief effort (Kabra and Ramesh, 2015). Disaster preparedness policies are developed and implemented by government bodies. It aids in the development of both immediate and long-term responses by the government (Kabra and Ramesh 2015a). In the absence of a government policy statement or disaster legislation, it is important to note that in many cases, organisational structures have emerged from some planning base (such as a national plan or even numerous provincial plans). The responsibility for fully covering day-to-day liaison, immediate reaction, and dealing with international help needs to be clearly defined, especially so that there can be no ambiguity as to who should take relevant action under the stresses of disaster impact. Emergency supply chains function best when their management mode is meticulously crafted to guarantee that all participating departments have a firm grasp on their specific roles and responsibilities (Yadav and Barve, 2015). If we take the floods that struck Chennai, India, in 2015 as an example, the government's failure to provide adequate infrastructure for disaster assistance was a major setback. Donors were unable to deliver aid since no official was there to accept the packages. The huge effects of Cyclone Hudhud on India's eastern coast were mitigated because of the government's swift response and careful preparation (Singh *et al.*, 2018).

According to the European Commission (2018),

"A DG ECHO policy statement that provides clarity on its approach to logistics, its level of ambition for its engagement in humanitarian logistics, what it requires of partners, and how it intends to contribute to the strengthening of logistics systems across the humanitarian sector, would benefit both staff and partners. The development and implementation of a policy for logistics will require additional logistics expertise and capacity in the organization. The policy would expect partners to work together on joint logistics efforts".

7.3.1.10 Risk awareness / Knowledge management

Knowledge is described as "the fact or condition of knowing something with a considerable degree of familiarity through experience, association, or interaction" by Mohanty *et al.*, (2006). There are three types of knowledge: explicit, tacit, and implicit. Explicit knowledge, also known as codified or formal knowledge, is knowledge that is stated in detail (Tatham and Spens, 2011). Anyone can obtain explicit knowledge through books, images, or video clips.

According to Nonaka *et al.,* (2001), Tacit knowledge is derived from personal experience and conveyed via the actions of persons in the form of judgments, attitudes, points of view, commitments, and motivation. The individual who holds tacit knowledge also loses it. The knowledge that could be articulated is referred to as implicit knowledge (Mohanty *et al.,* 2006). In other words, implicit knowledge is a collection of present information but not explicitly stated. Knowledge management is known as creating, disseminating, and utilizing new information (Deshmukh *et al.,* 2008). According to Tatham and Spens, (2011), the term "knowledge management" refers to "a strategy to collect, store, and systematically retrieve knowledge, and then distribute the results to those who need it in a timely manner." In other words, knowledge management is a strategy to "collect, store and systematically retrieve knowledge" (Tatham and Spens, 2011). To put it more simply, knowledge management is the process of ensuring that the appropriate information is available at the appropriate time and location. However, it is important to keep in mind that knowledge management systems can only offer decision support; in actuality, it is the people who are put in dangerous situations who are the ones who must cope with the emergency or tragedy. Because of this, the precise actions and duties of individuals are unable to be identified in advance due to the occurrence of certain unanticipated occurrences during the crisis (Otim, 2006).

According to one expert,

"This strategy is very much useful in the commercial sector. However, with relief organizations, when they tackle problems, they tackle problems on different scales since there is little or no information about the next disaster. When these relief organizations move, they rely on local support. Adapting to a new situation is usually challenging. Hence, every emergency supply chain needs to possess three important strategies: agility, adaptability, and alignment. Hence, knowledge management is relevant but must be integrated with adaptability and alignment. Whenever a relief organization moves to a new location, the majority of the team is often picked up from the location environment, and only very few people have experience. There is no time to train people in the disaster relief context".

To respond effectively to disasters, decision-makers must have access to up-to-date information, as stated by Asghar Pourezzat *et al.,* (2010). There is also limited room for delay in decision-making and response activities during a disaster. Accordingly, the quality of judgements and, by extension, the quality of disaster response is negatively impacted by any problems or delays in data collection, access, usage, and distribution (Asghar Pourezzat *et al.,* 2010). Knowledge management has the potential to play a crucial part by assuring the availability and accessibility of up-to-date and trustworthy knowledge pertaining to disasters at all times, as well as by facilitating the most efficient possible learning (Seneviratne et al., 2010).

Another expert explains,

"This is a critical strategy. The strategy requires contribution from various key players to contribute to that knowledge base and to recognise the values of this knowledge base. The big challenge here is communicating this knowledge. Knowing is one; disseminating this knowledge is another. Several stakeholders are involved in the relief operation. Hence, it is important to ensure all these actors are aware of these information/knowledge bases. It is great to know, but if these actors are unaware of its existence, it is not right".

In order to be able to respond effectively to unpredictability, agility is required; nevertheless, a resilient supply chain also requires a supportive management culture (Christopher and Peck, 2004) and direct assistance from senior management (Ponomarov and Holcomb, 2009). According to Sheffi and Rice (2005), "it is vital to not underestimate the importance of culture to the flexibility and resilience of an organisation." For organisations to be resilient, they need to develop appropriate management policies and actions that continuously assess risk and coordinate the efforts of their supply network (Kleindorfer and Saad, 2005). Partners in the supply chain need to have a shared understanding and awareness of the potential risks that could arise within their operations (Faisal *et al.*, 2006). A primary characteristic of resilience is the ability to draw lessons from previous challenges and improve one's level of preparedness for situations that may arise in the future (Ponomarov and Holcomb, 2009). As a result, the most successful businesses today educate their workers, vendors, and end users on the risks associated with supply chain resilience through training programmes that focus on supply chain security and supply network threats (Blackhurst *et al.*, 2011; Rice and Caniato, 2003). In addition, knowledge and comprehension of supply chain structures, whether they be physical or informational, are essential components of supply chain resilience (Scholten *et al.*, 2014). Businesses need reliable knowledge management systems to organise and keep track of their information (Centobelli *et al.*, 2017). Two types of knowledge management systems (KMSs) exist knowledge management tools (KM-Tools) and knowledge management practices (KM-Practices). Relief organisations should learn how to effectively manage logistics in highly volatile circumstances, as suggested by Lu *et al.*, (2013) and Tatham and Spens, (2011).

Increased efficiency in emergency relief efforts is possible with proper identification, recruiting, and training of volunteers (Yadav and Barve, 2015). The staff should be made up of multi-skilled specialists who can assist with and carry out the most fundamental aid relief activities, such as administering vaccinations, distributing aid, helping people regain psychological stability, etc. Experts in logistics, demolition, and reconstruction are also on hand, in addition to those who oversee the mission's overall strategy and oversee operational tasks like medical care and security. For a relief operation to be successful, it is crucial to have access to skilled professionals. As a result of the high incidence of skilled personnel turnover, it has been determined that an induction and training programme is required (Pettit and Beresford, 2009; Yadav and Barve, 2015; Singh *et al.,* 2018).

7.3.1.11 Cash-based Interventions

Donors providing donations for disaster response operations want their contributions to be used to alleviate the immediate suffering in a visible manner (Beamon and Kotleba, 2006). The usual emergency supply chain relies on robust logistics infrastructure and resources, such as transport, warehousing, and inventory, as well as many logisticians (Heaslip *et al.,* 2018). Emergency relief distribution can encounter unanticipated logistical and bureaucratic obstacles at every step, necessitating adjustments to distribute aid (Heaslip, 2013). Some of the biggest aid donors and organizations, like the International Committee of the Red Cross, International Federation of the Red Cross and Red Crescent Societies, Oxfam, and the World Food Programme, have started funding cash and voucher-based innovations to try new things and learn from them (Fenton *et al.,* 2014; Heaslip *et al.,* 2018a; Heaslip *et al.,* 2018b). With cash-based intervention, the affected population receives emergency aid through cash, vouchers, cards, or tokens that can be redeemed for various critical relief supplies and services (ICRC, 2018). The ability to access markets and meet the population’s wants in a manner that is most convenient to them is transferred to beneficiaries, enhancing spending power. Therefore, the primary concern of cash transfers is meeting the requirements of recipients in a way that is compatible with the existence of markets. Cash-based programming can be considered a pull-based response since it makes the fewest possible assumptions about the services supplied (Garc and Castillo, 2021).

Since 2015, the number of cash programmes has significantly expanded. The United Nations High Commissioner for Refugees (UNHCR) spent 2.4 billion dollars on cash assistance between 2016 and 2020, of which 95% was cash support for multiple purposes (UNHCR, 2019). Comparatively, cash made up only 27% of WFP's pay-outs in 2016, but in 2018, it made up 45% of those payments (WFP, 2019). It is commonly believed that cash is more cost-efficient, that it can boost output, that it is more dignified for beneficiaries and that it provides a stronger incentive for the markets in which it is used (Garc and Castillo, 2021).

Cross-sector partnerships, also known as diagonal partnerships, refer to collaborations between "actors at different levels on the value chain and from different sectors and industries." The development of the emergency supply chain has shifted towards diagonal partnerships in recent years (Cozzolino, 2012). Working with commercial partners such as Visa or Western Union, as well as enterprises that deal in mobile phones, local non-governmental organisations (NGOs), community groups, or local authorities, is what this entails for cash-based interventions. Working with other partners, on the other hand, brings up the subject of risks and security (Christopher and Peck, 2004) because doing so places the locus of control outside of the aid organisation, and cash-based programmes offer their own unique set of dangers and security concerns (Heaslip *et al.*, 2018a).

According to Heaslip *et al.* (2015) and Kovács (2014), cash-based interventions generally indicate a reconfiguration of the emergency supply chain with significant downstream effects on the local economy. A local partner, such as the local authorities or local NGOs, frequently conducts the activity of distribution in emergency supply chains where the primary activity is the provision of critical relief supplies (Altay and Ramirez, 2010). Although financial flows refer to cash as a commodity, there is a change in the distribution of cash-based interventions toward an actor who can manage the financial flow better. For example, banks. Moreover, the existence of operating marketplaces nearby and the beneficiary's access to those markets remain prerequisites. Cash transfers are more cost-effective and make better use of donor money than in-kind contributions, making them preferable from a financial and administrative standpoint. This effectiveness can be evaluated using a metric known as the total cost-to-transfer ratio, which is defined as the proportion of funds that beneficiaries get in comparison to the entire budget for the programme (ECHO, 2017). Between needs assessment and distribution, ECHO suggests aiming for an efficiency ratio of 85:15 as a goal to reach between the two processes. If prices go up or there is a lack of product availability, this indicator could give the wrong impression about whether beneficiaries' demands are being effectively satisfied (Heaslip *et al.*, 2018). Cash-based interventions are delivered through a variety of mechanisms, including unconditional cash transfer, conditional cash transfer, vouchers, and cash for work (Heaslip *et al.*, 2015). New communications methods for cash transfers, such as "mobile money" provided by Safaricom, have made this type of emergency relief aid more accessible in many developing nations in recent years (Fenton *et al.*, 2014; Kovács, 2014; Heaslip *et al.*, 2018).

One expert discusses,

"Gaining traction over the last ten years, several means have been applied to demonstrate this strategy, such as mobile money, food vouchers, paper vouchers, cash-cash vouchers, and social protection mechanisms. This is useful, but having the right strategy to distribute cash is essential. However, this can only be adopted firstly when there is an available local market, so in cases when these local markets have been severely impacted by a disaster or the presence of a major conflict or a case where there is no access to the local markets, then this strategy does not help the situation. Generally, cash-based intervention is more cost-effective to assist those affected even though markets are impacted since these markets recover quickly".

Cash-based Interventions are not a panacea, and there are several challenges and concerns surrounding their use. According to Heaslip *et al.,* (2018), beneficiaries are put in a vulnerable position when cash is used since it puts them in the path of complicated market dynamics such as inflation, product availability, and delivery-related safety concerns. When transferring money, it is important to keep everyone involved—the recipients and the people handing out the cash—safe (Bailey *et al.,* 2008). The receiver can easily conceal cash, and the thief can easily make off with it (Harvey and Bailey, 2011). Concerns about secure delivery, as well as the influence of the currency on the conflict and if it could make the conflict worse, arise when cash-based interventions are used in contexts of armed conflict. While there is some evidence that secure cash transfer can be accomplished even in war zones (Bailey *et al.,* 2008), quantifying the effect of disaster relief cash programmes on armed conflicts is challenging.

Another expert explains,

"Yes, this strategy is relevant. This strategy is applicable in some countries but not in others. I will say this strategy will only work out in some situations. For example, this strategy is very effective when dealing with crises in Haiti since the local community is fully motivated enough. Still, in some countries like Japan, it will not be as effective as required. This strategy is contingent on specific conditions, such as the national culture and beliefs of the affected populations".

Another challenge of cash-based intervention is the possibility of price inflation of critical relief supplies needed by the affected population as a result of cash injection into the local economy.

Inflation increases risk and devalues cash-based interventions. Any cash-based program faces the risk of inflation eroding the real value of the grant, but cash-based intervention can also actually generate inflation, which is bad for the market and bad for recipients and non-recipients (Bailey *et al.,* 2008). If the value of the cash award declines due to inflation, it may be difficult for the agency to reallocate its limited resources to meet the project's continuing needs. Market dynamics, as seen during the food price crises of 2007-2008, can likewise drive up food costs, leading to the same difficulties for fixed cash transfers (Wheeler and Devereux, 2010; Heaslip *et al.,* 2018)

According to another expert,

"For me, yes.

Absolutely. I mean, in most sophisticated or semi-sophisticated environments, people always prefer cash because they know what they need, right? It could be anything from clothes for the kids food to medical items. It is applicable for a couple of reasons. One is that you are not even sure what. You know what they need in kind. Moreover, secondly, of course, you are disrupting the market so that you can give them cash, and the market is working. So, if they can buy what they need in the market, then cash should be the answer.

We work on a cash-first principle, right? There are many environments, though, where cash does not work right. So, in Yemen, we were there ten years ago, we were using cash for about 80% of our operation. Today, we are using cash for probably 5% because the environment changes, and you need to have that flexibility to move from cash to in-kind and back again. You might use cash in certain parts, or you might use it even in certain commodities. Yeah, but you will not use it for others."

After completing this empirical study, only eight risk mitigation techniques were selected for in-depth evaluation due to the limited amount of data available. While every strategy is ultimately helpful, emergency relief operations are currently struggling to make the most of postponement, centralization, decision policies/procedures, and cash-based methods. Risk mitigation strategies selected for in-depth study are summarised in Figure 7.3.

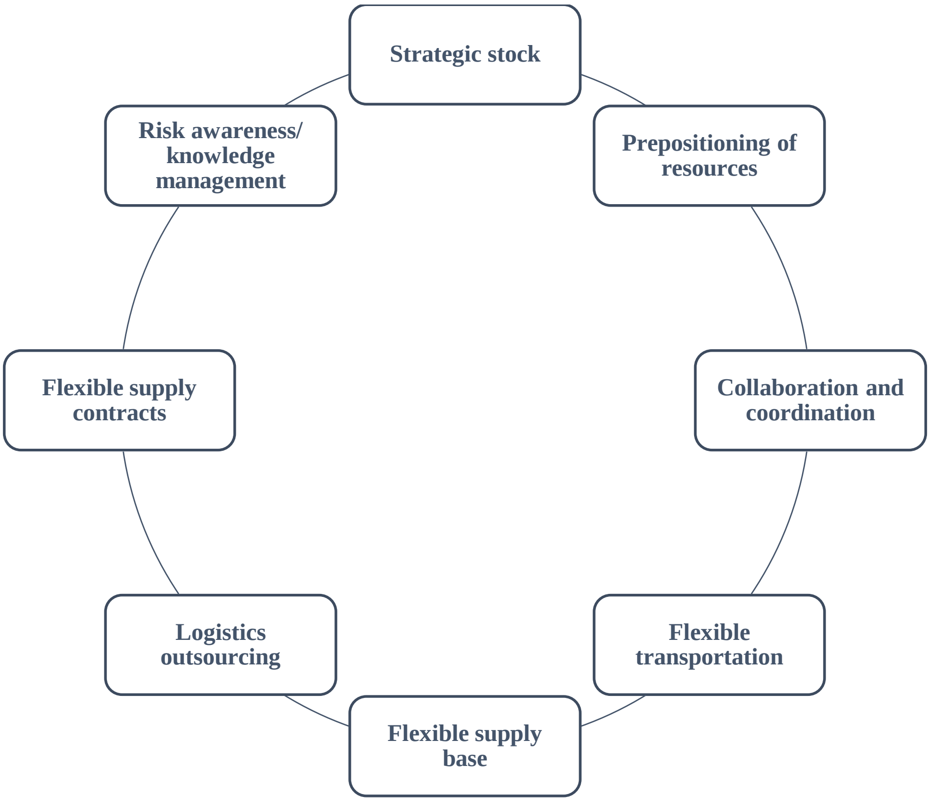

Figure 7.3 Finalised supply strategies for risk mitigation in emergency supply chains

7.4 An Empirical Study

The paradigm for risk management consists of three distinct processes: risk identification, assessment, and risk mitigation. The proposed risk management model represents a dynamic and continuous process, and it is necessary to complete a cycle. In previous chapters, risk factors in emergency supply chains have been identified and assessed, but before the risk management process can be considered complete, the identified risk factors need to go through the phase of mitigation. The Fuzzy TOPSIS method was developed so that an analysis could be conducted to determine the relative value of each suggested risk mitigation strategy in comparison to the initial group of risk factors. With the help of a questionnaire survey, an investigation was carried out in order to gain a more in-depth comprehension of the relevance of the risk mitigation strategies that have been implemented and to establish appropriate solutions for risk management in emergency supply chains. This study incorporated three distinct steps to complete the risk mitigation process. Firstly, completing a survey to gather relevant empirical data. Next, utilising the Fuzzy-TOPSIS methodology to analyse the retrieved information. Finally, a sensitivity analysis of the results.

