A comprehensive research on analyzing risk factors in emergency supply chains

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Abstract

Purpose – Unforeseen events can disrupt the operational process and negatively impact emergency resources optimization and its supply chain. A limited number of studies have addressed risk management issues in the context of emergency supply chains, and this existing research lacks inbuilt and practical techniques that can significantly affect the reliability of risk management outcomes. Therefore, this paper aims to identify and practically analyze the specific risk factors that can most likely disrupt the normal functioning of the emergency supply chain in disaster relief operations.

Design/methodology/approach – This paper has used a three-step process to investigate and evaluate risk factors associated with the emergency supply chain. First, the study conducts a comprehensive literature review to identify the risk factors. Second, the research develops a questionnaire survey to validate and classify the identified risk factors. At the end of this step, the study develops a hierarchical structure. Finally, the research investigates the weighted priority of the validated risk factors using the fuzzy-analytical hierarchy process (FAHP) methodology. Experts were required to provide subjective judgments.

Findings – This paper identified and validated 28 specific risk factors prevalent in emergency supply chains. Based on their contextual meanings, the research classified these risk factors into two main categories: internal and external risk factors; four subcategories: demand, supply, infrastructural and environmental risk factors; and 11 risk types: forecast, inventory, procurement, supplier, quality, transportation, warehousing, systems, disruption, social and political risk factors. The most significant risk factors include war and terrorism, the absence of legislative rules that can influence and support disaster relief operations, the impact of cascading disasters, limited quality of relief supplies and sanctions and constraints that can hinder stakeholder collaboration. Therefore, emergency supply chain managers should adopt appropriate strategies to mitigate these risk factors.

Research limitations/implications – This study will contribute to the general knowledge of risk management in emergency supply chains. The identified risk factors and structural hierarchy taxonomic diagram will provide a comprehensive risk database for emergency supply chains.

Practical implications – The research findings will provide comprehensive and systemic support for respective practitioners and policymakers to obtain a firm understanding of the different risk categories and specific risk factors that can impede the effective functioning of the emergency supply chain during immediate disaster relief operations. Therefore, this will inform the need for the improvement of practices in critical aspects of the emergency supply chain through the selection of logistics and supply chain strategies that can ensure the robustness and resilience of the system.

Originality/value – This research uses empirical data to identify, categorize and validate risk factors in emergency supply chains. This study contributes to the theory of supply chain risk management. The study also adopts the fuzzy-AHP technique to evaluate and prioritize these risk factors to inform practitioners and policymakers of the most significant risk factors. Furthermore, this study serves as the first phase of managing risk in emergency supply chains since it motivates future studies to empirically identify, evaluate and select effective strategies that can eliminate or minimize the effects of these risk factors.

Keywords Risk management, Empirical study, Fuzzy-AHP, Emergency supply chain

Paper type Research paper

1. Introduction

The global presence of diverse disasters continues to increase in severity and frequency, according to the records of the Emergency Events Database (Thomas and López, 2015). Every disaster necessitates an immediate response operation involving different stakeholders, including governments, local and foreign donor agencies, non-governmental organisations and organizations of the United Nations (UN) aiming to speedily provide and distribute critical supplies to the affected

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population to alleviate unnecessary sufferings (Chiappetta Jabbour *et al.*, 2019). Therefore, the stakeholders deploy an emergency supply chain to change resources into critical supplies and deliver them effectively and efficiently to various beneficiaries. Thomas and Kopczak (2005) define the emergency supply chain as the:

> [...]process of planning, implementing, and controlling the efficient, cost-effective flow and storage of goods and materials, as well as related information, from the point of origin to the point of consumption to alleviate the suffering of the vulnerable people.

The emergency supply chain includes various tasks, such as figuring out what is needed, buying what is needed, getting resources together, transporting, storing and delivering to the last mile (Gustavsson, 2003). Activities in the emergency supply chain can cost up to 80% of the total cost of disaster relief operations (Van Wassenhove, 2006). These activities occur in extremely volatile conditions, and stakeholders are often confronted with numerous risks and uncertainties, including unpredictable demand, uncertainty in supply, nonexistent and damaged infrastructure, inadequate logistics resources, volatile political situations, security issues and insufficient information (L'hermitte *et al.*, 2014). The prevalence of these risks disrupts the normal functioning of the emergency supply chain (Wang *et al.*, 2012; Mangla *et al.*, 2013) and can lead to the loss of human lives and properties.

Supply chain risk management involves identifying and mitigating threats to supply chain performance (Bandaly *et al.*, 2012). The strategic importance of supply chain risk management, which is the process of identifying, assessing and managing supply chain-related risks to lessen overall supply chain vulnerability (Manuj and Mentzer, 2008a), is becoming increasingly apparent in global business environments and is attracting notable interest from academics and practitioners (Manuj and Mentzer, 2008b). However, there has been surprisingly little focus on the importance of risk management in emergency supply chains.

Risk management is essential yet difficult in a dynamic environment such as the operating environment of the emergency supply chain, where decision-makers face short timelines and limited information (Aqlan and Lam, 2015). Risk management in emergency supply chain is important for two reasons: a disruption of the emergency supply chain can contribute to an existing situation or create another, and the emergency supply chain operates in a highly volatile environment, as such, encounters multiple forms of risk (McLachlin *et al.*, 2009). However, no study has attempted to scientifically examine individual risk factors and define distinct classes of risks and uncertainties. To close this gap, the study aims to investigate risk factors prevalent in emergency supply chains. To meet the fundamental purpose of the emergency supply chain, stakeholders must get critical relief supplies to the affected population without any form of disruption. Practitioners and policymakers need to be aware of the specific risk factors that can likely impede the effective functionality of the emergency system and pay more attention to the most significant risk factors since it can be challenging to focus on all likely risk factors. Knowledge of these risk factors in emergency supply chains can enable practitioners and policymakers to effectively tailor their practices by selecting only relevant supply chain strategies. To meet the aim of this research, this study will answer two questions:

Q1. What are the prevalent risk factors in emergency supply chains, and what are their respective categories?

Q2. What are the most important risk factors in the emergency supply chain?

Hence, this study aims to identify, categorize and prioritize the prevalent risk factors in emergency supply chains. To address these questions, this study proposes a novel risk analysis model that can support emergency relief practitioners and policymakers in investigating the most critical risk factors likely to disrupt the emergency supply chain. The model encompasses a comprehensive literature review, high-level surveys and the fuzzy-AHP technique. The study used a comprehensive literature review and high-level surveys to identify and validate the specific risk factors and their respective categories likely to disrupt the emergency supply chain. Determining the most significant risk factors is a multi-criteria decision-making (MCDM) problem. The analytical hierarchy process (AHP) can solve this problem. AHP is a method that helps assess the relative importance of system variables.

In contrast to tools such as the analytic network process (ANP), it is simpler to implement and calls for a limited number of pairwise comparison matrices (Harputlugil *et al.*, 2011). However, this tool uses expert opinion for its input. Expert opinions are generally subjective and associated with vagueness and uncertainty. Thus, the study adopted the fuzzy-AHP since it captures the ambiguity and uncertainty associated with data. Moreover, AHP based on fuzzy logic is an excellent choice for problems with few criteria and choices. Otherwise, the number of pairwise comparisons dramatically grows and becomes burdensome (Mangla *et al.*, 2015). Practitioners and policymakers face difficulties in identifying potential risk variables that are likely to disrupt the emergency supply chain due to the lack of a risk analysis framework for the emergency supply chain. This study contributes to the theory of risk management in emergency supply chains. In the disaster relief context, this study is the first to use a MCDM tool to identify the most important risk factors in an emergency. The suggested methodology will help practitioners quickly identify the greatest risks, even in highly subjective situations.

This study is structured as follows: Section 2 briefly reviews the literature on the emergency supply chain and its associated risk factors. Section 3 details the fuzzy analytical hierarchy process methodology used, and Section 4 describes the proposed framework for prioritizing the risk factors of the emergency supply chain. Section 5 presents the application of the proposed framework through an empirical case study, while Section 6 introduces the results and Section 7 introduces some research implications. To complete this research, Section 8 details the conclusions, some limitations and areas for future research.

2. Literature review

2.1 Emergency supply chain

Emergency supply chain management is associated with several disasters, such as earthquakes, tsunamis and hurricanes (Kovács and Spens, 2009). Altay and Green (2006) described 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.

Disasters take varied forms but can either originate naturally or man-made, also, with the speed of onset, sudden-onset or slow-onset disasters (Van Wassenhove, 2006; Dwivedi *et al.*, 2018). By enabling the delivery of the right quantity of appropriate relief supplies to people in desperate need at the right time through an effective channel, the emergency supply chain can aid in alleviating the suffering of populations affected by sudden-onset disasters (Maghsoudi and Moshtari, 2021). Dashtpeyma and Ghodsi (2021) explain that when a disaster strikes, it's crucial to keep relief operations running smoothly and provide supplies where they are needed as soon as possible. Ritchie and Roser (2014) pointed out that persons living in poverty are hit the hardest by natural disasters in low- to middle-income nations, which have fewer infrastructure amenities available (Tasnim *et al.*, 2022).

The number of natural and man-made disasters is on the rise due to factors such as the degradation of the environment, the acceleration of global warming, the emission of greenhouse gases, the shifting of weather patterns, the rapid growth of urbanization, the destruction of forests, the access of humans to potentially dangerous locations and the increased rate of industrialization in developing nations. Compared to how things are right now, forecasts suggest that the number of natural disasters will grow by a factor of five during the next 50 years (Dubey *et al.*, 2016). As a result, the pressure placed on relief organizations is increasing, and they must contend with various obstacles (Dubey *et al.*, 2016a). Figure 1 presents a typical emergency supply chains (ESC) diagram. The presence of minimal or zero lead time, demand unpredictability, uncertainty, inadequate resources and other dynamic influences define the activities of emergency supply chains (Balcik and Beamon, 2008). Irrespective of these complexities, logisticians are tasked with meeting the needs of beneficiaries. The question of "what is required," "when" and "where" are key attributes that differentiate them from their commercial counterpart. However, Bealt *et al.* (2016) explain that supply chain management, emergency supply chain management and disaster response management all have tight interactions, which greatly impact the degree of efficiency during emergency relief activities. Maon *et al.* (2009) underline that commercial and emergency supply chain management (SCM) mark some significant similarities, such as the critical theories related to the flows of goods, information and finances. In addition, the primary SCM practices, demand management, supply management and fulfillment management, remain unchanged (Ernst, 2003).