7.4.1 Questionnaire survey

In October 2022, a pilot study was developed and distributed to various experts, including members of the supervisory team. Members of the supervisory team and two other academic researchers were engaged to review and comment on the appropriateness and clarity of the survey questions. A revised and final questionnaire was developed based on these comments. The developed questionnaire is web-based and can be accessed easily through an online link. Before the dissemination of the questionnaire, the study obtained ethical approval to validate the questionnaire's contents.

The survey via questionnaire was carried out over five weeks, beginning on November 9th and ending on December 9th, 2022. In order to finish the survey, a variety of experts who each possess their unique level of expertise and abilities as well as a considerable degree of knowledge in the fields of emergency supply chain management, disaster management, and supply chain risk management were contacted. The eligible experts were contacted and asked to confirm that they would be willing to participate in the survey. Therefore, after receiving a response indicating that they were interested in participating, the questionnaire was sent to the expert. In addition, the survey was completed by both academics and practitioners who are considered to be authorities in their fields.

Several channels, including LinkedIn and the Humanitarian Logistics Association (HLA), were used to contact various experts in the field. However, only 13 experts agreed to participate in the survey. Some showed interest but provided a few reasons why they would not take part in the survey. At the end of the survey, four experts did begin the survey but did not complete it. Only nine responses were completed and accepted for further analysis. The return rate of the survey is acceptable since relevant information was received from experts with sufficient knowledge and expertise. Table 7.2 presents the details of experts who provided full feedback for the survey.

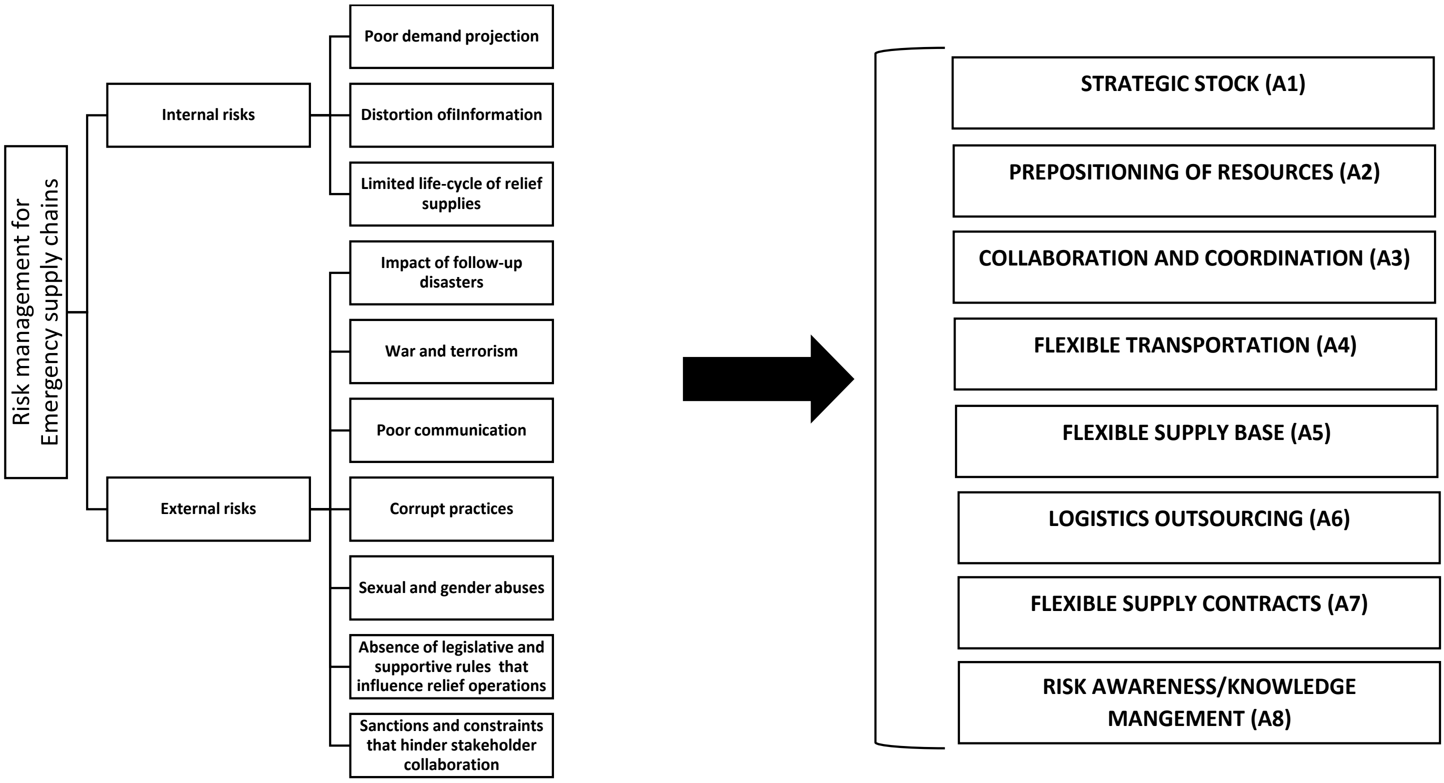

Figure 7.4 Decision hierarchy for risk factors mitigation in emergency supply chains

Table 7.2 Profile of survey participants

Experts	Affiliated Organisation	Job description	Years of work experience	Relief operation participated	Organisational size
1	Relief organisation	Supply chain and logistics consultant	>20	Yes, I have participated in several relief operations	400
2	Non-governmental organisation	Project coordinator	>20	Yes, Flood,2000, SIDR-2007, AILA,2009; Water Logging, 2011; Cyclone Bulbul, 2019 Cyclone Foni, 2019 Cyclone AMPHAN, 2020 Cyclone YAAS, 2021 Cyclone Shitrang, 2022 Cyclone, YAAS	650
3	Human research institute	Researcher	6-10	Yes, in my previous position (4 years with an NGO), I helped multiple field positions.	>60k
4	Self-employed	Consultant	>20	Yes – various since 1995	1
5	Relief organisation	Disaster management coordinator	11-15	Yes, the Distribution of NFIs	180
6	Relief organisation	Operations and Programmes coordinator	11-15	During my 13 years of experience, I participated in several relief operations, be it country level or at the international level	>100k
7	Non-governmental organisation	Regional logistics manager	11-15	Yes	5000
8	Non-governmental organisation	Emergency, preparedness, and response specialist	16-20	Yes	80
9	Non-governmental organisation	Logistic manager	11-15	Lombok Earthquake Palu and Donggala Earthquake and Tsunami Sunda Strait Tsunami:	50

7.4.2 Fuzzy TOPSIS Methodology for Risk Mitigation Strategies

In the prior chapter, the relative weights of essential risk factors in emergency supply chains were computed. This chapter will continue this work. In addition, as part of the conclusion of the empirical inquiry, a total of eight risk mitigation strategies were determined to give management solutions for the emergency supply chain. Figure 7.4. presents a visual representation of the decision hierarchy. Following are the actions that are taken to analyse these mitigation techniques using Fuzzy-TOPSIS so that we can decide the priority order in which they should be implemented.

STEP 1: *Choose the linguistic rating values for the alternative with respect to the criteria.*

Fuzzy assessment matrices based on the linguistic scales for subjective judgements were constructed with the help of the participating experts. Very poor (VP), poor (P), medium (M), good (G), and very good (VG) are the basic language preferences used in this study. The complexity, incompleteness of definition, and uncertainty that underlie most real-world decision-making situations make the concept of linguistic variables an excellent fit (Chatterjee and Kar, 2016). Therefore, the discovered risk mitigation strategies are evaluated in terms of their effectiveness in managing each risk factor based on the linguistic scale presented in Table 3.7. Tables 7.3 and 7.4 show the results of the linguistic evaluation matrix and the fuzzy evaluation matrix for three experts when considering the risk factor, war and terrorism.

Table 7.3 Linguistic scale evaluation for a risk factor (war and terrorism) (3 experts)

Risk Factor	**Alternative**	**Experts**		
		E1	**E2**	**E3**
War and terrorism	Strategic Stock	VG	G	M
	Prepositioning Resources	VG	M	M
	Collaboration and Coordination	VG	G	VG
	Flexible Transportation	G	VG	VG
	Flexible Supply Base	G	M	VG
	Logistics Outsourcing	VG	M	P
	Flexible Supply Contracts	G	P	P
	Risk Awareness/ Knowledge management	VG	M	G

Table 7.4 Fuzzy evaluation matrix for risk mitigation strategies (3 experts)

Risk Factor	**Alternative**	**Experts**		
		E1	**E2**	**E3**
War and terrorism	Strategic Stock	(7,9,11)	(5,7,9)	(3,5,7)
	Prepositioning Resources	(7,9,11)	(3,5,7)	(3,5,7)
	Collaboration and Coordination	(7,9,11)	(5,7,9)	(7,9,11)
	Flexible Transportation	(5,7,9)	(7,9,11)	(7,9,11)
	Flexible Supply Base	(5,7,9)	(3,5,7)	(7,9,11)
	Logistics Outsourcing	(7,9,11)	(3,5,7)	(1,3,5)
	Flexible Supply Contracts	(5,7,9)	(1,3,5)	(1,3,5)
	Risk Awareness/ Knowledge management	(7,9,11)	(3,5,7)	(5,7,9)

STEP 2: *Calculate the aggregate fuzzy rating for all alternatives.*

In this step, the study pools the expert's responses to get the aggregated fuzzy rating of $\tilde{X}_{ij}$ of alternatives with respect to each criterion. Eq. (3.25) is used to compute these values and is presented in Table 7.5.

$$a = \min_k\{ak\}, \quad b = \frac{1}{K}\sum_{k-1}^{k} b_k\,, \quad c = \max_k\{c_k\}$$

Table 7.5 Aggregate fuzzy decision matrix for alternatives

	R1	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**R10**
A1	(3,6.778,11)	(1,6.333,11)	(3,7.444,11)	(1,6.111,11)	(1,5.667,11)	(1,5.000,11)	(1,4.556,11)	(1,4.778,11)	(1,6.333,11)	(1,5.222,11)
A2	(3,7.222,11)	(1,7.000,11)	(3,7.889,11)	(1,6.556,11)	(1,6111,11)	(1,5.222,11)	(1,5.000,11)	(1,5.444,11)	(1,5.444,11)	(1,5.222,11)
A3	(5,8.111,11)	(3,7.889,11)	(5,8.333,11)	(3,8.333,11)	(1,7.000,11)	(1,7.222,11)	(1,6.556,11)	(1,7.000,11)	(1,7.667,11)	(1,7.889,11)
A4	(5,7.889,11)	(3,6.333,11)	(5,8.111,11)	(3,7.000,11)	(1,5.667,11)	(1,5.889,11)	(1,4.333,11)	(1,5.000,11)	(1,7.000,11)	(1,5.889,11)
A5	(3,7.222,11)	(1,7.000,11)	(3,7.667,11)	(3,7.000,11)	(1,5.889,11)	(1,6.778,11)	(1,4.556,9)	(1,5.000,11)	(1,7.222,11)	(1,5.889,11)
A6	(1,6.556,11)	(1,7.222,11)	(1,6.778,11)	(3,7.222, 11)	(1,5.444,11)	(1,6.778,11)	(1,5.222,11)	(1,5.000,11)	(1,6.333,11)	(1,6.111,11)
A7	(1,6.111,11)	(1,6.778,11)	(1,7.000,11)	(3,7.444,11)	(1,6.333,11)	(1,6.556,11)	(1,5.889,11)	(1,4.778,11)	(1,7.222,11)	(1,6.111,11)
A8	(3,7.6667,11)	(1,7.000,11)	(1,7.222,11)	(1,6.556,11)	(1,6.556,11)	(1,7.444,11)	(1,5.889,11)	(1,7.444,11)	(1,6.111,11)	(1,7.444,11)

STEP 4: *Construct the fuzzy decision matrix and the normalized fuzzy decision matrix.*

In this study, since all criteria are risk factors that can prevent the emergency supply chain from meeting its operational objectives, they are viewed as cost criteria. To compute the normalised values, Eq. (3.26) and Eq. (3.29) are utilised, and the output is presented in Table 7.7

STEP 5: *Construct the weighted normalized fuzzy decision matrix*. This step is to obtain a fuzzy weighted evaluation matrix. Using the priority weight calculated by Fuzzy AHP in the previous chapter, the weighted evaluation matrix is established using Eq. (3.30). Table 7.8 presents the output of this operation.

STEP 6: *Determine the fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS).*

The risk factors are all considered cost criteria since they are likely to disrupt the normal functioning of the emergency supply chain. Therefore, the fuzzy positive ideal solution $(FPIS, A^{*})$ and fuzzy negative ideal solution $(FNIS, A^{-})$ are taken as $\tilde{V}^{*} = (0,0,0)$ and $\tilde{V}^{*} = (1,1,1)$ for all these criteria. Then, compute the distance d_v of each alternative from FPIS (A^{*}) and FNIS (A^{-}) using Eq. (3.33) and Eq. (3.34)

For example, for alternative A1 with respect to criteria R1:

$$d(A_1, A^{*}) = \sqrt{\frac{1}{3}\ (0-0.008)^2 + (0-0.013)^2 + (0-0.030)^2}$$

$$d(A_1, A^{*}) = 0.01943$$

$$d(A_1, A^{-}) = \sqrt{\frac{1}{3}\ (1-0.008)^2 + (1-0.013)^2 + (1-0.030)^2}$$

$$d(A_1, A^{-}) = 0.98305$$

Similarly, calculations are done for all alternatives with respect to all criteria. At the end of the calculations, the cumulative distances of d_1^{*} and d_1^{-} are also computed. For alternative A1, the cumulative distances from the positive ideal solution, $d_1^{*} = 0.32576$ and negative ideal solution, $d_1^{-} = 0.0.7618$. Table 7.9 and 7.10 presents the values of FPIS and FNIS for all alternatives and criteria.

STEP 7: *Calculate the closeness coefficient (CC_i) of each alternative.*

The closeness coefficient represents the distance between the fuzzy positive ideal solution and the fuzzy negative ideal solution.

Here, the study adopts Eq. (3.35)

$$CC_i = \frac{d_1^{-}}{d_1^{-} + d_1^{+}}$$

For example, the CC_i for alternative A1 can be computed as follows:

$$CC_i = \frac{9.7618}{(0.32576 + 9.7618)} = 0.967706759$$

Similar calculations are done for all alternatives before proceeding to the final step. Table 7.11 presents the CC_i values for all alternatives.

STEP 8: *Ranking the alternatives.* See Table 7.11

Table 7.6 Normalised fuzzy decision matrix for alternatives.