The emergency supply chain encompasses all phases of disaster relief operation. Several studies have suggested different phases of disaster relief operations such as emergency relief, rehabilitation and development phases (Kovács and Spens, 2009); preparedness, response and recovery (Pettit and Beresford, 2005); mitigation, preparedness, response and recovery (Altay and Green, 2006). For logisticians, the three phases of emergency logistics and supply chain management – preparation, response and recovery – constitute a central area of focus (Van Wassenhove, 2006). Accordingly, the stages of disaster management most often addressed are the phases of preparedness and response, whereas the recovery phase has received less attention (Leiras *et al.*, 2014):

- Mitigation is a critical predisaster phase that concerns the activities needed to prevent disasters, lessen their impact and minimize the severity of any resulting damage, such as loss of lives or properties (Holguin Veras *et al.*, 2012; Natarajarathinam *et al.*, 2009). This phase does not need the direct involvement of logisticians and instead focuses on the legal concerns and practices that mitigate social vulnerability. It focuses mostly on problems directly connected to the duties of the government (Negi and Negi, 2021).
- Preparedness is the next phase in the cycle. This phase is analogous to strategic planning in commercial supply chains (John *et al.*, 2012). It is important to note that many activities occur during the preparatory phase before a catastrophe occurs. This phase is just before the disaster era that involves the development of necessary tactics or plans of action that will pave the way for a successful operational response (Haddow *et al.*, 2013; Kumar and Harvey, 2013). Essential activities, such as creating a physical network, developing a cooperation base and creating information and communication technology systems, occur during this phase. Important assets, critical partners like suppliers, and potential threats are just some things that need to be identified and described to educate employees and prepare for potential disasters. The success of the emergency supply chain depends primarily on the preceding phase of preparation (Kunz *et al.*, 2014; Duran *et al.*, 2011).
- The next phase is Response. The term "response" refers to the subsequent steps taken in the aftermath of a disaster. Included are the measures that are taken immediately to deal with disasters or other crises. Aid distribution is an important part of emergency preparation and reaction (Ozen and Krishnamurthy, 2018). During this phase, efforts put in place to react to a disaster by collecting and organizing supplies, personnel and

Figure 1 Typical diagram of an emergency supply chain

Source: (Oloruntoba and Gray, 2006)

information; transporting essential services to affected regions; and preparing emergency repairs to infrastructure (Natarajarathinam *et al.*, 2009; Altay *et al.*, 2018). One of the most important tasks during this phase is ensuring that the various assistance actors communicate effectively (Negi and Negi, 2021).

- The recovery phase contains the final set of activities in the management cycle (Natarajarathinam *et al.*, 2009). These are actions taken with time after emergency response operations that help stabilize and rebuild the affected community. People who leave their homes are assisted to return, and those in the most vulnerable conditions receive the necessary aid to recuperate (Goldschmidt and Kumar, 2016). Better homes and infrastructure can be rebuilt, long-term consequences can be mitigated and community resilience can be bolstered (Altay *et al.*, 2018).

In summary, every disaster relief operation focuses on providing critical supplies to vulnerable populations to ensure survival. Relief organizations work in volatile situations, which requires them to integrate strategies that may allow them to react to risks and uncertainties in demand, supply and procedures. These strategies must be adaptable to a wide range of circumstances (Balcik and Beamon, 2008). An effective operation necessitates being well-prepared, being able to deploy needed resources rapidly and having the capacity to adjust effectively while on-site in a variety of unique local circumstances. According to the findings of several studies (L'hermitte *et al.*, 2015), the emergency supply chain's operational success relies on the organization's capacity to adapt quickly to external interruptions and engage in dynamic operations. Supply chains need to be cost-effective to accomplish this goal (McLachlin *et al.*, 2009; Pettit and Beresford, 2009) and responsive (Blecken *et al.*, 2009; Oloruntoba and Gray, 2009; Merminod *et al.*, 2009).

2.2 Risk management and emergency supply chains

The primary responsibility of a typical emergency supply chain is to provide a prompt and effective response to catastrophes by providing essential resources to populations who are particularly at risk. Relief actors can achieve this objective by distributing aid to those in need (Besiou *et al.*, 2011; Blecken, 2010). Supply chain problems, such as unexpected changes in the flow of materials due to delays or disruptions, result from risks (Chopra and Sodhi, 2004). The presence of risk in supply chains is not a novel phenomenon, as "doing business requires the acceptance of some level of risk within organizations" (Olson and Wu, 2010). No supply chain can be risk-free (Tummala and Schoenherr, 2011) since risk results from uncertain events that prevent the supply chain from achieving its performance aims (Heckmann *et al.*, 2015). Moreover, preventing an undesirable/desirable event from occurring is impossible. Disruptions such as crises and catastrophes have led to organizations assessing "how vulnerable global supply chains" can be (Wieland and Wallenburg, 2012). Juttner *et al.* (2003) defined supply chain risk as "the possibility and effect of mismatch between supply and demand." Manuj and Mentzer (2008) described supply chain risk as an "expected outcome from an uncertain event. It is also defined as "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" (Ho *et al.*, 2015). In disaster relief, logistics and supply chain activities take place in uncertain and dynamic environments, and relief organizations encounter diverse forms of risk when transporting, storing and delivering relief supplies. These include unpredictable demand (such as the time, location and amount of critical supplies required), supply uncertainty, inadequate or nonexistent infrastructures, volatile political issues, policy issues, limited or insufficient information and socioeconomic and financial issues are likely to arise (L'hermitte *et al.*, 2016; Day, 2014; Overstreet *et al.*, 2011). Baharmand *et al.* (2017) discussed that risks develop due to several challenges, including wrong assessment and misjudgments based on uncertainties (supply, demand, fleets, locations, etc.), complex operating conditions in the field, the effect of the disaster on local labor and infrastructure and structural differences between responders, especially emergency relief organizations. Thomas and Kopczak (2005) stated that some challenges relief organizations face while delivering aid include a shortage of expert logisticians, limited collaboration and coordination, manual supply chain processes and inadequate assessments and planning. According to L'hermitte *et al.* (2016), relief organizations are subjected to several risks and uncertainties during emergency response operations including unpredictable demand, uncertainty in supply, inadequate or damaged infrastructure, unstable political settings, security problem and partial or no information. Balcik *et al.* (2010) mentioned that the number of diverse actors, donor expectations and funding structures, uncertainty about the occurrence of a disaster, resource scarcity and oversupply of critical aid challenges the emergency supply chain.

Considering that the effects of risks in emergency supply chains can impede the effectiveness of the emergency supply chain, potentially resulting in loss of lives, management of such risks is critical. The burden rests on decision-makers and stakeholders to adopt new approaches toward operations (Stefanovic *et al.*, 2009). Before stakeholders and decision-makers can develop and deploy means of eliminating or reducing risks in the emergency supply chains, emergency managers must attain knowledge and insights into various forms of risk and the factors that drive them. Too much can go wrong in the emergency supply chain during disaster response operations, and information on what can go wrong in the emergency supply chain is scattered across a few studies. Therefore, the general supply chain literature provides relevant insights and a well-defined interpretation of the demanding and restricting factors that can negatively impact logistics and supply chain operations. From scattered evidence in the literature, 45 risk factors prevalent in emergency supply chains are identified. Table 1 presents the specific risk factors retrieved from scattered literature.

Emergency management cannot improve its operational performance; rather, it must break down the management process into relevant pieces and aspects to assist the entire management activity. Therefore, managers and decision-makers should concentrate on the most important aspects of emergency management. In the commercial sector, several studies have presented diverse classifications of supply chain risks. For example, Manuj *et al.* (2007) discussed that these adverse events could be grouped into supply, process, demand and security risks. Christopher and Peck (2004) categorized it

Table 1 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	Stauffer *et al.* (2016), Jahre *et al.* (2016)
High variation in demand	Overstreet *et al.* (2011), Kovács and Tatham (2009), Chakravarty (2014), Van Wassenhove (2006), Pedraza-Martinez and Van Wassenhove (2012), De la Torre *et al.* (2012)
High inventory holding cost	Kovács and Spens (2009), Balcik and Beamon (2008)
Limited life-cycle of relief supplies	Kovács and Sigala (2021)
Poor supplier flexibility	Altay (2008), John *et al.* (2019)
Error in supplier fulfillment	Holguín-Veras *et al.* (2014)
Inadequate supplier capacity	Baharmand *et al.* (2017)
Absence of competitive pricing	Kovács and Sigala (2021), Jahre (2017)
Poor level of supplier responsiveness	Jahre and Heigh (2008), Altay (2008)
Variation in transit time	Barbarosolu *et al.* (2002), Baharmand *et al.* (2017), Oloruntoba and Gray (2006)
Noncompliance with supply contracts	John and Ramesh (2016), Balcik *et al.* (2010)
Purchasing key supplies from a single source	Kovács and Sigala (2021), Kovács and Spens (2009), Baldini *et al.* (2012)
Exchange rate fluctuations	Jahre (2017), John and Ramesh (2016), Baldini *et al.* (2012), Balcik *et al.* (2010), Fritz (2005)
Long-term vs short-term contracts	L'hermitte and Nair (2020), Dubey *et al.* (2019), Olarewaju *et al.* (2020)
Defective or damaged relief supplies	Holguín-Veras *et al.* (2014), Kovács and Spens (2009), Holguín-Veras *et al.* (2012)
Wrong or unsolicited relief supplies	Kovács and Spens (2007), Kovács and Spens (2009)
Counterfeit relief supplies	Holguín-Veras *et al.* (2012), Kovács and Spens (2009)
Damaged transport infrastructure	Fritz (2005), Kovács and Spens (2009), Kovács and Spens (2007), Barbarosoğlu and Arda (2004)
Absence of alternative transport modes	Kovács and Sigala (2021), Fritz (2005)
Excessive handling of relief supplies during mode changes	Kovács and Sigala (2021), Barbasoglu *et al.* (2002), Kovács and Spens (2009)
Ineffective last-mile delivery	Oloruntoba and Kovács (2015), Van Wassenhove (2006)
Theft of relief supplies and resources	Baldini *et al.* (2012), Pettit and Beresford (2006)
Damaged warehousing facilities	Fritz (2005), Kovács and Spens (2009), Kunz and Reiner (2012), Baldini *et al.* (2012), Altay *et al.* (2009)
Transit time from facility location to relief sites	Dubey *et al.* (2019), Tayal and Singh (2019), Fritz (2005)
Limited holding capacity of facilities	Baharmand *et al.* (2017), Fritz (2005), Maghsoudi and Moshtari (2021)
Poor I.T infrastructure	Schulz and Blecken (2010), Kabra and Ramesh (2015)
Absence of transparency in information dissemination	Altay and Pal (2014), Kovács and Spens (2007)
Presence of delays during information transmission	Kumar and Harvey (2013), Kovács and Spens (2007), Pathriage *et al.* (2012), Altay (2008)
Presence of the wrong media	Holguín-Veras *et al.* (2014), Maghsoudi and Moshtari (2017)
Donor restriction on relief supplies	Kovács and Spens (2009), Oloruntoba and Gray (2009)
Poor funding transparency	Thomas and Kopczak (2005), Dubey *et al.* (2019)
Limited experienced personnel	Kovács *et al.* (2012), Overstreet *et al.* (2011), Sandwell (2011), Pettit and Beresford (2009), Van Wassenhove (2006)
Mistrust among stakeholders	Balcik *et al.* (2010), McEntire (2002), Moshtari and Gonçalves (2011), Kovács and Tatham (2010)
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	Long and Wood (2005), Perry (2007), Jahre (2017)
Fire incidents	Jahre (2017)
War and terrorism	Listou, (2008), McLachlin *et al.* (2009), Jahre and Jensen (2010), Budass (2014), Jahre (2017)
Poor communication	Altay *et al.* (2009), Altay *et al.* (2019), Balcik *et al.* (2010)
Presence of cultural differences	Jahre (2017), Kunz and Reiner (2012), Maon *et al.* (2009)
Corrupt practices	Altay (2008), Kunz and Reiner (2012)
Sexual and gender abuses	Kunz and Reiner (2012), Kovács and Spens (2009), Oloruntoba (2005), Maon *et al.* (2009)
Stakeholders poor judgment	Ergun *et al.* (2009), Yadav and Barve (2016)
Absence of legislative and supportive rules that influence relief operations	Kunz and Gold (2015), Day *et al.* (2012), L'hermitte *et al.* (2014), Maon *et al.* (2009), Oloruntoba (2005), Maghsoudi and Moshtari (2021)
Sanctions and constraints that hinder stakeholder collaboration	Sandwell (2011), Maon *et al.* (2009), Oloruntoba (2005), Altay *et al.* (2009), Kunz and Reiner (2012)