	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
A1	(0.090,0.148,0.333)	(0.090,0.158,1)	(0.090,0.134,0.333)	(0.090,0.164,1)	(0.090,0.176,1)	(0.090,0.200,1)	(0.090,0.219,1)	(0.090,0.209,1)	(0.090,0.158,1)	(0.090,0.191,1)
A2	(0.090,0.138,0.333)	(0.090,0.143,1)	(0.090,0.127,0.333)	(0.090,0.153,1)	(0.090,0.164,1)	(0.090,0.191,1)	(0.090,0.200,1)	(0.090,0.184,1)	(0.090,0.184,1)	(0.090,0.191,1)
A3	(0.090,0.123,0.200)	(0.090,0.127,0.333)	(0.090,0.120,0.200)	(0.090,0.120,0.333)	(0.090,0.143,1)	(0.090,0.138,1)	(0.090,0.153,1)	(0.090,0.143,1)	(0.090,0.130,1)	(0.090,0.127,1)
A4	(0.090,0.127,0.200)	(0.090,0.158,0.333)	(0.090,0.123,0.200)	(0.090,0.143,0.333)	(0.090,0.176,1)	(0.090,0.170,1)	(0.090,0.231,1)	(0.090,0.200,1)	(0.090,0.143,1)	(0.090,0.170,1)
A5	(0.090,0.138,0.333)	(0.090,0.143,1)	(0.090,0.130,0.333)	(0.090,0.143,0.333)	(0.090,0.170,1)	(0.090,0.148,1)	(0.111,0.219,1)	(0.090,0.200,1)	(0.090,0.138,1)	(0.090,0.170,1)
A6	(0.090,0.153,1)	(0.090,0.138,1)	(0.090,0.148,1)	(0.090,0.138,0.333)	(0.090,0.184,1)	(0.090,0.148,1)	(0.090,0.191,1)	(0.090,0.200,1)	(0.090,0.158,1	(0.090,0.164,1)
A7	(0.090,0.164,1)	(0.090,0.148,1)	(0.090,0.143,1)	(0.090,0.134,0.333)	(0.090,0.158,1)	(0.090,0.153,1)	(0.090,0.170,1)	(0.090,0.209,1)	(0.090,0.138,1)	(0.090,0.164,1)
A8	(0.090,0.130,0.333)	(0.090,0.143,1)	(0.090,0.138,1)	(0.090,0.153,1)	(0.090,0.153,1)	(0.090,0.134,1)	(0.090,0.170,1)	(0.090,0.134,1)	(0.090,0.164,1)	(0.090,0.134,1)

Table 7.7 Weighted normalised fuzzy decision matrix for alternatives.

	R1	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**R10**
A1	(0.008,0.013,0.030)	(0.008,0.014,0.086)	(0.008,0.011,0.029)	(0.008,0.014,0.084)	(0.007,0.013,0.074)	(0.005,0.011,0.0545)	(0.005,0.012,0.0539)	(0.005,0.011,0.0534)	(0.004,0.007,0.0417)	(0.004,0.008,0.0406)
A2	(0.008,0.013,0.030)	(0.008,0.012,0.086)	(0.008,0.011,0.029)	(0.008,0.013,0.084)	(0.007,0.012,0.074)	(0.005,0.010,0.0545)	(0.005,0.011,0.0539)	(0.005,0.010,0.0534)	(0.004,0.008,0.0417)	(0.004,0.008,0.0406)
A3	(0.008,0.011,0.018)	(0.008,0.011,0.029)	(0.008,0.010,0.017)	(0.008,0.010,0.028)	(0.007,0.011,0.074)	(0.005,0.008,0.0545)	(0.005,0.008,0.0539)	(0.005,0.008,0.0534)	(0.004,0.005,0.0417)	(0.004,0.005,0.0406)
A4	(0.008,0.012,0.018)	(0.008,0.014,0.029)	(0.008,0.011,0.017)	(0.008,0.012,0.028)	(0.007,0.013,0.074)	(0.005,0.009,0.0545)	(0.005,0.012,0.0539)	(0.005,0.011,0.0534)	(0.004,0.006,0.0417)	(0.004,0.007,0.0406)
A5	(0.008,0.013,0.030)	(0.008,0.012,0.086)	(0.008,0.011,0.029)	(0.008,0.012,0.028)	(0.007,0.013,0.074)	(0.005,0.008,0.0545)	(0.006,0.012,0.0539)	(0.005,0.011,0.0534)	(0.004,0.006,0.0417)	(0.004,0.007,0.0406)
A6	(0.008,0.014,0.091)	(0.008,0.012,0.086)	(0.008,0.013,0.086)	(0.008,0.012,0.028)	(0.007,0.014,0.074)	(0.005,0.008,0.0545)	(0.005,0.010,0.0539)	(0.005,0.011,0.0534)	(0.004,0.007,0.0417)	(0.004,0.007,0.0406)
A7	(0.008,0.015,0.091)	(0.008,0.013,0.086)	(0.008,0.012,0.086)	(0.008,0.011,0.028)	(0.007,0.012,0.074)	(0.005,0.008,0.0545)	(0.005,0.009,0.0539)	(0.005,0.011,0.0534)	(0.004,0.006,0.0417)	(0.004,0.007,0.0406)
A8	(0.008,0.012,0.030)	(0.008,0.012,0.086)	(0.008,0.012,0.086)	(0.008,0.013,0.084)	(0.007,0.011,0.074)	(0.005,0.007,0.0545)	(0.005,0.009,0.0539)	(0.005,0.011,0.0534)	(0.004,0.007,0.0417)	(0.004,0.005,0.0406)
W	0.0906	0.0858	0.0857	0.0843	0.074	0.0545	0.0539	0.0534	0.0417	0.0406

Table 7.8 Fuzzy positive ideal solution (FPIS) values

	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	d_1^*
A1	0.01943	0.05052	0.01849	0.04938	0.04357	0.03223	0.03201	0.03161	0.02452	0.024	0.32576
A2	0.01943	0.05035	0.01849	0.04929	0.04347	0.03212	0.03189	0.0315	0.02462	0.024	0.32516
A3	0.01303	0.01849	0.01229	0.01778	0.04338	0.03193	0.03159	0.03131	0.02436	0.02373	0.24789
A4	0.01332	0.01916	0.01257	0.01818	0.04357	0.03202	0.03201	0.03161	0.02443	0.0239	0.25077
A5	0.01943	0.05035	0.01849	0.01818	0.04357	0.03193	0.03207	0.03161	0.02443	0.0239	0.29396
A6	0.05336	0.05035	0.05043	0.01818	0.04367	0.03193	0.03178	0.03161	0.02452	0.0239	0.35973
A7	0.05345	0.05043	0.05035	0.01797	0.04347	0.03193	0.03168	0.03161	0.02443	0.0239	0.35922
A8	0.01922	0.05035	0.05035	0.04929	0.04338	0.03186	0.03168	0.03161	0.02452	0.02373	0.35599

Table 7.9 Fuzzy negative ideal solution (FNIS) values

	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	d_1^-
A1	0.98305	0.96465	0.98404	0.96528	0.96914	0.97675	0.97661	0.9771	0.98258	0.9826	9.7618
A2	0.98305	0.96533	0.98404	0.96562	0.96948	0.97709	0.97694	0.97744	0.98225	0.9826	9.76384
A3	0.98768	0.98404	0.98834	0.98471	0.96982	0.97776	0.97796	0.97812	0.98326	0.98361	9.8153
A4	0.98734	0.98304	0.98801	0.98404	0.96914	0.97742	0.97661	0.9771	0.98292	0.98294	9.80856
A5	0.98305	0.96533	0.98404	0.98404	0.96914	0.97776	0.97627	0.9771	0.98292	0.98294	9.78259
A6	0.96308	0.96533	0.96499	0.98404	0.9688	0.97776	0.97728	0.9771	0.98258	0.98294	9.7439
A7	0.96273	0.96499	0.96533	0.98437	0.96948	0.97776	0.97762	0.9771	0.98292	0.98294	9.74524
A8	0.98338	0.96533	0.96533	0.96562	0.96982	0.9781	0.97762	0.9771	0.98258	0.98361	9.74849

Table 7.10 Fuzzy-TOPSIS results

Alternative	d_1^+	d_1^-	CC_i	Rank
A1	0.32576	9.76180	0.967706759	5
A2	0.32516	9.76384	0.967708390	4
A3	0.24789	9.81530	0.975366580	1
A4	0.25077	9.80856	0.975070904	2
A5	0.29396	9.78259	0.970827316	3
A6	0.35973	9.74390	0.964395964	8
A7	0.35922	9.74524	0.964449362	7
A8	0.35599	9.74849	0.964769092	6

7.4.3 Sensitivity analysis

To assess how sensitive the ranking of alternatives is to make shifts in the relative importance of various barriers, a sensitivity analysis is carried out. There was a total of thirteen experiments carried out. The results of the experiment are presented in 7.12, which can be found here. It is clear from looking at Table 7.12 that during the first ten experiments, the weight of each barrier was gradually made progressively heavier one at a time until they were all at the same level. For instance, in experiment 1, the weight of criteria (R1) = 0.50, and the weight of the remaining nine criteria (R2–R10) are presumed to be of equal value; as a result, they are allotted the same weight, which is 0.25. Experiment 11 finds that the total weight of all the barriers amounts to 0.04. In experiment 12, the weight of the barriers (R1–R5) was equal to 0.125, and the weight of the other obstacles was 0. The changes that occur in the final ranking of the risk mitigation strategies for emergency supply chains are depicted in Figure 7.5. These changes take place when the weights of the barriers are altered.

Table 7.12 and Figure 7.5 illustrate the fact that, out of a total of 13 experiments, the alternative A3 (collaboration and coordination) received the highest score, followed by A4, A5, A2, A1, A8, A7 and A6. The ranking of the alternatives remained the same in eleven experiments (Expt. 1,2,3,5,6,7,8,9,10,11,12). In experiment 4, the alternatives A7 and A8 moved to fourth and fifth place and A2, A1, and A8 emergency as the least three alternatives. In experiment 13, alternative A8, A7, A6 and A5 follows alternative A3 respectively. A4, A2 and A1 emerged as the least three strategies. When the weights of the criteria are changed, the rankings of other alternatives shift considerably. As a result, the ranking of supply chain strategies for risk management in emergency supply chains is relatively sensitive to the weights of the criteria.

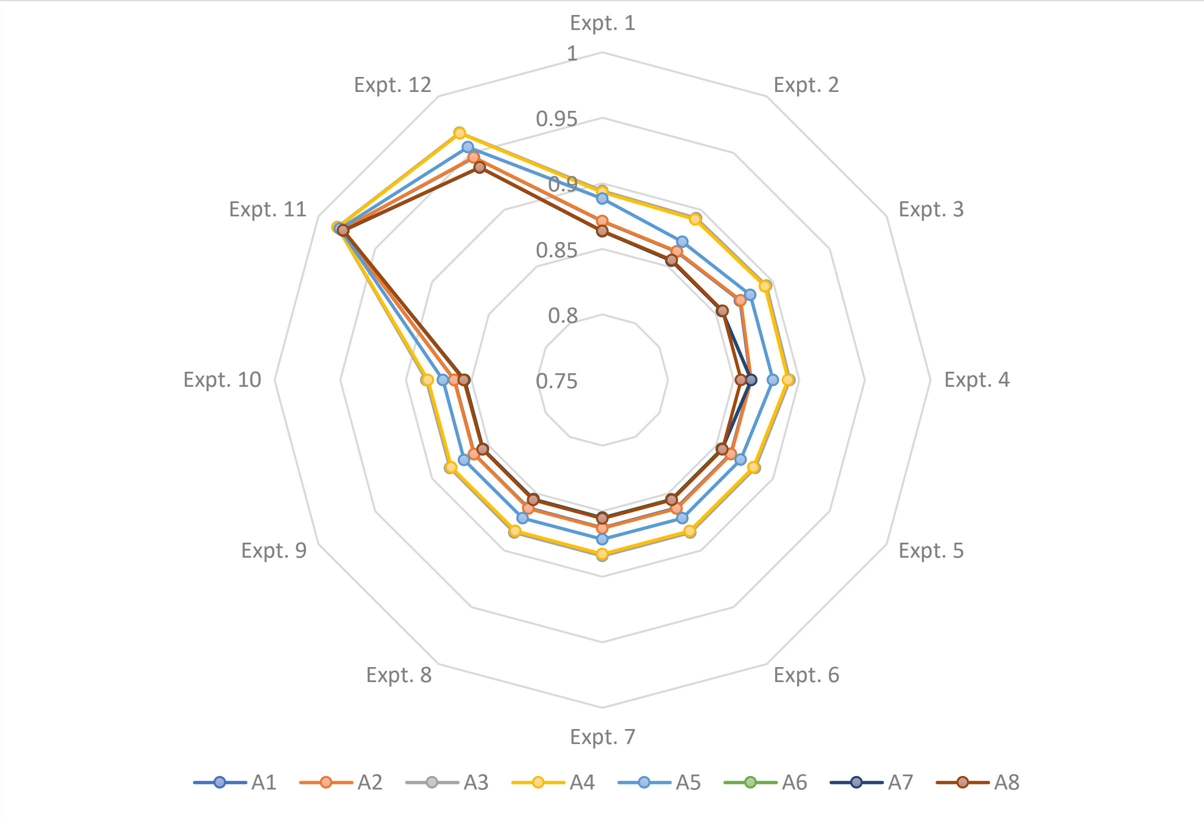

Figure 7.5 Result of sensitivity analysis (CC_i scores)

7.6 Results and Discussion

When it comes to mitigating risks associated with supply chains, one of the most critical steps is said to be selecting suitable risk mitigation solutions. Through empirical research, it was determined that the management strategies that are currently being put into practice are the solutions for risk management. After that, the Fuzzy TOPSIS approach was utilised to rank the importance levels of the risk mitigation strategies in connection to the top ten risk factors. The Fuzzy TOPSIS model's technique consisted of analysing the subjective opinions of nine different subject matter experts. It is an ideal technique to assist in making multi-attribute decisions in a fuzzy environment when the data that is accessible is subjective and hazy. These strategies also consider all potential dangers, as well as the efficacy of various tactics in reducing the likelihood of these risks happening. Stakeholders will require a large amount of additional money and time before they can commit to investing in the new management practices before they can modify any management practices or adopt any new initiatives. The decision of which acceptable mitigation methods to adopt necessitates making a trade-off between the advantages of applying such strategies and the cost savings that would result from doing so. In the process of constructing the strategic plan, importance should be given to the alternatives that received the highest rating; specifically, strategy A3, "collaboration and coordination", strategy A4, "flexible transportation", and strategy A5, “flexible supply bases”.

Collaboration and coordination (A3) emerge as the most critical strategy to adopt. Due to the high level of complexity and unpredictability associated with large-scale disasters, there is a necessity for improved collaboration and coordination among the various actors who join together to assist in disaster relief operations. Collaboration and coordination are seen as the holy grail of emergency relief operations despite the fact that they incur high costs and cause delays, which can often be one of the reasons why certain aid organisations do not want to take part in them. The strategy of collaboration and coordination is essential for a number of reasons, the most important of which are that it helps save lives and makes the most of the limited supplies and resources that are available. Even while this strategy does not guarantee success, it helps ensure that emergency relief efforts are organised and aligned.

Table 7.11 Experiments for sensitivity analysis

Ex. No	Definition	A1	A2	A3	A4	A5	A6	A7	A8
1	R1=0.50, R2-R10=0.25	0.871035087	0.871391442	0.894205197	0.893120028	0.88844624	0.863359132	0.86351156	0.863771791
2	R2=0.50, R1, R3-R10=0.25	0.862888097	0.863245841	0.89261141	0.891324057	0.871729584	0.855141091	0.85524899	0.855668682
3	R3=0.50, R1-R2, R4-R10=0.25	0.871132207	0.87147954	0.894190397	0.893060162	0.880024296	0.855110814	0.85526426	0.85568365
4	R4=0.50, R1-R3, R5-R10=0.25	0.862869015	0.863215495	0.892647188	0.891412495	0.879952648	0.863220032	0.86337901	0.855637938
5	R5=0.50, R1-R4, R6-R10=0.25	0.862829679	0.863180851	0.8842035	0.88298267	0.871646511	0.85499294	0.85521765	0.855637938
6	R6=0.50, R1-R5, R7-R10=0.25	0.862746355	0.863090259	0.884217567	0.883001846	0.871714812	0.855110814	0.85523346	0.85569543
7	R7=0.50, R1-R6, R8-R10=0.25	0.86267604	0.863058322	0.884174509	0.882788218	0.871423093	0.854968422	0.85517864	0.855583211
8	R8=0.50, R1-R7, R9-R10=0.25	0.862713524	0.8631145	0.8842035	0.882901934	0.871544792	0.854936143	0.8550413	0.85569543
9	R9=0.50, R1-R8, R10=0.25	0.862888097	0.8631145	0.884239477	0.883083094	0.871744077	0.85507946	0.85527925	0.855602879
10	R10=0.50, R1-R9=0.25	0.862778324	0.863090259	0.884247504	0.883001846	0.871646511	0.855060133	0.85519834	0.85569543
11	R1-R10=0.04	0.97952876	0.979572134	0.983181298	0.983025505	0.981053058	0.978128115	0.97814619	0.978197434
12	R1-R5=0.125, R6-R10=0	0.945978203	0.946167916	0.967757538	0.967334621	0.955095573	0.937160384	0.93721319	0.937299651
13	R1-R5=0, R6-R10=0.125	0.927729127	0.92782458	0.928526489	0.927905602	0.92797802	0.928074239	0.928144227	0.92841088

Integrating a flexible transportation strategy (A4) is next. One of the most important and difficult components of relief efforts following a natural disaster is transportation. Prepositioned supplies travel through several phases of the emergency supply chains after beginning their journey in globally dispersed warehouses and are ready to be deployed in the event of severe calamities. The conveyance of emergency relief supplies involves a variety of deliveries, including "last mile" deliveries to the population that has been impacted. A transportation system that is both flexible and adaptable removes the difficulty that relief organisations face in arranging the movement of critical supplies after a disaster. Since the operating environment is unstable and primarily characterised by inadequate transport infrastructure, the strategy helps to eliminate or lessen the emergency supply chain's vulnerability to certain risks. This is because the operating environment is characterised primarily by inadequate transport infrastructure. A flexible transportation strategy makes it possible for the emergency supply chain to adopt a number of different modal possibilities, and the specific modal choice that is used can be determined by the type of disaster that has occurred. Each of the modal choices offers certain benefits that the others do not. As a result, the strategy will make it possible to move between modes continuously during any stage of the emergency relief efforts. The adoption of adaptable transportation strategies enables relief organisations to provide improved assistance to the most vulnerable population members.

Flexible supply base (A5) is the third most important strategy. The goal of the procurement procedure is to ensure that those working in relief have access to the resources and goods necessary to meet the requirements of the population that is at risk. The ability to respond to emergencies effectively requires having reliable suppliers. It is difficult for relief organisations to evaluate potential suppliers since there is a significant amount of fluctuation in the location of disasters and the size of the demand. In emergency relief operations, adopting a strategy with a flexible supply base can help eliminate or significantly reduce the effects of supply disruptions. The supply chain is put in danger of experiencing supply shortages and loses its ability to accommodate natural fluctuations in demand when a single-sourcing approach is used, even though it may help reduce costs. The supply chain is able to overcome these challenges from a single provider thanks to the flexible sourcing approach, which also ensures the availability of essential supplies that are necessary to safeguard the afflicted population and prevent further loss of life.

Logistics outsourcing emerged as the least important strategy. Disaster relief organisations cannot function without the help of logistical outsourcing companies. This method can facilitate the quick ramp-up of relief activities and allow for the simultaneous functioning of many emergency relief programmes. There are practitioners and policymakers in the relief community who do not think this is the best course of action because of the challenges it presents in areas like establishing rapport with private logistical firms. The logistics service providers are not seen as acting in the best interest of the vulnerable people by some relief actors.

7.7 Conclusion

This chapter covered the final stage of the process for managing risks in supply chains, which was the selection and evaluation of risk mitigation techniques. For this investigation, all strategies were gleaned from real-world applications through the utilisation of empirical research. This study proposed a total of twelve different risk mitigation strategies, eight of which were empirically validated. These included the following: strategy A1, "strategic stock"; Strategy A2, "prepositioning of resources"; Strategy A3, "collaboration and coordination"; Strategy A4, "flexible transportation"; Strategy A5, "flexible supply base"; Strategy A6, "logistics outsourcing"; Strategy A7, "flexible supply contracts"; and Strategy A8, "risk awareness/knowledge management." Following the completion of the identification process, a risk mitigation strategy questionnaire survey was carried out in order to determine the relative value of each of these techniques. Quantitative and qualitative approaches have been utilised, respectively, by researchers and practitioners in the field of risk management in order to address various problems in this area. However, risk management is a complicated topic that involves ambiguity and uncertainty in the process of decision-making. As a result, a Fuzzy TOPSIS model was built as a means of providing a practical decision support tool for the evaluation of risk mitigation options. In contexts characterised by the presence of unresolved questions and problems, the utilisation of the fuzzy technique can be of great assistance in the process of decision-making. The eight strategies are listed in the order of their relative importance, from most important to least important, as follows: A3, A4, A5, A2, A1, A8, A7, and A6. Both the "collaboration and coordination" strategy A3 and the "flexible transportation" strategy A4 have the highest relative closeness indices and should thus be suggested as the top strategies for the emergency supply chains in disaster relief operations.

CHAPTER 8 – CONCLUSIONS

8.1 Introduction

This final chapter provides a synopsis of the study and outlines potential avenues for further research and development. The chapter begins by circling back to the study's stated goals and research questions to lay forth the study's most salient findings. What follows is a summary of how this adds to prior knowledge and what consequences this has in the real world. After that, the chapter discusses some of the study's limits and potential future research directions based on the results.

8.2 Research Findings

Emergency supply chain management aims to get relief to those who need it quickly. Emergency supplies are managed before, during, and after a disaster to ensure people's needs are prioritised, and appropriate action is taken to help those affected. To rephrase, the goal of emergency supply chain management is to lessen the suffering of the most vulnerable populations as much as possible. Since high levels of uncertainty and complexity characterize disasters, emergency supply chain management is a relatively new and challenging area of study. Researchers, policymakers, and industry professionals are increasingly focusing on the burgeoning topic of emergency supply chain management. One reason for this growth is the growing size and complexity of disasters (UNHCR, 2016), but another is the difficulty of this research area from a supply chain and operations perspective. It is not uncommon for emergency logistics and supply chain activities to take place in highly unpredictable settings and for relief groups to face several risks and uncertainties in the course of shipping, storing, and distributing assistance materials. Challenges can arise from many sources, such as an uncertain need (when, where, and how much relief supplies and resources will be required), a lag in supply, a lack of or damaged infrastructure, a lack of logistics resources, political instability, security concerns, and a lack of information. Therefore, relief organizations need to be able to cope with these uncertain conditions, and they also need to be able to change their operations to meet the demands of the vulnerable population as quickly and efficiently as possible. Initially conceived in a business setting, supply chain risk management entails identifying, analysing, and controlling common and uncommon risks along the supply chain. Emergency supply chain management relies heavily on the rapidly developing field of supply chain risk management for two main reasons: (1) a disruption in the supply chain can directly cause or contribute to a disaster, and (2) emergency relief efforts frequently confront several hazards, hence, the motivation for conducting this research.

To spot knowledge gaps, this study begins with an extensive literature review on disaster management, emergency supply chain management, and supply chain risk management. Firstly, this study discovered that only a few studies had linked emergency supply chains and supply chain risk management. Research must be done in this area so that the emergency supply chain and disaster relief activities can be improved in the future. Secondly, no comprehensive framework for risk management in emergency supply was discovered. A fresh paradigm that encompasses the critical stages of the supply chain risk management process is urgently needed to meet the requirements of practitioners and policymakers. Thirdly, to our knowledge, no research has yet to seek to objectively and thoroughly define the risk factors likely to hinder the daily activities of the emergency supply chain. Academics and professionals must focus on this area to create a knowledge base that will allow for increased effectiveness in emergency relief operations. Fourthly, the discipline needs a clear and defined supply chain risk classification model. With a well-defined classification model, professionals will have no trouble pinpointing the disrupted supply chain's specific links. Next, no research has attempted to rank the relative severity of the various risk factors to identify which ones should receive the most attention from multiple stakeholders.

For this reason, conducting this kind of research is crucial, as it will allow policymakers and practitioners to modify their procedures and supply chain strategies to mitigate the most pressing threats and maximize the efficiency of the response operation. Finally, the most critical risks associated with emergency supply chains have yet to be the subject of any research to identify and evaluate effective risk mitigation measures. Practitioners and policymakers can use the findings of such a study to strengthen the emergency supply chain more quickly.

Accordingly, the study's research questions were formulated to fill these blanks. An interdisciplinary strategy based on a combination of a questionnaire survey, a document examination, and semi-structured interviews was used to deduce the answers. The research questions are discussed further below.

Answer to research question 1: What constitutes an emergency supply chain management framework?

A novel conceptual framework was established to aid emergency supply chain managers in proactively containing risks. This framework considers disaster influence, community characteristics, disaster conditions, risk sources, relief actors, supply chain strategies, performance results, and the risk management process. The suggested framework is the main focus, with its essential components providing a more solid description of the elements that determine the form of risk management responses in various contexts. Disaster influence and community characteristics define the disaster conditions; stakeholders will meet when they arrive at the scene. Based on these disaster conditions, emergency supply chain risk management is defined. Risk sources, stakeholders/relief actors, supply chain strategies, performances and the risk management process make up the primary elements of emergency supply chain risk management. One component depends on another, as indicated by the circular, repeated, and articulating process it employs. The risk factors must specify the possible dangers for risk management to be effective. After that, we can figure out what tools and methods we have at our disposal to help us manage risks. Practitioners and policymakers can adopt various risk management strategies to bring about the desired change based on different attitudes of risk relevant to the scenario. Due to their unique vantage point, emergency supply chain managers emphasize service quality enhancement and beneficiary satisfaction while evaluating performance outcomes. If implemented, the proposed conceptual framework can serve as a risk management platform, meeting the needs of businesses everywhere for a concrete decision-support methodology and easing the way for cutting-edge techniques like the Fuzzy Analytic Hierarchy Process (AHP) and Fuzzy Technique for Order Preference by Similarity to Ideal Solution to be incorporated into the process of managing risks in the emergency supply chain.

Answer to research question 2: What risk factors often disrupt the emergency supply chain, and how to categorize those risk factors?

Identifying potential threats is a crucial first step in any risk management strategy (Kleindorfer and Saad, 2005). To date, no risk management action has been taken until risks have been identified. The purpose of risk identification is to unearth all potential threats. This means a first evaluation is required to determine whether a risk is relevant and, consequently, will be subject to additional evaluation. Practitioners and policymakers need a deep comprehension of the sources and prevalence of the most common risks. Through a review of the existing literature, this investigation compiles a detailed inventory of potential threats to emergency supply chains. In the beginning, 48 potential danger indicators were found. Even though emergency supply chain systems have many of the same hazards as standard supply chains, they also have specific risk characteristics that set them apart. In particular, emergency supply chain systems appear to be vulnerable to problems like "the wrong or unsolicited relief supplies," "ineffective last-mile delivery," "the limited life cycle of relief supplies," "sanctions and constraints that hinder collaboration and coordination," "the impact of follow-up disasters," "legislative and supportive rules that influence disaster relief operations," "poor or damaged warehouse infrastructure," and "the absence of alternative transport modes." In addition, there may be new vulnerabilities in the inter- and intra-organizational domains because of the convergence of several relief actors. Experts offered insightful feedback on the suggested risk categorization methodology and questionnaires detailing the most critical risks to emergency supply networks. In the end, researchers identified 28 unique threats to emergency supply networks. In addition, the novel risk classification model used in this research classifies the various types of risk as follows: internal risk, external risk, supply risk, demand risk, infrastructure risk, and environmental risk; and finally, eleven risk types: forecast, inventory, procurement, supplier, quality, transportation, warehousing, systems, disruption, social, and political risks. This research presents a hierarchical structure model for outlining the potential dangers in the healthcare supply chain. The "research team" and other experts in disaster management, supply chain, and risk management were consulted multiple times to ensure the validity and dependability of the generated hierarchy diagram. Eventually, consensus was reached amongst the experts, and the hierarchy diagram was approved.

Answer to research question 3: What is the relative importance of these risk factors?

After identifying potential risks to the emergency supply chain, the next step is to analyse the level of those risks. Almost all definitions of risk assessment in the literature focus on determining the probability that a risk event will occur and the magnitude of its potential consequences. Therefore, the central goal of risk assessment is to supply sufficient specifics about the risk to effectively prevent it, lessen its possibility and impact, accept its occurrence, or prepare for it (Baird and Thomas, 1985). Fuzzy AHP, modelled after fuzzy set theory, was created to mitigate the ambiguity inherent in the mapping of experts' opinions in this thesis. This methodology was utilized to assign relative importance ratings to the many risk elements that were studied in the course of risk assessment projects. It is important to note that risk assessment is inherently uncertain and imprecise. Therefore, any methodology that fails to account for these features risks producing seriously misleading information and, consequently, significant errors. A total of 19 responses from randomly selected respondents across the globe were considered valid. Respondents have a wide range of occupations in academia and industry. Emergency supply chain operations are more likely to be hampered by the presence of war and terrorism in the face of disaster relief operations. With a mass of 0.09016, war and terrorism make it extremely difficult for stakeholders and relief organizations to collaborate for the common good of the community they are attempting to help. The impact of follow-up disasters is the next most important risk factor, with a weight of 0.08568, followed by the absence of legislative and supportive rules that can influence disaster relief operations (0.08584). The impact of follow-up disasters is a concern that can compound an already tricky working environment. Fourth on the list is the limited life cycle of relief supplies (0.0833), followed by sanctions and constraints that hinder stakeholders' collaboration and coordination (0.07401), poor communication between stakeholders (0.05454), corrupt practices (0.05389), sexual and gender abuses (0.05341), poor demand projections (0.04174), and distortion of information (0.04058). Each of these unique aspects has the potential to alter significantly and hence enhance the complexity of the emergency supply chain's actions. Stakeholders and decision-makers are asked to consider emergency supply chain resilience by implementing supply chain initiatives that reduce the impact of these risks.

Answer to research question 4: What supply chain strategies are currently implemented for risk mitigation in disaster relief operations?

The third stage, risk mitigation, uses the information gathered in the first two to devise effective strategies for dealing with potential threats. This entails both proactive measures taken to lessen the impact of potential risk and more reactive measures developed in case risk materializes (after the risk event). An adequate risk mitigation strategy must be created and implemented for each identified threat. The process of reducing risk entails not only coming up with solutions but also weighing the costs and benefits of various mitigation measures (Chopra *et al.*, 2007; Kleindorfer and Saad, 2005; Manuj and Mentzer, 2008b; Wagner and Bode, 2006). Preventative measures are preferable to reactive ones, according to Kleindorfer and Saad (2005); hence, risk managers should prioritize the treatment of the most pressing threats. Even if difficult trade-offs exist between cost efficiency and preparedness in disaster relief contexts (Van Wassenhove, 2006; Jahre and Heigh, 2008; Jahre *et al.*, 2016; Scholten *et al.*, 2014), improved preparedness leads to a more effective response. However, managers can only take swift action if they regard risk management as an essential part of their job and treat it as such. The research used empirical investigations to determine the emergency supply chain strategies currently in use. The empirical study relies on a thorough analysis of relevant literature and government material, as well as a questionnaire and semi-structured interview. Starting with a literature search and examining organizational reports, this research sought to identify existing supply chain strategies used in the industry. Several strategies were identified, including strategic stock, prepositioning of resources, postponement, collaboration and coordination, flexible supply base, flexible transportation, flexible supply contracts, centralization, logistics outsourcing, decision policies/procedures, risk awareness/knowledge management, and cash-based interventions. The next step was to use a questionnaire survey and semi-structured interviews to confirm the uncovered methods and expose the overlooked ones. This component of the empirical investigation spanned 60 days and involved the participation of five specialists. In situations when the borders between phenomenon and context are hazy, an empirical study enables the researcher to delve deeply into the topic at hand while also examining it in its actual setting. The existing situation can be fully grasped through the research findings when multiple approaches are used in the empirical study. At the end of the empirical investigation, only nine mitigation strategies were deemed necessary for further analysis: strategy stock (A1), prepositioning of resources (A2), collaboration and coordination (A3), flexible transportation (A4), adjustable supply bases (A5), logistics outsourcing (A6), flexible supply contracts (A7), and risk awareness/knowledge management (A8).

Answer to research question 5: What are the priorities of these supply chain strategies implemented in emergency supply chains?