into three: internal to the organization, external to the organization but internal to the supply network and external to the supply network. Likewise, Pfohl *et al.* (2011) discussed that supply chain risks could be classified as risks within the focal company related to suppliers and those external to the supply chain. Balcik and Beamon (2008) presented demand, supply and process risks in the emergency supply chain context. Chari *et al.* (2019) categorized supply chains into economic, social, environmental, infrastructural and political risks. Jahre (2017) grouped risk into abnormal and normal risks and discussed that abnormal risks, such as natural and man-made disasters, may influence normal risks: demand, supply and infrastructural risks. In addition to risks and uncertainties associated with demand, supply and during the process of providing aid, relief organizations also contend with complicated contextual elements (L'hermitte *et al.*, 2014). L'hermitte *et al.* (2015) discussed that there is no defined classification of risks and uncertainties that relief organizations encounter along the emergency supply chain. Therefore, this study initially classifies the identified risk factors. Based on meaning and similarities (Mangla *et al.*, 2014), the specific risk factors are grouped into two main categories: internal and external risk factors, five subcategories and 13 risk types. Demand risks include forecast risk and inventory risk; supply risks cover procurement risk, supplier risk and quality risk; process risks encompass transportation risk, warehousing risk and systems risk; control risks consist of decision-maker risk and strategic risk; and finally, environmental risks contain disruption risk, social risk and political risk.

2.3 Research gap

The numerous challenging issues linked to disaster relief mandate an emerging need to develop new methodologies or variants of old ones, such as emergency logistics and supply chains. Similarly, Tatham *et al.* (2009) mentioned several contributions that research can make to emergency supply chains, including the provision of objective evidence, methodology development, knowledge transfer from the commercial sector, etc. Conclusions can be drawn that more research is mandated in different areas of the emergency supply chain, particularly in risk management and must consider the distinct features of its operational environment. Supporting this assertion, disasters are unique and require distinct emergency supply chains for immediate response operations. Several factors, such as disaster type, impact and location, influence specific risk factors likely to disrupt emergency supply chains. However, knowledge of the global supply chain risks in this context is critical. L'hermitte *et al.* (2016) discussed that the volume of research on risk management in the emergency supply chain is limited (Larson, 2011), and clear categories of risks and uncertainties encountered along the emergency supply chains remain to be empirically established and tested (L'hermitte *et al.*, 2015). No study has comprehensively and empirically investigated the specific risk factors prevalent in the emergency supply chain. This research attempts to fill these gaps by developing a two-phase methodology (Mangla *et al.*, 2014) to meet the following objectives empirically identify and classify the specific risk factors that are likely to disrupt the emergency supply chains globally. Evaluate and prioritize these risk factors to capture the most significant.

3. Methodology

This section proposes a detailed methodology for managing risk in emergency supply chains. The research involved various crucial stages. A fuzzy AHP has been used to explore and prioritize risk factors likely to disrupt the effective functioning of the emergency supply chain. The proposed methodology consists of three phases (Patil and Kant, 2014). First, a comprehensive and rigorous literature review is conducted to deepen the understanding of the topic and identify the risk factors that can negatively affect the emergency supply chain. In the second phase, a pilot study is conducted using a five-point Likert scale questionnaire. Experts in disaster relief, emergency supply chain and risk management were contacted and asked to validate the likelihood of identified risk factors. Finally, after finalizing the most likely risk factors associated with the emergency supply, a pairwise comparison questionnaire was developed and distributed to experts to give preference to the finalized identified risk factors from the results of the pilot study. The weights and priorities of each factor were obtained using the fuzzy AHP. Figure 2 presents the research design.