For this thesis, risk management approaches were ranked using Fuzzy TOPSIS. To account for the fuzziness of uncertainty in weighing potential risk-reduction techniques, the model draws on both fuzzy set theory and traditional TOPSIS approaches. Fifteen academics and five professionals from the business world were asked to fill out the poll. Strategy A3 (collaboration and coordination), Strategy A4 (flexible transportation), and Strategy A5 (adjustable supply bases) emerged as the top three possible mitigation solutions in the analysis. However, Strategy A6 (logistics outsourcing) slipped behind other options since some relief practitioners and policymakers do not think it is the best course of action due to difficulties in areas like building relationships with private logistical organizations. Some practitioners and policymakers believe that logistics firms are not looking out for the interests of the vulnerable population.

8.3 Research Contribution to Knowledge

Every supply chain has some inherent risk, which is why risk management is essential. This study makes several significant contributions to the existing research and decision-makers in emergency supply chains.

8.3.1 Research Implications

- Firstly, this study contributes to the literature by presenting a comprehensive picture of emergency supply chain risk management. This can serve as a foundation for researchers and enable the development of a common understanding of the discipline for internal consistency, and it facilitates potential application to various disaster types for external consistency.

- Secondly, this research proposes a conceptual framework that encapsulates several critical elements, including sources of risk, decision-makers, management strategies, the three fundamental phases of supply chain risk management, and the objectives of the emergency supply chain.
- Thirdly, this research proposes a unique risk classification model comprising two common risk categories, four risk sub-categories and eleven risk types arising from the emergency supply chain across various unique disaster types. This comprehensive risk classification model can help researchers and practitioners identify various potential risk factors with differing degrees of impact that are both external and internal to the emergency supply chain.
- Fourthly, combining various points of view of academicians and industrial experts, this research develops a holistic list of potential risk factors affecting the eleven risk types presented. This will not only help researchers and practitioners identify and classify potential risk factors unique to a particular disaster relief scenario but also provide a starting point for creating a supply chain risk index model.

8.3.2 Managerial Implications

- This research takes a holistic approach to ESCRM, which should encourage decision-makers and stakeholders to develop an orientation to the context so that they can form a complete picture of emergency risk factors and ESCRM. Decision-makers must consider the interrelatedness of complexities and unique features of the ESC and its operating environment, the three fundamental stages of supply chain risk management, the risk factors, various stakeholders, and the objectives of the system.
- Incorporating the Fuzzy AHP and Fuzzy TOPSIS as an integrated methodology is what makes the model that has been proposed unique. This has been done so that the specific preferences of the decision maker can be considered when making a strategic decision regarding risk management in emergency supply chains. In addition to that, the model considers the uncertainties that are brought about by data that is not known. As a result, putting fuzzy logic theory into practice can assist relief organizations in resolving the issue of effectively managing uncertainty in decision-making promptly.

- This research makes practical contributions by conducting empirical studies all over the globe to support a resource-effective and time-efficient decision-making tool for emergency relief practitioners. Therefore, the findings of this research can support decision-makers and stakeholders with the most recent data that can render a precise picture of the global disaster management industry as it stands right now.
- Notably, this study investigated the currently applied mitigation techniques, which proved more feasible in practice than those identified only from a literature survey. Therefore, relief organizations can use the risk mitigation strategies and methods proposed in this study to assess their current risk management efforts. The introduction of these eight techniques, supported by data from both experts and organizational reports, can help relief organizations better prepare for and respond to potential risks.
- Finally, the findings of this research enable stakeholders and decision-makers to easily foresee and proactively deal with prospective risk factors thanks to the profile of emergency supply chain risks. This study does not cover every possible risk that could arise during emergency relief operations. However, it does a thorough job of investigating many of the more critical risk factors, drawing on sources such as academic literature, official reports, and the insights of practitioners in a variety of relevant positions in the disaster management industry.

8.4 Research Limitations

The limitations of this research are discussed below.

- Although risk management in emergency supply chains is gaining attention, the field as a whole is still relatively new. There is a lack of a centralized source of information on risk variables, and no single study has unambiguously identified risk factors in the worldwide emergency supply chain. As a result, a conventional literature review was performed, and there is no assurance that all potential dangers were found. Identifying the unaccounted-for risk factors will make this study more thorough.
- There is much change happening in the disaster management sector. Each mission requires a new team of experts and decision-makers, as it is a new project. The knowledge transfer problem emphasizes how challenging it is to collect primary and secondary data. Furthermore, this study's nature does not allow for the participation of a large number of specialists because it only requires participants

to have either extensive academic knowledge or extensive practical experience in the field. Therefore, only sure experts who hold specific job positions were included in this research sample. This highlights another limitation of the current research.

- Due to time constraints and the size of the questionnaire survey, which generally needed pair-wise comparison between each component, this study does not explore all of the identified 28 risk variables in detail. This is because of the size of the questionnaire survey. The amount of time spent doing the interview is another critical aspect that must be considered. For this research, the interview questions were developed to ensure that interviews lasted no longer than 45 minutes (the total amount of time allotted for the discussions). However, some participants may have felt there were an excessive number of questions, and these sentiments would have harmed how they thought about the questions. This reflects another form of limitation for this study.

8.5 Recommendations and Future Research Directions

Additional study is required in a variety of areas of inquiry. In the future, it is suggested that the following issues be resolved.

- The management of emergency supply chains, in general, is the subject of this research. It is essential to understand that every setting in which disaster relief effort is provided is one of a kind and features a particular set of characteristics. The effect, severity, timing, and location of the disaster determine these characteristics. Using this study as a basis, subsequent research should concentrate on the many types of disasters to identify the unique risk factors and response techniques that are relevant to the various contexts in which relief efforts are being carried out.
- The work of providing aid in times of emergency attracts participants from a wide variety of fields and all parts of the world. Donors, the government, relief organisations, non-governmental organisations, suppliers of logistics services, the armed forces, and the beneficiaries are all considered to be actors in the relief effort. In the course of this research, only seasoned professionals from a select number of fields offered their insights for further examination. Despite multiple attempts, it was not possible to retrieve the inputs from the sponsors, the government, or the military. Although this does not ensure that the relief efforts will be successful, it does require a collaborative approach from all of the actors involved in order to increase the effectiveness of the efforts. Similarly, the scope of this study will be expanded if inputs can be gathered

from the participating sectors. For this reason, further research ought to make certain that all relief actors are included in the empirical investigation that they do in order to enhance the validity and robustness of their findings.

- In the emergency supply chain, there are many different kinds of risk factors. Some of these risk variables were left out of this research because they were deemed less significant and because doing so would save time; however, they should still be a cause for concern. As a result, further study can integrate various risks of their own into the structural model, allowing for the possibility of obtaining more comprehensive results.
- Even if there are difficult trade-offs to be made between cost efficiency and flexibility, better preparedness increases reaction. There is a need to weigh the pros and cons of adopting suitable risk management mitigation measures, as the implementation of any strategy will necessitate significant expenses. The first goal of any emergency relief effort must always be to prevent loss of life. Since the sector typically deals with limited funds, additional studies can cover cost and benefit analysis to support major strategic decisions on risk management in emergency supply chains.

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Appendix I- Risk Analysis of Emergency Supply Chains with Particular Focus on Inter-Modal Transport.

Dear Sir/Madam,

My name is Onyeka John Chukwuka, who is currently a PhD researcher at the Liverpool Logistics Offshore and Marine Research Institute (LOOM) in John Moores University. My research topic is "Risk analysis on emergency supply chain with particular focus on inter-modal transport". The research aims to propose a novel methodology to **identify, evaluate and mitigate the risk factors** in managing emergency supply chains. I will be very pleased if you can take part in this study in view of your professional knowledge in risk management, emergency supply chain management or disaster management. It is necessary to pre-test the reliability and validity of the identified risk factors in the research and your assistance is important in making this a meaningful questionnaire. The information gathered in this survey will be kept highly confidential and not be released by any means. The researcher will make every effort to prevent anyone who is not on the research team from knowing that you provided this information, or what the information is. If you have any questions about this study, please feel free to contract me either email O.J.Chukwuka@2019.ljmu.ac.uk or by phone. Where necessary, you also can contact my principal supervisor, Dr Jun Ren, at (44)1512312236, or by email j.ren@ljmu.ac.uk

Yours faithfully,

Onyeka John Chukwuka,
PhD researcher, Liverpool Logistics Offshore and Marine Research Institute (LOOM)
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Room 292, James Parsons Building
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Section A: Participant Profile

1. What is the type of your organisation?
   ☐ Government
   ☐ Donor
   ☐ Non-Governmental Organisation
   ☐ Military
   ☐ Academia

2. What is your job title?
   ____

3. How many years of work experience have you acquired?
   ☐ 1-5 years
   ☐ 6-10 years
   ☐ 11-15 years
   ☐16-20 years
   ☐ >20 years

4. Would you like to provide additional information and participate in the next survey if necessary?
   ☐ Yes ☐No

Questionnaire

The aim of the questionnaire is confirm the validity of the identified risk factors in emergency supply chains. It is important to be aware that the following factors have selected after an intensive literature review of different disciplines. Fig 1 illustrates a tree structure of risk sources in emergency supply chains developed based on the synthesis of existing literature in supply chain risk management and emergency supply chains.

Therefore based on your experience, kindly rate the level of significance of the identified risk factors using the following rating scale:

'1' represents 'very unimportant'.
'2' represents 'less likely unimportant'.
'3' represents 'moderate'.
'4' represents 'less likely important'.
'5' represents 'very important'.

After you have carried out the rating, kindly add any comments in the 'comment box' (if you have).

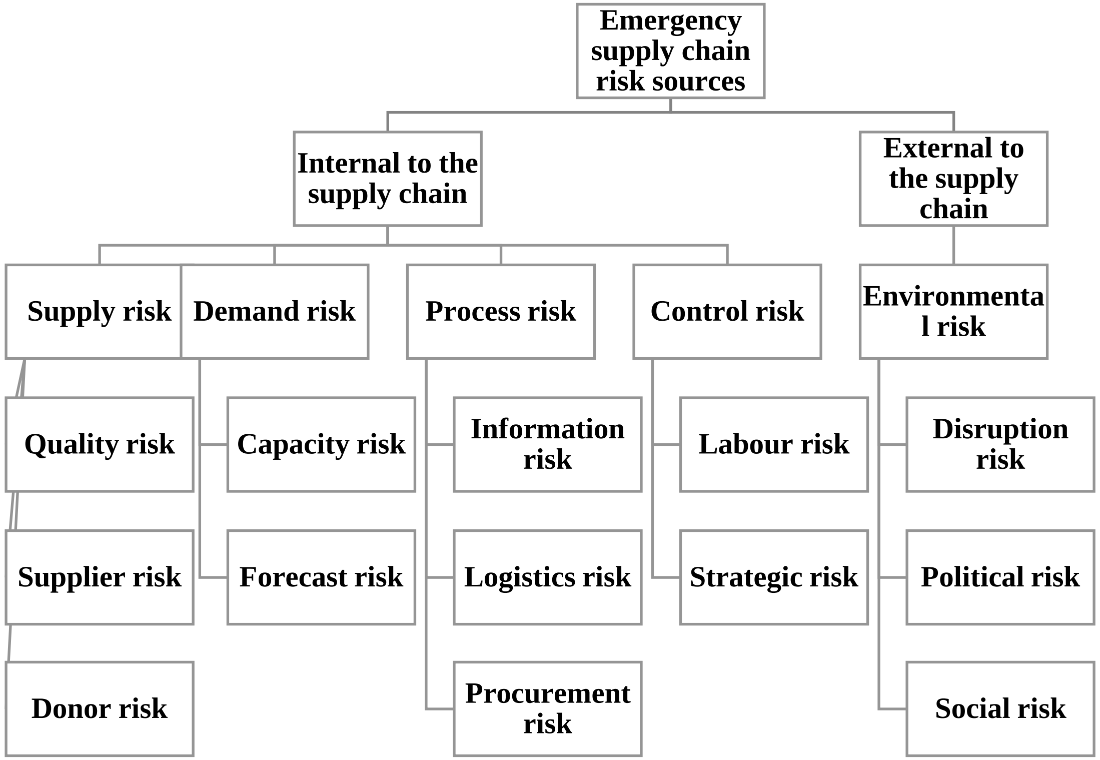

Fig. 1 Tree structure of risk sources in Emergency supply chains

Section B:

Based on the research, risk factors in emergency supply chains are classified into two main groups.

- External to the supply chain: **environmental risk.**
- Internal to the supply chain**: process, control, demand and supply risks**.

Internal to the supply chain network: Related to actors, stakeholders and decision-makers in the supply chain. The interactions between them within the emergency supply chain give rise to the risk sources.

1. **Supply risks:** These risks adversely affect the inward flow of any type of resource to enable operations to take place or the transpiration of significant and/or disappointing failures with inbound goods and services.
   - Quality risks
   - Supplier risks
   - Donor risk

Identified Risk Factors (Quality Risks)		Very unimportant	Less unimportant	Moderate	Less important	Very important
Quality risks	S1 Counterfeiting	☐1	☐2	☐3	☐4	☐5
	S2 Poor quality of relief supplies/resources	☐1	☐2	☐3	☐4	☐5
	S3 Short life cycle of relief supplies	☐1	☐2	☐3	☐4	☐5

Identified Risk Factors (Supplier Risks)		Very unimportant	Less unimportant	Moderate	Less important	Very important
Supplier risk	S4 Inflexibility of relief supply sources	☐1	☐2	☐3	☐4	☐5
	S5 Relief supplier fulfilment errors	☐1	☐2	☐3	☐4	☐5
	S6 Selection wrong relief supply partner	☐1	☐2	☐3	☐4	☐5
	S7 Inability to handle volume of relief demand changes	☐1	☐2	☐3	☐4	☐5
	S8 Inadequate provision of competitive pricing	☐1	☐2	☐3	☐4	☐5
	S9 Relief supplier's supply responsiveness	☐1	☐2	☐3	☐4	☐5
	S10 Transit time variability	☐1	☐2	☐3	☐4	☐5
	S11 High-capacity utilisation	☐1	☐2	☐3	☐4	☐5
	S12 Supplier bankruptcy	☐1	☐2	☐3	☐4	☐5

Identified Risk Factors (Donor Risks)		Very unimportant	Less unimportant	Moderate	Less important	Very important
Donor risk	S13 Lack of funding transparency	☐1	☐2	☐3	☐4	☐5
	S14 Fragmented instalments of funding	☐1	☐2	☐3	☐4	☐5
	S15 Short donor budgeting cycles	☐1	☐2	☐3	☐4	☐5
	S16 Changes in donor priorities	☐1	☐2	☐3	☐4	☐5
	S17 Politicised donations	☐1	☐2	☐3	☐4	☐5
	S18 Restriction on donations	☐1	☐2	☐3	☐4	☐5

Considering the elements contributing to risks associated with supply risks are categorised into "quality risks" and "supplier risks". Do you think this categorisation is appropriate?

Risk element categories	Yes	No	Any Comments
Quality risks			
Supplier risks			
Donor risks			
Any other elements to be considered			

2. **Demand risks:** These risks arise from possible need changes from the beneficiaries/ vulnerable population.
    - Capacity risks
    - Forecast risks.

Identified Risk Factors (Capacity risks)		Very unimportant	Less unimportant	Moderate	Less important	Very important
Capacity risks	S19 Capacity flexibility	☐1	☐2	☐3	☐4	☐5
	S20 Cost of capacity	☐1	☐2	☐3	☐4	☐5

Identified Risk Factors (Forecast risks)		Very unimportant	Less unimportant	Moderate	Less important	Very important
Forecast risks	S21 Inadequate demand forecast	☐1	☐2	☐3	☐4	☐5
	S22 Bullwhip effect or information distortion due to lack of supply chain visibility and exaggeration of relief demand of limited relief supplies.	☐1	☐2	☐3	☐4	☐5
	S23 Relief demand variability	☐1	☐2	☐3	☐4	☐5

Considering the elements contributing to risks associated with demand risks are categorised into "capacity risks" and "forecast risks". Do you think this categorisation is appropriate?