3.1 Fuzzy logic

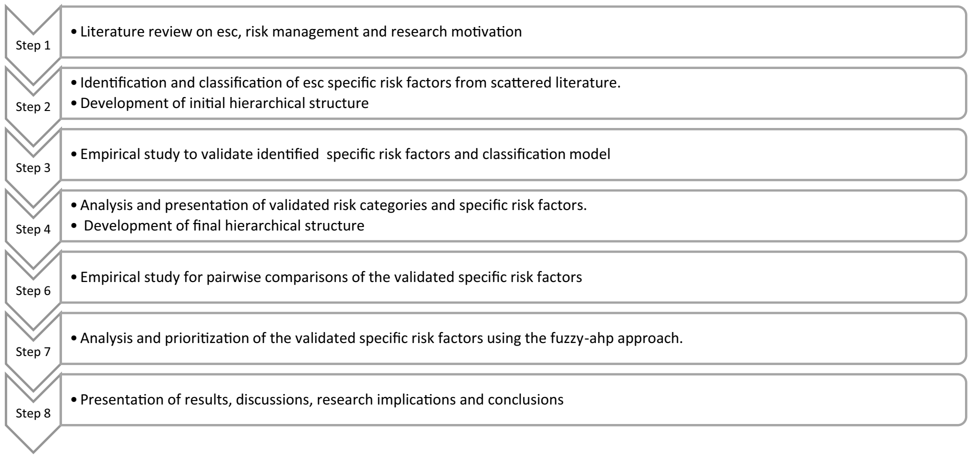
In many professional situations, experts are confronted with a set of alternatives they need to choose from, for example, when selecting a supplier or technology. This decision is intuitive when considering a single attribute or criterion since these experts can select the attribute with the highest relevance. When several criteria have varying degrees of importance, decision-making becomes complex and challenging for experts. Hence, formal methods are needed to ensure a structured means of decision-making. MCDM is suitable to meet the research goal, but since emergency supply chain activities are conducted in unstable and uncertain environments, integration of fuzzy set theory can improve the decision-making process. Fuzzy set theory is a mathematical approach developed by Zadeh (1965) to deal with uncertain, imprecise, vague and ambiguous information retrieved from computational perception. 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. 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. The fuzzy logic includes some important definitions:

- A fuzzy set $\tilde{A}$ is a subset of a universe of discourse X, which is a set of ordered pairs and is characterized by a membership function U_A (x) representing a mapping U_A: x → [0, 1]. The function of U_A (x) for the fuzzy set, A is called the membership value of x in A, which represents the degree of truth that x is an element of the fuzzy set A. It is assumed that $u_A(x)$ € $[0, 1]$, where U_A (x) = 1 reveals that x completely belongs to A, while U_A (x) = 0 indicates that x does not belong to the fuzzy set A:

$$\tilde{A} = \{ \ (\ x, \ U_A \ (x) \ ) \ \}, \ x \in X \tag{1}$$

where U_A (x) is the membership function and X = $\{x\}$ represents a collection of elements x:

Figure 2 Research design



1 A fuzzy number $\tilde{A}$, if it belongs to a triangular fuzzy number like Figure 1, it should satisfy the following properties:
- $U_A(x) = 0$, for all x € $(-\infty, 1)$;
- $U_A(x)$ = is strictly increasing on $[1, m]$;
- $U_A(x) = 1$, for $x = m$;
- $U_A(x)$ = is strictly decreasing on $[m, u]$; and
- $U_A(x) = 0$ for all x € (u, ∞);

2 Let $\tilde{A}$ be a triangular fuzzy number (l, m, u), and its membership function can be defined as:

$$U_A\ (x) = \begin{cases} \dfrac{x-l}{m-l} & l \le x \le m \\ \dfrac{u-x}{u-m} & m \le x \le u \\ 0 & otherwise \end{cases} \tag{2}$$

3 The α-cut of the fuzzy set $\tilde{A}$ of the universe of discourse, X is defined as:

$$A_\propto = \{\ x \text{ € } X,\ u_A\ (x) \ge \propto\ \} \text{ where } \alpha \text{ € } [0, 1] \tag{3}$$

4 Suppose $a = (a1, a2, a3)$ and $b = (b1, b2, b3)$ are two transformed into definite values (TFNs), the distance between them is calculated as:

$$d_v\ (\tilde{a}, \tilde{b}) = \sqrt{\frac{1}{3}\left[(a_1 - b_1)^2 + (a_2 - b_2)^2 + (a_3 - b_3)^2\right]} \tag{4}$$

5 If $\tilde{A}_1 = (l_1,\ m_1,\ u_1)$ and $\tilde{A}_2 = (l_2,\ m_2, u_2)$ are representing two fuzzy triangular numbers, then algebraic operations can be expressed as follows (Figure 3):

$$\tilde{A}_1\ (+)\ \tilde{A}_1 = (l_1,\ m_1,\ u_1)\ and\ \tilde{A}_2 = (l_2,\ m_2, u_2) = (l_1 + l_2),\ (m_1 + m_2) \text{ and } \tilde{A}_2 = (u_1 + u_2) \tag{5}$$

$$\tilde{A}_1\ (-)\ \tilde{A}_1 = (l_1,\ m_1,\ u_1)\ and\ \tilde{A}_2 = (l_2,\ m_2, u_2) = (l_1 - l_2),\ (m_1 - m_2) \text{ and } \tilde{A}_2 = (u_1 u_2) \tag{6}$$

$$\tilde{A}_1\ (\times)\ \tilde{A}_1 = (l_1,\ m_1,\ u_1)\ and\ \tilde{A}_2 = (l_2,\ m_2, u_2) = (l_1 l_2),\ (m_1 m_2) \text{ and } \tilde{A}_2 = (u_1 u_2) \tag{7}$$

$$\tilde{A}_1\ (/)\ \tilde{A}_1 = (l_1,\ m_1,\ u_1)\ and\ \tilde{A}_2 = (l_2,\ m_2, u_2) = (l_1/l_2),\ (m_1/m_2) \text{ and } \tilde{A}_2 = (u_1/u_2) \tag{8}$$

$$A\ (\times)\ \tilde{A}_1 = (\propto l_1,\ \propto m_1,\ \propto u_1)\ where\ \propto\ \ge\ 0 \tag{9}$$

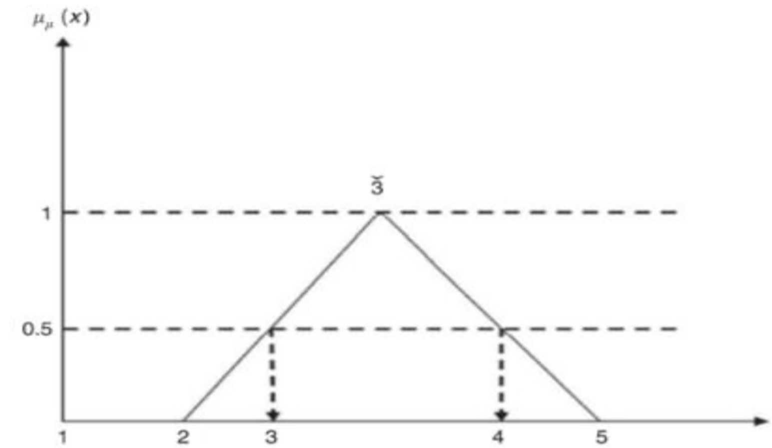
$$\tilde{A}_1^{-1} = (l_1,\ m_1,\ u_1)^{-1} = \left(\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1}\right) \tag{10}$$

3.2 Fuzzy analytical hierarchy process

The AHP is a general theory of measurement developed by Satty in 1980. 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 that reflects the relative strength of preferences and feelings. According to Vaidya 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 MCDM tools. The AHP solves multi-criteria (or attribute) decision-making 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. Although AHP is a celebrated method for MCDM problems, particularly when qualitative assessment is needed, it cannot process uncertain variables (Wang *et al.*, 2008). The pairwise comparison, the essence of AHP, introduces imprecision because it requires the judgments of experts. In practical cases, experts might not be able to assign exact numerical values to their preferences due to limited information or capability (Liu *et al.*, 2020; Xu and Liao, 2014). Confronting these uncertainties requires the application of some distinct methods, such as fuzzy set theory.

Fuzzy set theory is a mathematical approach developed by Zadeh (1965) to deal with uncertain, imprecise, vague and

Figure 3 α cut operation on a triangular fuzzy number



Note: $\alpha_{0.5}$ = (2,3,4) = [1.5,5]

ambiguous information retrieved from computational perception. 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. 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. Therefore, combining fuzzy set theory and AHP will extend Satty's AHP and reduce vagueness and uncertainty in decision-making. An explanation of the fuzzy-AHP method is presented as follows:

- Structure problem hierarchy

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, subcriteria and sub-sub criteria.

- Construct a fuzzy pairwise comparison matrix

Traditionally, AHP uses the nine-point Likert scale for pairwise comparison of attributes which introduces uncertainty and bias to expert judgment. The fuzzy-AHP uses linguistic preference to eliminate uncertainty and bias. Table 2 presents the linguistic terms adopted in this research to inform the degree of relevance of an attribute over another (pair-wise comparison). Here, linguistic terms are TFNs.

- Aggregation for group decisions and weight calculation

Each pairwise comparison matrix represents the judgments of one expert. There is a need to aggregate the judgments to achieve a collective consensus of all experts. The traditional AHP encompasses two basic approaches for aggregating individual preferences into a group preference, including aggregation of individual judgments (AIJ) and aggregation of individual priorities. This is also applicable in the fuzzy AHP. Aggregation of individual judgment allows the development of the group judgment matrix from the individual judgment matrices. AIJ is most often performed using geometric 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 unanimity and homogeneity condition. Following the aggregation of expert judgments for a consensus decision, the weight of each attribute and subattribute is calculated. In this research, the extent analysis method proposed by Chang (1996) and widely accepted by several researchers due to its simplicity is adopted. The ideology behind the method is concerned with estimating the extent of an attribute's satisfaction toward the research goal.

4. Proposed fuzzy-analytical hierarchy process framework

A fuzzy-AHP framework consists of two phases and is presented in Figure 4. This framework is used for identifying and prioritizing the risk factors that can impede the normal activities of the emergency supply chain in disaster relief operations.