Risk element categories	Yes	No	Any Comments
Capacity risks			
Forecast risks			
Any other elements to be considered			

3. **Process risks:** These risks are related to the managerial activities of the stakeholders across the emergency supply chain.
   - Information risks
   - Logistics risks
   - Procurement risks

Identified Risk Factors (Information risks)		Very unimportant	Less unimportant	Moderate	Less important	Very important
Information risks	S24 Poor usage of technology	☐1	☐2	☐3	☐4	☐5
	S25 Inadequate technology infrastructure	☐1	☐2	☐3	☐4	☐5
	S26 Inadequate information transparency	☐1	☐2	☐3	☐4	☐5
	S27 Information delays	☐1	☐2	☐3	☐4	☐5
	S28 Media risk	☐1	☐2	☐3	☐4	☐5

Identified Risk Factors (Procurement risks)		Very unimportant	Less unimportant	Moderate	Less important	Very important
Procurement risks	S29 Single source key relief procurement	☐1	☐2	☐3	☐4	☐5
	S30 Long term vs Short term contracts	☐1	☐2	☐3	☐4	☐5
	S31 Contract compliance	☐1	☐2	☐3	☐4	☐5
	S32 Exchange rate	☐1	☐2	☐3	☐4	☐5

Identified Risk Factors (Logistics risks)		Very unimportant	Less unimportant	Moderate	Less important	Very important
Logistics risks	S33 Inadequate transport infrastructure	☐1	☐2	☐3	☐4	☐5
	S34 Inadequate transport facilities	☐1	☐2	☐3	☐4	☐5
	S35 Theft	☐1	☐2	☐3	☐4	☐5
	S36 No transport solution alternatives	☐1	☐2	☐3	☐4	☐5
	S37 Delivery delay due	☐1	☐2	☐3	☐4	☐5
	S38 Short lead time	☐1	☐2	☐3	☐4	☐5
	S39 Inadequate outbound effectiveness	☐1	☐2	☐3	☐4	☐5
	S40 Accidents	☐1	☐2	☐3	☐4	☐5
	S41 Excess relief handling due to change in transportation mode	☐1	☐2	☐3	☐4	☐5

Considering the elements contributing to risks associated with process risks are categorised into “information risk”, “logistics risks” and “procurement risk”. Do you think this categorisation is appropriate?

Risk element categories	Yes	No	Any Comments
Information risks			
Logistics risks			
Procurement risks			
Any other elements to be considered			

4. **Control risks**: These are related to the assumptions, rules, systems and procedures that govern how an organisation exerts control over the processes. Control risk is therefore the risk arising from the application or misapplication of these rules.
    1. Strategic risks
    2. Labour risks

Identified Risk Factors (Strategic Risk)		Very unimportant	Less unimportant	Moderate	Less important	Very important
Strategic risks	S42 long term vs Short term planning	☐1	☐2	☐3	☐4	☐5
	S43 Prioritization-conflict between objectives	☐1	☐2	☐3	☐4	☐5

Identified Risk Factors (Labour Risk)		Very unimportant	Less unimportant	Moderate	Less important	Very important
Labour risk	S44 Inadequate experts	☐1	☐2	☐3	☐4	☐5
	S45 Inadequate incentive mechanism	☐1	☐2	☐3	☐4	☐5
	S46 Integration of Stakeholders	☐1	☐2	☐3	☐4	☐5
	S47 Setting of Boundaries	☐1	☐2	☐3	☐4	☐5
	S48 Credentialing	☐1	☐2	☐3	☐4	☐5
	S49 Lack of Trust	☐1	☐2	☐3	☐4	☐5
	S50 Strikes	☐1	☐2	☐3	☐4	☐5

Considering the elements contributing to risks associated with control risks are categorised into "strategic risks" and "labour risk". Do you think this categorisation is appropriate?

Risk element categories	Yes	No	Any Comments
Strategic risks			
Labour risks			
Any other elements to be considered			

External to the emergency supply chain network: These are risk related or driven by external forces such as weather, disasters, political and regulatory forces).

1. **Environmental risks**
   - Disruption risk
   - Political risk
   - Social risk

Identified Risk Factors (Disruption risk)		Very unimportant	Less unimportant	Moderate	Less important	Very important
Disruption risk	S51 Disasters exacerbated by integrity of several disasters	☐1	☐2	☐3	☐4	☐5
	S52 Unexpected changes in environmental conditions	☐1	☐2	☐3	☐4	☐5
	S53 Fire accidents	☐1	☐2	☐3	☐4	☐5

Identified Risk Factors (Social risk)		Very unimportant	Less unimportant	Moderate	Less important	Very important
Social risk	S54 Communication Barriers	☐1	☐2	☐3	☐4	☐5
	S55 Religious belief	☐1	☐2	☐3	☐4	☐5
	S56 Tradition of beneficiaries	☐1	☐2	☐3	☐4	☐5
	S57 Stakeholder culture	☐1	☐2	☐3	☐4	☐5
	S58 Poor Judgements	☐1	☐2	☐3	☐4	☐5
	S59 Kingship ties	☐1	☐2	☐3	☐4	☐5
	S60 Patronage	☐1	☐2	☐3	☐4	☐5
	S61 Corruption	☐1	☐2	☐3	☐4	☐5
	S62 Sexual abuses	☐1	☐2	☐3	☐4	☐5

Identified Risk Factors (Political Risk)		Very unimportant	Less unimportant	Moderate	Less important	Very important
Political risk	S63 Legislation and supportive rules	☐1	☐2	☐3	☐4	☐5
	S64 Customers clearance	☐1	☐2	☐3	☐4	☐5
	S65 Legal issues	☐1	☐2	☐3	☐4	☐5
	S66 Sovereign risk	☐1	☐2	☐3	☐4	☐5
	S67 Sanctions and constraints for cooperation	☐1	☐2	☐3	☐4	☐5
	S68 Nepotism	☐1	☐2	☐3	☐4	☐5
	S69 Insecurity	☐1	☐2	☐3	☐4	☐5

Considering the elements contributing to risks associated with environmental risks are categorised into “disruption risks”, “social risks” and “political risks”. Do you think this categorisation is appropriate?

Risk element categories	Yes	No	Any Comments
Disruption risks			
Social risks			
Political risks			
Any other elements to be considered			

Following the aforementioned Hazard sources and risk factors, are there other relevant information that have been omitted in this survey? Please list below;

………………………………………………………………………………

……………………………………………………………………………….

…………………………………………………………………………………………

………………………………………………………………………………………….

…………………………………………………………………………………………..

…………………………………………………………………………………………….

THANK YOU ONCE AGAIN FOR YOUR KIND PARTICIPATION IN THIS SURVEY.

Appendix II - Risk Analysis of Emergency Supply Chains

PARTICIPANT INFORMATION SHEET

Title of the research: Risk Analysis of Emergency Supply Chains with Particular Focus on Intermodal Transport

Researcher Information

My name is Onyeka John Chukwuka, and I am a Ph.D. candidate at the Logistics, Offshore, and Marine (LOOM) Research Institute, in the Faculty of Engineering and Technology at Liverpool John Moores University (LJMU), UK. Whether or not to participate in this study falls solely on the participant. Before a decision is made, it is necessary to understand the purpose and justification of this research. Hence, please kindly spend some time reading the following information provided. If more information is required, please do not hesitate to ask me or my supervisor or to contact the ethical committee through the contact details provided at the bottom of this sheet.

Purpose of the Study

The main goal of this study is to develop an integrated risk management analytical tool, which will assist and support decision-makers in assessing and mitigating risk factors present in emergency supply chains, so as to maintain operational efficiency in disaster relief operations.

Do I have to take part in this study?

Participation in this study is strictly voluntary. This information sheet will be presented to you along with the survey, link to allow the participant to understand the relevance of the study before deciding whether or not to participate. All participants are indulged to read the statement of consent before using the link and answering the survey questions. Following a positive decision to take part in this study, the participant is required to click 'I am happy to participate, as this will take you to answer the questions. However, if you click 'I do not want to participate this will end the process without you seeing the questions. Although, I will be disappointed to lose your valuable opinion. I will appreciate your decision.

What happens if a participant takes part in this study?

I should be most grateful if you could kindly spare your valuable time to complete the accompanying questionnaire. The questionnaire is designed to take the participant a maximum of fifteen minutes to complete. The questionnaire encompasses various risk factors and categories that are associated with emergency supply chains in disaster relief operations. The questionnaire link will remain valid for a duration of one month from the date of receipt of this information sheet.

Following the completion of the survey, only the principal researcher will be able to sign into the electronic survey to view the participant's responses. The responses remain valuable and will greatly contribute to the formulation of industry-wide opinions.

Risks and Benefits involved in this study.

This study holds no potential risks as well as personal benefits to the participants that will be involved.

Keeping feedbacks confidential

Participant responses from this questionnaire will be treated with the highest level of confidentiality and by no means be released. A request will be made to participants to provide contact email addresses to enable the return of the questionnaire if need be. However, this action is not mandatory. Also, following the completion of this round of study, another fuzzy-AHP-based questionnaire will be sent out again to participants to assist in providing subjective values/weight for the risk factors. Once again, the principal researcher of this study will have sole authority to handle and secure the responses provided by participants.

Ethical Approval

This study has received ethical approval (21/ENR/001) from LJMU's Research Ethics Committee.

Principal Researcher's Contact Details

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Faculty of Engineering and Technology

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Director of Study's Information

Dr. Jun Ren

Department of Maritime and Mechanical Engineering

Faculty of Engineering and Technology

Room 1.27c, James Parsons Building, Byrom Street, Liverpool, L3 3AF Liverpool John Moores University

Email: J. Ren@ljmu.ac.uk

Other Information

If you have any concerns regarding your involvement in this study, please discuss these issues with the researcher in the first instance. If you wish to make a complaint, please contact the research ethics committee at (researchethics@ljmu.ac.uk) and your communication will be re-directed to an independent person as appropriate.

Statement of Consent

Do you wish to participate in this study?

☐Yes ☐ No

Personal Information

I. Name (optional): …………………………………………………………….

II. Gender: ☐Male ☐Female

III. Nationality: ………………………………………………………………….

IV. What type of organization do you belong to?

☐Government ☐ Non-governmental ☐Relief organization ☐Military ☐Academic organization ☐Other

If you selected Other, please specify: ………………………………………………….

V. What is your country of operation? …………………………………………………………………

VI. How many years of work experience have you acquired?

☐1-5 ☐ 6-10 ☐ 11-15 ☐ 16-20 ☐> 20

VII. Would you like to provide additional information and participate in the next survey?

☐Yes ☐No

If you selected 'yes', please provide your email address ………………………………………………….

Questionnaire

The goal of this questionnaire is to explore the level of significance of the risk factors that influence the emergency supply chains in disaster relief operations based on experts' opinions. Based on an intensive review of various literature in different disciplines, the following risk factors have been identified. The identified risk factors show signs of links between them from observation. For example, the way relief supplies can be delivered timely to beneficiaries; this requires donors to provide unrestricted and solicited donations, suppliers to comply to supply contracts for the provision of inventory in warehouses, supported by coordinated activities and trained and skilled personnel that collaborate and effectively utilize the available transport resources to move the supplies to the last mile. The motivation of this questionnaire is to check the effects of these risk factors when analyzed and mitigated to ensure the effectiveness of emergency supply chains. Therefore, based on your experience, Kindly rate the level of significance of the risk factors to the overall effectiveness of the emergency supply chains in disaster relief operations, using the following rating scale:

'1' represents 'Very unimportant’.

'2' represents 'Less unimportant’.

'3' represents 'Moderate’.

'4' represents 'Less important’.

'5' represents 'Very important’.

Based on the research, risk factors in emergency supply chains are classified into two groups

1. **Internal to the supply chain:** related to actors, decision-makers, and stakeholders that can make up the supply chain. The interactions between them within the emergency supply chain give rise to the risk sources. This risk category consists of Supply, Demand, Process, and Control risk factors.

2. **External to the supply chain:** These are risk related or driven by external forces such as weather, disasters, and political and regulatory forces. This risk category covers the environmental risk.

Questionnaire

1. **Supply risks:** these stem from the challenges that negatively affect the internal flow of any type of resource, preventing the effective execution of the operation. Procurement risks, supplier risks, and quality risks are sub-categories that make up the supply risk.

(A) Procurement risks: are derived from an unforeseen increase in acquisition costs resulting from fluctuation in exchange rates or rising prices from suppliers. Thus, please choose the level of relevance of the following risk-driving factors.

	Very unimportant	Less unimportant	Moderate	Less important	Very important
Non-compliance with supply contracts					
Purchasing key supplies from a single source					
Exchange rate fluctuations/variations					

(B) Supplier risks: refers to any risks relating to the operation of the suppliers that may potentially have a negative impact on the entire disaster relief operation.

	Very unimportant	Less unimportant	Moderate	Less important	Very important
Lack of supplier flexibility					
Supplier fulfilment errors					
Wrong choice in supply partners					
Inadequate capacity from suppliers					
Lack of competitive pricing					
Poor level of responsiveness from suppliers					
Variation in transit time					

C) Quality risks: refers to issues that affect the relief supplies' quality, noting that each supplier may have a different concept of quality.

	Very unimportant	Less unimportant	Moderate	Less important	Very important
Defective or damaged supplies					
Wrong supplies					
Counterfeit supplies					

2. Demand risks: These risks result from the unpredictability of either the volume or mix of products that will be demanded by the beneficiaries in the chain. Forecast risk and inventory risk make up the demand risks.

(A) Forecast risk: results from the mismatch between demand projections and the actual demand. Errors in estimating demand which may lead to excess or supply shortage define this type of risk, considering this, please rate the level or relevance of the following risk factors.

	Very unimportant	Less unimportant	Moderate	Less important	Very important
Inadequate projection of demand due to short or zero lead time					
Distortion of information					

(B). Inventory risk: these are risks that result from challenges in managing demand and uncertainty and the value and the obsolescence rate of the relief rate. Taking this into consideration, please rate the level of relevance of the following risk factors.

	Very unimportant	Less unimportant	Moderate	Less important	Very important
Inventory holding cost					
Fluctuations/variations in demand					
Limited life cycle of supplies					

3. Process risks: are associated with operational disruptions that are dependent on the operating infrastructure and internal assets held or managed by stakeholders and decision-makers across the emergency supply chain. This dimension of risk includes the information/systems risk, transport

risk and warehousing risk.

(A). Systems risk: results from the inefficiency in processes and electronic systems, movement and access to information data capture and use permission processes. This risk is defined by the failure in the information system (Downtime in the information infrastructure, system integration, or extensive networks and e-commerce systems). Considering this, please rate the following risk factors with respect to their level of relevance.

	Very unimportant	Less unimportant	Moderate	Less important	Very important
Inadequate technology infrastructure					
Absence of transparency in information dissemination					
Presence of delays during information transfer					
Presence of the wrong media					

(B) Transportation risk: stems from the inefficiencies in the flow of supplies and resources that exist between different stakeholders in the emergency supply chain. Considering this, please rate the following risk factors/triggers with respect to their level of relevance.

	Very unimportant	Less unimportant	Moderate	Less important	Very important
Poor or damaged transport infrastructure					
Absence of alternative modes					
Excessive handling of supplies during mode changes					
Poor effectiveness during last-mile delivery					
Theft of supplies and resources					

(C). Warehousing risk: relates to the challenges faced by the supply holding facilities. Taking this into consideration, please rate the following risk factors or triggers with respect to the level of relevance.

	Very unimportant	Less unimportant	Moderate	Less important	Very important
Poor or damaged infrastructure					
Transit time from facility to the relief site					
Limited holding capacity of facility					

4. Control risk: these are risks that arise from the application or non-application of assumptions, rules, systems, and procedures that guide how decision-makers exert control over the entire supply chain in disaster relief operations. This category of risk includes decision-maker risk and strategic risk.

(A). Decision-maker risks: results from decisions made by an individual or group within an organization or the emergency supply chain. Considering this, please rate the following risk factors or triggers with respect to level or relevance respectively.

	Very unimportant	Less unimportant	Moderate	Less important	Very important
Restriction on the use of donations					
Absence of transparency in funding					
Inadequate skill and expertise of relief workers					
Inadequate collaboration resulting from mistrust					

(B) Strategic risks: stems from the challenges that affect the implementation of plan action of the relief operation. Considering this, please rate the following risk factors or triggers with respect to the level of relevance of each.

	Very unimportant	Less unimportant	Moderate	Less important	Very important
Long term vs Short term planning					
Absence of coordination of relief activities and objectives					

Environmental risk: stems from the events the chain cannot control including social, political, economic, or technological events in addition to disruption events. These events may affect the relief organizations or the entire emergency supply chain.

(A) Disruption risk: stems from the interruption of relief supplies and resources which occurs because of some external factors. Considering this, please rate the following risk factors with respect to the level of relevance of each.

	Very unimportant	Less unimportant	Moderate	Less important	Very important
Impact of follow-up natural disasters					
Variations in the climatic condition					
Fire incidents					
War and Terrorism					

(B) Social risks: stem from the differences in the culture, attitude, and behaviour of beneficiaries, relief workers, and organizations that hamper the efficiency of the relief operation. Considering this, please rate the following factors with respect to the level of relevance.

	Very unimportant	Less unimportant	Moderate	Less important	Very important
Difficulty in communicating with beneficiaries and other stakeholders within the emergency supply chain					
Presence of cultural differences					
Presence of corrupt practices from upstream to downstream along the chain					
Sexual and gender abuses					
Presence of insecurity affecting relief workers and beneficiaries					
Presence of poor judgments from stakeholders					

(C) Political risks: stems from the host government authority and its laws. Considering this, please rate the following risk factors with respect to the level of relevance of each.

	Very unimportant	Less unimportant	Moderate	Less important	Very important
Absence of legislative and supportive rules that influence disaster relief operations					
Sanctions and constraints that hinder stakeholder cooperation and collaboration					

Any other relevant information?

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Thank you very much for sparing some time to complete this survey. Much appreciated.

Appendix III - Weighting and Prioritization of Risk Factors In Emergency Supply Chains

Page 1: INTRODUCTION

Dear Sir/Madam,

My name is Onyeka John Chukwuka, who is currently a PhD student at the Liverpool Logistics Offshore and Marine (LOOM) Research Institute. My research is titled "Risk analysis of emergency supply chains with particular focus on intermodal transport". The research aims to develop a novel decision-support methodology for the identification, evaluation and mitigation of risk factors that are present in emergency supply chains. This questionnaire is designed for the evaluation of the risk factors and the results will aid in weighting and prioritizing the factors respectively.

I would be very pleased if you could take part in this study in view of your professional knowledge in risk management, emergency/humanitarian supply chain and disaster relief operations. The information gathered in this survey will be treated in the strictest confidence, as this has always been the policy of Liverpool John Moores University. The questionnaire is anonymous; thus, your response cannot be attributed to you or your organization.

If you have any questions about this study, please feel free to contact me either email O.J.Chukwuka@2019.ljmu.ac.uk or by phone. You can also contact my supervisor, Dr Jun Ren, by mail J.Ren@ljmu.ac.uk.

Yours faithfully,

Onyeka John Chukwuka

PhD Student, Liverpool Logistics Offshore and Marine (LOOM) Research Institute

Tel: +(44)7564857808, Email: O.J.Chukwuka@2019.ljmu.ac.uk

Room 239, James Parsons Building, Liverpool John Moores University, Byrom Street, L3 3AF, UK

Page 2: Respondent's profile

1. What is the type of organization?

☐ Government ☐ Relief organization ☐ non-governmental organization ☐ Academic ☐ Other ☐

2. What is your job title (optional)?

3. How many years of work experience do you have in the industry?

☐ 1-5 years ☐ 6-10 years ☐ 11-15 years ☐ 16-19 years ☐ 20 years or more

Page 3: Explanation

Section B - Analytical Hierarchy Process (AHP) Questionnaire

A. Explanation

For your opinion as an expert, the pairwise comparison scale can be used to assess or express the importance of one element over another. The linguistic judgements and their explanations used for evaluating the relative importance of the elements in pairwise-comparison is shown in Table 1.

Table 1. Linguistic judgements for fuzzy AHP

Linguistic Judgements	**Explanations**
Equal Importance (Eq)	Two activities contribute equally to the objective
Weak Importance (Wk)	Experience and Judgement slightly favour one over another
Strong Importance (ST)	Experience and Judgement strongly favour one over another
Very strong Importance (Vs)	An activity is favoured very strongly over another
Absolute strong Importance (As)	The evidence favouring one activity over another is of the highest possible order of affirmation.

Questionnaire

Classes of risk

Based on the research, risk factors in emergency supply chains are classified into two groups.

I. **Internal to the supply chain**: related to actors, decision-makers and stakeholders that can make up the supply chain. The interactions between them within the emergency supply chain give rise to the risk sources. This risk category consists of Supply Demand, Infrastructural risk factors.

II. **External to the supply chain**: These are risk related or driven by external forces such as weather, disasters, political and regulatory forces.

1. Based on your expertise, what is the relative importance between these risks with respect to their effects on the emergency supply chain in disaster response operations?

	Abs	Vs	St	Wk	Eq	Wk	St	Vs	Abs	
Internal risk										External risk

I. **Supply risks:** stems from the challenges that negatively affect the internal flow of any type of resource, preventing the effective execution of the operation. Procurement risks, supplier risks and quality risks are sub-categories that make up the supply risk.

II. **Demand risks:** results from the unpredictability of either the volume or mix of products that will be demanded by the beneficiaries in the chain. Forecast risk and inventory risk make up the demand risks.

III. **Infrastructural risks:** stems from the challenges that materialize from the infrastructures required by stakeholders for emergency supply chain operations. Systems, transportation, warehousing, and strategic risks make up the infrastructural risks.

IV. **Environmental risk:** stems from the events the chain cannot control including social, political, economic or technological events in addition to disruption events. These events may affect the relief organisations or the entire emergency supply chain.

2. Based on your expertise, what is the relative importance between these risks with respect to their effects on the emergency supply chain in disaster response operations?

	Abs	Vs	St	Wk	Eq	Wk	St	Vs	Abs	
Demand										Supply
Demand										Infrastructural
Supply										Infrastructural

Categories of risk

I. **Forecast risk:** results from the mismatch between demand projections and the actual demand. Errors in estimating demand which may lead to excess or supply shortage define this type of risk.

II. **Inventory risk:** results from challenges in demand management and uncertainty, the relief value, and its obsolescence rate.

3. Forecast and inventory risks make up demand risks. Based on your expertise, what is the relative importance between these risks with respect to their effects on the emergency supply chain in disaster response operations?

	Abs	Vs	St	Wk	Eq	Wk	St	Vs	Abs	
Forecast										Inventory

I. **Procurement risks**: are derived from an unforeseen increase in acquisition costs resulting from fluctuation in exchange rates or rising prices from suppliers.

II. **Supplier risks:** refers to any risks relating to the operation of the suppliers that may potentially have a negative impact on the entire disaster relief operation.

III. **Quality risks:** refers to issues that affect the relief supplies' quality, noting that each supplier may have a different concept of quality.

4. Procurement, supplier and quality risk make up the supply risks. Based on your expertise, what is the relative importance between these risks with respect to their effects on the emergency supply chain in disaster response operations?

	Abs	Vs	St	Wk	Eq	Wk	St	Vs	Abs	
Procurement										Supplier
Procurement										Quality
Supplier										Quality

I. **Transportation risk:** stems from the inefficiencies in the physical flow supplies that exist between different stakeholders in the emergency supply chain.

II. **Systems risk:** results from the inefficiency in processes and electronic systems, movement and access to information data capture and use permission processes. This risk is defined by the failure in the information system (Downtime in the information infrastructure, system integration or extensive networks and e-commerce systems).

III. **Warehousing risk:** relates to the challenges faced by the facilities that are used to store relief supplies.

IV. **Strategic risks:** stems from the challenges that affects the implementation of the action plan of the emergency supply chain in disaster response operations.

5. Systems, transportation, warehousing, and strategic risks make up the infrastructural risks. Based on your expertise, what is the relative importance between these risks with respect to their effects on the emergency supply chain in disaster response operations?

	Abs	Vs	St	Wk	Eq	Wk	St	Vs	Abs	
Transportation										Warehousing
Transportation										Systems
Warehousing										Systems

I. **Disruption risks:** stems from the interruption of relief supplies and resources which occurs because of some external factors.

II. **Social risks:** stems from the differences in the culture, attitude and behavior of beneficiaries, relief workers and organisations that hamper the efficiency of the relief operation.

III. **Political risks:** stems from the host government authority and its laws.

6. Disruption, social and political risks make up the environmental risk. Based on your expertise, what is the relative importance between these risks with respect to their effects on the emergency supply chain in disaster response operations?

	Abs	Vs	St	Wk	Eq	Wk	St	Vs	Abs	
Disruption										Social
Disruption										Political

Social										Political

Demand risks

7. Forecast risks are caused by several risk factors. Based on your expertise, what is the relative importance between these factors with respect to their effects on the emergency supply chain in disaster response operations?

	Abs	Vs	St	Wk	Eq	Wk	St	Vs	Abs	
Poor demand projection										Distortion of Information

Supply risks

8. Procurement risks are brought about by several risk factors. Based on your expertise, what is the relative importance between these factors with respect to their effects on the emergency supply chain in disaster response operations?

	Abs	Vs	St	Wk	Eq	Wk	St	Vs	Abs	
Non-compliance of supply contracts										Purchasing of key supplies from a single source
Non-compliance of supply contracts										Long-term vs Short-term contracts
Purchasing key supplies from a single source										Long-term vs Short-term contracts

9. Supplier risks are exacerbated by diverse factors. Based on your expertise, what is the relative importance between these factors with respect to their effects on the emergency supply chain in disaster response operations?

	Abs	Vs	St	Wk	Eq	Wk	St	Vs	Abs	
Inadequate supplier capacity										Poor level of supplier responsiveness
Inadequate supplier capacity										Variation in transit time
Poor level of supplier responsiveness										Variation in transit time

10. Quality risk results from several factors. Based on your expertise, what is the relative importance between these factors with respect to their effects on the emergency supply chain in disaster response operations?

	Abs	Vs	St	Wk	Eq	Wk	St	Vs	Abs	
Defective or damaged supplies										Wrong or unsolicited supplies
Defective or damaged supplies										Counterfeit supplies
Wrong or unsolicited supplies										Counterfeit supplies

Infrastructural risks

11. Transportation risks can result from several factors. Based on your expertise, what is the relative importance between these factors with respect to their effects on the emergency supply chain in disaster response operations?

	Abs	Vs	St	Wk	Eq	Wk	St	Vs	Abs	
Poor or damaged transport infrastructure										Absence of alternative transport modes
Poor or damaged transport infrastructure										Ineffective last mile delivery
Poor or damaged transport infrastructure										Theft of relief supplies
Absence of alternative transport modes										Ineffective last mile delivery
Absence of alternative transport modes										Theft of relief supplies
Ineffective last mile delivery										Theft of relief supplies

12. Warehousing risk is caused by several risk factors. Based on your expertise, what is the relative importance between these factors with respect to their effects on the emergency supply chain in disaster response operations?

	Abs	Vs	St	Wk	Eq	Wk	St	Vs	Abs	
Poor or damaged warehouse infrastructure										Limited holding capacity

13. Systems ‘risk is exacerbated by different risk factors. Based on your expertise, what is the relative importance between these factors with respect to their effects on the emergency supply chain in disaster response operations?

	Abs	Vs	St	Wk	Eq	Wk	St	Vs	Abs	
Poor I.T infrastructure										Absence of transparency in information dissemination
Poor I.T infrastructure										Presence of delays during information transfer
Absence of transparency in information dissemination										Presence of delays during information transfer

Environmental risks

14. Several factors can lead to disruption risk. Based on your expertise, what is the relative importance between these factors with respect to their effects on the emergency supply chain in disaster response operations?

	Abs	Vs	St	Wk	Eq	Wk	St	Vs	Abs	
Impact of follow-up disasters										War and terrorism

15. Social risk is caused by several risk factors. Based on your expertise, what is the relative importance between these factors with respect to their effects on the emergency supply chain in disaster response operations?

	Abs	Vs	St	Wk	Eq	Wk	St	Vs	Abs	
Difficulty in communicating with beneficiaries and stakeholders										Corruption
Difficulty in communicating with beneficiaries and stakeholders										Sexual and gender abuses
Corruption										Sexual and gender abuses

16. Political risks are exacerbated by several risk factors. Based on your expertise, what is the relative importance between these factors with respect to their effects on the emergency supply chain in disaster response operations?

	Abs	Vs	St	Wk	Eq	Wk	St	Vs	Abs	
Absence of supportive and legislative rules that influence disaster relief operations										Sanctions and constraints that hinder stakeholder collaboration

THANK YOU ONCE AGAIN FOR YOUR KIND PARTICIPATION IN THIS SURVEY.

YOUR RESPONSE WILL BE KEPT CONFIDENTIAL

Appendix IV – Empirical Study on Risk Mitigation Strategies for Emergency Supply Chains

To: Whom it may concern

A research project at Liverpool John Moores University is currently being carried out with regard to the impact of emergency supply chain risks on disaster relief operations. I will be most grateful if you could kindly spend your valuable time and take part in this study. Your participation in this survey is voluntary and will only take a few minutes. All the information that you provide during your interview, completion of questionnaires or in general discussion will be greatly benefit and contribute to achieve the aim of this project. The information gathered in this survey will be treated in the strictest confidence.

The questionnaire is anonymous; thus, your response can not be attributed to you or your organization. Any refusal or incomplete questionnaire will be excluded without any responsibility on the participant. Completion of the questionnaire will indicate your willingness to participate in this study. If you require additional information or have any questions about this study, please feel free to contact me either by email or by phone at the addresses listed below.

Yours faithfully,

Onyeka John Chukwuka,

PhD researcher, LOOM

Tel: + (44) 7564857808

Email:O.J.Chukwuka@2019.ljmu.ac.uk

Dr Jun Ren (Director of Study)

Reader, LOOM

Faculty of Engineering and Technology

Email: J.Ren@ljmu.ac.uk

Other Information

For concerns regarding your involvement in this study, please discuss these issues with the researcher in the first instance. If you wish to make a complaint, please contact the research ethics committee at researchethics.ljmu.ac.uk and your communication will be re-directed to the appropriate person-in-charge.

Section A: Introduction

This research proposed a novel risk assessment methodology for identifying, evaluating, and mitigating the risk factors that are most likely to disrupt the activities of the emergency supply chain in disaster relief operations. Based on the findings from the previous survey, the following risk factors shown in the below table (table 1) have been weighted by the experts as the most significant risk factors that can impede the efficiency and effectiveness of the emergency supply chain. We further need to determine the relevant risk mitigation strategies for each specific risk factor based on a particular case.

Section B: Questionnaire

Part 1: Experimental Case Study

Country X has just been struck by a massive earthquake of 7.0MW which has resulted into a huge death toll of over 200,000, and an estimated 300,000 people are confirmed injured. The earthquake has been so destructive that the country has continuously experienced over 52 after-shock quakes measuring 4.5 or more on the Richter scale 12 days following the original quake. This earthquake and the following destruction have placed immense stress on the population and infrastructure. It has also left approximately one million citizens homeless and vulnerable. The infrastructure of Country X is badly affected, and over 30,000 commercial buildings and one million residential buildings have already collapsed.

A global response has been initiated and people from all over the world are viewing live coverage of the destruction and displacement. Various stakeholders (donors, international agencies, international NGOs, local NGOs, community-based organisations) have immediately arrived at the scene of the disaster, and an emergency supply chain is designed to be deployed to meet the needs of the vulnerable population. A risk management process has been initiated and the most important risk factors that are likely to impede the normal functioning of emergency supply have been identified and detailed in the table 1 below.

Table 1. Significant Emergency Supply Chain Risk Factors

RISK FACTORS	**DESCRIPTION**
Absence of legislative and supportive rules that influence relief operations	Inadequate and lengthy procedures for bureaucratic decision-making policies.
Sanctions and constraints that hinder collaboration amongst stakeholders.	Restrictions preventing chain integration, lack of knowledge about each other, ineffective information sharing and absence of clear mandates.
War and terrorism	Presence of chaos, civilian unrest and rebel groups making the environment unsafe.
Impact of follow-up disasters	Aftershocks, and other forms of disaster impacting the same locations following the original disaster.
Limited life cycle of relief supplies	Relief supplies nearing expiry dates
Poor communication	Difficulty in information exchange between stakeholders and beneficiaries.
Corrupt practices	Stakeholders and governments engaged in bribery, and diversion of critical supplies.

Sexual and gender abuses	Rape and sexual violence, mostly amongst women and girls
Poor demand projection	When there is an error in forecasting the needs of the vulnerable population.
Distortion of information	Wrong or misleading information about the needs and demands of those affected.

The next step is to identify and define relevant strategies that can aid in mitigating these significant risks already identified. Several risk mitigations strategies have been extracted from literature, including applied strategies that have been utilised in various case studies. These case studies provide an overview of empirical research of logistics and supply chain activities in disaster relief operations. Table 2 provides a description of the identified mitigation strategies.

Table 2. Risk mitigation Strategies for Emergency Supply Chain risk factors

Mitigation Strategy	**Description**
Strategic Stock	Locating basic relief supplies in strategic points to ensure speedy response.
Prepositioning of Resources	Emergency funds, staff development, provision of items, facilities, and equipment's (Field hospitals and health clinics)
Collaboration and Coordination	Coordination, Supplier relations, Joint planning and procurement, Information sharing
Flexible transportation	Includes operational mix (using vehicles for both long-term operations and emergencies), alternative evacuation routes and transport modes (Whatever mode is available and needed during on the destruction of infrastructure), Synchro modality.
Flexible supply base	Decentralised decision making (allowing for local adaptations), Alternative sources (e.g., multiple suppliers and diverse item specification), Vendor managed inventory, Transfer mechanisms between programs, Buttressed supply chains.
Logistics outsourcing	Engaging third party logistics providers
Flexible supply contracts	Framework agreement, Pre-purchasing with option contract
Risk awareness / Knowledge management	Being informed and having a firm understanding of the existence of risk in the supply chain and putting steps in place to tackle these risks

<u>Part 2: Questions</u>

1. Based on your opinion as an expert and the described case study, please kindly rate the relevance and applicability of the following supply chain strategies for the mitigation of the risk factors.

Supply chain Strategies	Very unimportant	Less unimportant	Moderate	Less important	Very important
Strategic stock	☐1	☐2	☐3	☐4	☐5
Prepositioning of resources	☐1	☐2	☐3	☐4	☐5
Postponement	☐1	☐2	☐3	☐4	☐5
Vertical collaboration and coordination	☐1	☐2	☐3	☐4	☐5
Flexible transportation	☐1	☐2	☐3	☐4	☐5
Flexible supply base	☐1	☐2	☐3	☐4	☐5
Centralisation	☐1	☐2	☐3	☐4	☐5
Logistics outsourcing	☐1	☐2	☐3	☐4	☐5
Flexible supply contracts	☐1	☐2	☐3	☐4	☐5
Decision policy and procedure	☐1	☐2	☐3	☐4	☐5
Risk awareness	☐1	☐2	☐3	☐4	☐5
Cash-based Interventions	☐1	☐2	☐3	☐4	☐5

2. Based on your experience, Is there any other supply chain strategy that may have been omitted and is suitable for this study?

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Part 3. General Information

1. What kind of organisation are you affiliated to?

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2. What position do you hold in your organisation?

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3. How many years have you been involved in disaster relief?

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4. What type of operation have you participated in?

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5. How many personnel is employed in your organisation?

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This is the end of the questionnaire. Thank you very much for your help.

Appendix V – Semi-structured Interview

Interview Protocol

1. Risk management is an integral part of the commercial supply chain, Is this the case in emergency/humanitarian supply chains?

2. What is the nature of the risk management process in emergency supply chains?

3. From the literature review, several strategies have been identified to support manages, what are views on these respective strategies?

4. What is the degree of relevance of each respective strategy to the experimental case study and identified risk factors?

- Strategic Stock
- Prepositioning of resources
- Postponement
- Collaboration and coordination
- Flexible supply base
- Flexible transportation
- Flexible supply contracts
- Centralisation
- Logistics outsourcing
- Decision policies/procedures
- Risk awareness/Knowledge management
- Cash-based interventions

5. What other strategies have been omitted and how relevant are they to this study?

Appendix VI- Evaluation of Risk Mitigation Strategies for Emergency Supply Chains

To: Whom it may concern

A research project at Liverpool John Moores University is currently being carried out with regard to the impact of emergency supply chain risks on disaster relief operations. I will be most grateful if you could kindly spend your valuable time and take part in this study. Your participation in this survey is voluntary and will only take a few minutes. All the information that you provide during your interview, completion of questionnaires or in general discussion will be greatly benefit and contribute to achieve the aim of this project. The information gathered in this survey will be treated in the strictest confidence.

The questionnaire is anonymous; thus, your response can not be attributed to you or your organization. Any refusal or incomplete questionnaire will be excluded without any responsibility on the participant. Completion of the questionnaire will indicate your willingness to participate in this study. If you require additional information or have any questions about this study, please feel free to contact me either by email or by phone at the addresses listed below.

Yours faithfully,

Onyeka John Chukwuka,
PhD researcher, LOOM
Tel: + (44) 7564857808
Email:O.J.Chukwuka@2019.ljmu.ac.uk

Dr Jun Ren (Director of Study)
Reader, LOOM
Faculty of Engineering and Technology
Email: J.Ren@ljmu.ac.uk

General Information

1. What position do you hold in your organisation?

   …………………………………………………………….

2. How many years have you been involved in disaster relief?

   …………………………………………………………..

3. What type of operation have you participated in?

   ……………………………………………………

4. How many personnel is employed in your organisation?

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Section A: Introduction

This research proposed a novel risk assessment methodology for identifying, evaluating, and mitigating the risk factors that are most likely to disrupt the activities of the emergency supply chain in disaster relief operations. Based on the findings from the previous survey, the following risk factors shown in the below table (table 1) have been weighted by the experts as the most significant risk factors that can impede the efficiency and effectiveness of the emergency supply chain. We further need to determine the degree of importance of relevant risk mitigation strategies for each specific risk factor based on a particular case.

Section B: Questionnaire

Part 1: Experimental Case Study

Country X has just been struck by a massive earthquake of 7.0MW which has resulted into a huge death toll of over 200,000, and an estimated 300,000 people are confirmed injured. The earthquake has been so destructive that the country has continuously experienced over 52 after-shock quakes measuring 4.5 or more on the Richter scale 12 days following the original quake. This earthquake and the following destruction have placed immense stress on the population and infrastructure. It has also left approximately one million citizens homeless and vulnerable. The infrastructure of Country X is badly affected, and over 30,000 commercial buildings and one million residential buildings have already collapsed.

A global response has been initiated and people from all over the world are viewing live coverage of the destruction and displacement. Various stakeholders (donors, international agencies, international NGOs, local NGOs, community-based organisations) have immediately arrived at the scene of the disaster, and an emergency supply chain is designed to be deployed to meet the needs of the vulnerable population. A risk management process has been initiated and the most important risk factors that are likely to impede the normal functioning of emergency supply have been identified and detailed in the table 1 below.

Table 1. Significant Emergency Supply Chain Risk Factors

RISK FACTORS	DESCRIPTION
Absence of legislative and supportive rules that influence relief operations	Inadequate and lengthy procedures for bureaucratic decision-making policies.
Sanctions and constraints that hinder collaboration amongst stakeholders.	Restrictions preventing chain integration, lack of knowledge about each other, ineffective information sharing and absence of clear mandates.
High inventory holding cost	High cost of holding strategic stock prior to disaster response
War and terrorism	Presence of chaos, civilian unrest and rebel groups making the environment unsafe.
Impact of cascading disasters	Aftershocks, and other forms of disaster impacting the same locations following the original disaster.
Variations of climatic conditions	Erratic weather patterns and climate events such as flooding, that exacerbate already existing disasters
Fire incidents	Fire outbreaks during response operations
Limited life cycle of relief supplies	Relief supplies nearing expiry dates
Poor communication	Difficulty in information exchange between stakeholders and beneficiaries.
Corrupt practices	Stakeholders and governments engaged in bribery, and diversion of critical supplies.
Sexual and gender abuse	Rape and sexual violence, mostly amongst women and girls
Presence of cultural differences	Presence of diverse belief, religion amongst stakeholders and beneficiaries
Stakeholders' poor judgement	Wrong or poor decision-making from stakeholders
Poor demand projection	When there is an error in forecasting the needs of the vulnerable population.
Distortion of information	Wrong or misleading information about the needs and demands of those affected.
High variation in Demand	Constant changes or fluctuations in beneficiary demands.

The next step is to identify and define the most effective mitigation strategy with respect to each specific risk factor. These risk mitigations strategies have been extracted from literature, and validated through some series of semi-structured interviews and high-level surveys. Table 2 provides a description of the identified mitigation strategies.

Table 2. Risk mitigation Strategies for Emergency Supply Chain risk factors

Mitigation Strategy	**Description**
Strategic Stock	Locating basic relief supplies in strategic points to ensure speedy response.
Prepositioning of Resources	Emergency funds, staff development, provision of items, facilities, and equipment's (Field hospitals and health clinics)
Postponement	Includes non-earmarked funding and goods, stock centralisation, prepositioning of semi-finished goods, Cooperation agreements with potential partners, Standardisation, Modular design
Collaboration	Coordination, Supplier relations, Joint planning and procurement, Information sharing
Flexible transportation	Includes operational mix (using vehicles for both long-term operations and emergencies), alternative evacuation routes and transport modes (Whatever mode is available and needed during on the destruction of infrastructure), Synchro modality.
Flexible supply base	Decentralised decision making (allowing for local adaptations), Alternative sources (e.g., multiple suppliers and diverse item specification), Vendor managed inventory, Transfer mechanisms between programs, Buttressed supply chains.
Centralisation	Centralised prepositioned stock, Fleet hub
Redesign of chain configuration	Outsourcing logistics
Flexible supply contracts	Framework agreement, Pre-purchasing with option contract
Decision policy and procedure	Eliminate unnecessary decision process steps to reduce human-related issues that occur in lengthy administration processes

Part 2: Questions

Based on your opinion as an expert, please kindly select the most appropriate strategies for the respective significant risk factors.

1. With respect to War and terrorism, please define the importance of the following risk mitigation strategies.

RISK MITIGATION STRATEGIES	Very Poor	Poor	Moderate	Good	Very Good
Strategic stock	☐1	☐2	☐3	☐4	☐5
Prepositioning of resources	☐1	☐2	☐3	☐4	☐5
Collaboration and coordination	☐1	☐2	☐3	☐4	☐5
Flexible transportation	☐1	☐2	☐3	☐4	☐5
Logistics outsourcing	☐1	☐2	☐3	☐4	☐5
Flexible supply contracts	☐1	☐2	☐3	☐4	☐5
Risk awareness/Knowledge management	☐1	☐2	☐3	☐4	☐5

2. With respect to Absence of legislative and supportive rules that can influence disaster relief operations, please define the importance of the following mitigation strategies.

RISK MITIGATION STRATEGIES	Very Poor	Poor	Moderate	Good	Very Good
Strategic stock	☐1	☐2	☐3	☐4	☐5
Prepositioning of resources	☐1	☐2	☐3	☐4	☐5
Collaboration and coordination	☐1	☐2	☐3	☐4	☐5
Flexible transportation	☐1	☐2	☐3	☐4	☐5

Logistics outsourcing	☐1 ☐2 ☐3 ☐4 ☐5
Flexible supply contracts	☐1 ☐2 ☐3 ☐4 ☐5
Risk awareness/Knowledge management	☐1 ☐2 ☐3 ☐4 ☐5

3. With respect to Impact of follow-up disasters, please define the importance of the following mitigation strategies.

RISK MITIGATION STRATEGIES	Very Poor	Poor	Moderate	Good	Very Good
Strategic stock	☐1	☐2	☐3	☐4	☐5
Prepositioning of resources	☐1	☐2	☐3	☐4	☐5
Collaboration and coordination	☐1	☐2	☐3	☐4	☐5
Flexible transportation	☐1	☐2	☐3	☐4	☐5
Logistics outsourcing	☐1	☐2	☐3	☐4	☐5
Flexible supply contracts	☐1	☐2	☐3	☐4	☐5
Risk awareness/Knowledge management	☐1	☐2	☐3	☐4	☐5

4. With respect to limited life cycle of relief supplies, please define the importance of the following mitigation strategies.

RISK MITIGATION STRATEGIES	Very Poor	Poor	Moderate	Good	Very Good
Strategic stock	☐1	☐2	☐3	☐4	☐5
Prepositioning of resources	☐1	☐2	☐3	☐4	☐5
Collaboration and coordination	☐1	☐2	☐3	☐4	☐5

Flexible transportation	☐1 ☐2 ☐3 ☐4 ☐5
Logistics outsourcing	☐1 ☐2 ☐3 ☐4 ☐5
Flexible supply contracts	☐1 ☐2 ☐3 ☐4 ☐5
Risk awareness/Knowledge management	☐1 ☐2 ☐3 ☐4 ☐5

5. With respect to Sanction and constraints that hinder stakeholder collaboration and cooperation, please define the importance of the following mitigation strategies.

RISK MITIGATION STRATEGIES	Very Poor	Poor	Moderate	Good	Very Good
Strategic stock	☐1	☐2	☐3	☐4	☐5
Prepositioning of resources	☐1	☐2	☐3	☐4	☐5
Collaboration and coordination	☐1	☐2	☐3	☐4	☐5
Flexible transportation	☐1	☐2	☐3	☐4	☐5
Logistics outsourcing	☐1	☐2	☐3	☐4	☐5
Flexible supply contracts	☐1	☐2	☐3	☐4	☐5
Risk awareness/Knowledge management	☐1	☐2	☐3	☐4	☐5

6. With respect to poor communication between stakeholders and beneficiaries, please define the importance of the following mitigation strategies.

RISK MITIGATION STRATEGIES	Very Poor	Poor	Moderate	Good	Very Good
Strategic stock	☐1	☐2	☐3	☐4	☐5
Prepositioning of resources	☐1	☐2	☐3	☐4	☐5
Collaboration and coordination	☐1	☐2	☐3	☐4	☐5

Flexible transportation	☐1 ☐2 ☐3 ☐4 ☐5
Logistics outsourcing	☐1 ☐2 ☐3 ☐4 ☐5
Flexible supply contracts	☐1 ☐2 ☐3 ☐4 ☐5
Risk awareness/Knowledge management	☐1 ☐2 ☐3 ☐4 ☐5

7. With respect to corrupt practices, please define the importance of the following mitigation strategies.

RISK MITIGATION STRATEGIES	Very Poor	Poor	Moderate	Good	Very Good
Strategic stock	☐1	☐2	☐3	☐4	☐5
Prepositioning of resources	☐1	☐2	☐3	☐4	☐5
Collaboration and coordination	☐1	☐2	☐3	☐4	☐5
Flexible transportation	☐1	☐2	☐3	☐4	☐5
Logistics outsourcing	☐1	☐2	☐3	☐4	☐5
Flexible supply contracts	☐1	☐2	☐3	☐4	☐5
Risk awareness/Knowledge management	☐1	☐2	☐3	☐4	☐5

8. With respect to the presence of sexual and gender abuses, please define the importance of the following mitigation strategies.

RISK MITIGATION STRATEGIES	Very Poor	Poor	Moderate	Good	Very Good
Strategic stock	☐1	☐2	☐3	☐4	☐5
Prepositioning of resources	☐1	☐2	☐3	☐4	☐5
Collaboration and coordination	☐1	☐2	☐3	☐4	☐5

Flexible transportation	☐1 ☐2 ☐3 ☐4 ☐5
Logistics outsourcing	☐1 ☐2 ☐3 ☐4 ☐5
Flexible supply contracts	☐1 ☐2 ☐3 ☐4 ☐5
Risk awareness/Knowledge management	☐1 ☐2 ☐3 ☐4 ☐5

9. With respect to poor demand projections, please define the importance of the following mitigation strategies.

RISK MITIGATION STRATEGIES	Very Poor	Poor	Moderate	Good	Very Good
Strategic stock	☐1	☐2	☐3	☐4	☐5
Prepositioning of resources	☐1	☐2	☐3	☐4	☐5
Collaboration and coordination	☐1	☐2	☐3	☐4	☐5
Flexible transportation	☐1	☐2	☐3	☐4	☐5
Logistics outsourcing	☐1	☐2	☐3	☐4	☐5
Flexible supply contracts	☐1	☐2	☐3	☐4	☐5
Risk awareness/Knowledge management	☐1	☐2	☐3	☐4	☐5

10 With respect to distortion of information, please define the following mitigation strategies.

RISK MITIGATION STRATEGIES	Very Poor	Poor	Moderate	Good	Very Good
Strategic stock	☐1	☐2	☐3	☐4	☐5
Prepositioning of resources	☐1	☐2	☐3	☐4	☐5
Collaboration and coordination	☐1	☐2	☐3	☐4	☐5

Flexible transportation	☐1 ☐2 ☐3 ☐4 ☐5
Logistics outsourcing	☐1 ☐2 ☐3 ☐4 ☐5
Flexible supply contracts	☐1 ☐2 ☐3 ☐4 ☐5
Risk awareness/Knowledge management	☐1 ☐2 ☐3 ☐4 ☐5