4.1 Phase 1. Identification of risk factors in emergency supply chains

The research will commence with a comprehensive literature review to identify the risk factors that can negatively influence the emergency supply chains and develop an initial risk taxonomic diagram that depicts a proposed risk classification model in this context. Information concerning risk management in emergency supply chains is scant and scattered around in pertinent studies. Subsequently, several experts with vast experience in the field and from distinct geographical regions will validate the identified risk factors and uncover other ignored factors. In addition, the risk taxonomic diagram is assessed. Upon completion, this research will present an appropriate risk taxonomic diagram.

4.2 Phase 2. Weight calculation and prioritization of risk factors in an emergency supply chain using fuzzy analytical hierarchy process

Following the development of the decision hierarchy, this research will adopt the fuzzy AHP to assess and calculate the weights of the risk factors in the emergency supply chain. This assessment will involve a pairwise comparison between the respective risk factors. Experts will use the scale presented in Table 2 to provide subjective inputs for the respective risk

Figure 4 Fuzzy-AHP-based research framework

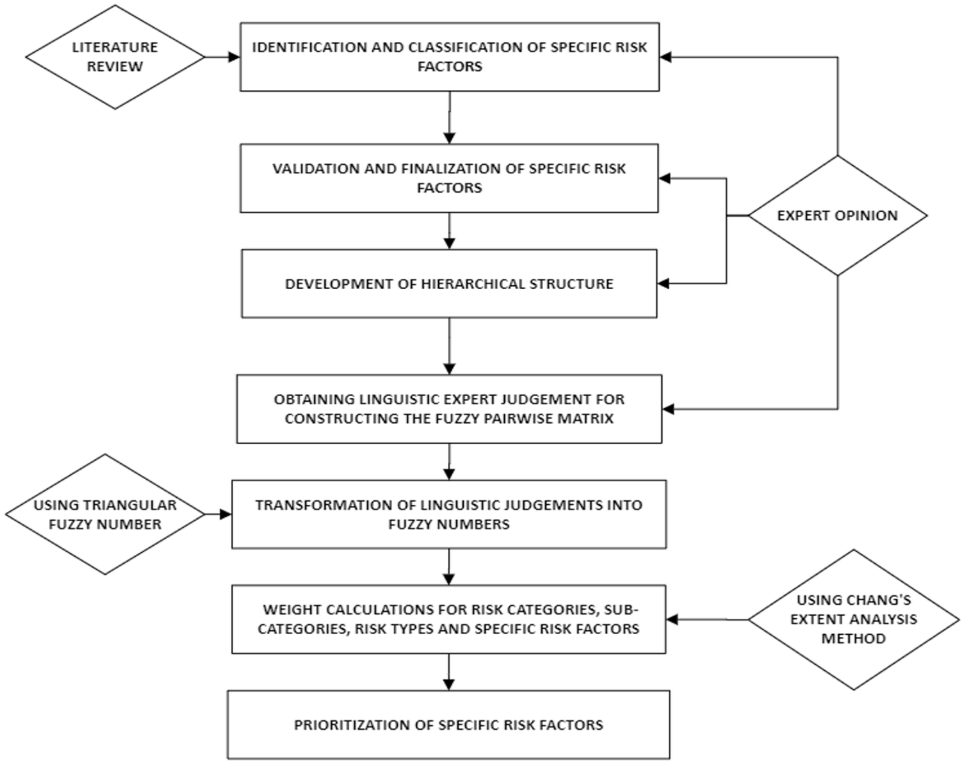


Table 2 Triangular fuzzy conversation scale

Linguistic scale	Triangular fuzzy conversation scale	Triangular fuzzy reciprocal scale
Equal importance	(1, 1, 1)	(1, 1, 1)
Weak importance	(1, 3/2, 2)	(1/2, 2/3, 1)
Strong importance	(3/2, 2, 5/2)	(2/5, 1/2, 2/3)
Very strong importance	(2, 5/2, 3)	(1/3, 2/5, 1/2)
Absolute strong importance	(5/2, 3, 7/2)	(2/7, 1/3, 2/5)

Sources: (Chang, 1996; Lee, 2010)

factors, and then the research will aggregate respective expert inputs to calculate the priority weight of each risk factor. Therefore, ranking the risk factors based on the weights.

5. Application of fuzzy-analytical hierarchy process framework

5.1 Case description

In the disaster context, relief organizations often conduct logistics and supply chain activities in highly volatile conditions, and when transporting, storing and delivering critical items, they face multiple risks and uncertainties. Studies on risk management in emergency supply chains are limited (Larson, 2011), and specifically, clear categories of risks and uncertainties encountered along the emergency supply chains remain to be empirically established and tested (L'hermitte *et al.*, 2015). Managing supply chain risks includes identifying risk events, assessing the likelihood and severity of these events and establishing preventive, corrective actions (Atkinson, 2006). Risk management is especially important in an emergency supply chain since an interruption can cause or at least contribute to an emergency crisis. Moreover, emergency relief efforts often face multiple risk events simultaneously, including operational sources of risk, "the interruption" that caused the crisis and various political and infrastructural issues (McLachlin *et al.*, 2009). Hence, identifying the nature of risk factors that impede the optimal functionality of the emergency supply chain is crucial and relevant. In addition, establishing the frequency of occurrence and the potential impacts of these risk factors on logistics activities is necessary.

5.2 Data collection

In this research, data collection covers two phases; first, the validation of the identified risk factors that can disrupt the effective functioning of the emergency supply chain, and second, an analysis of the validated risk to establish the respective priorities among them. The research used several criteria for expert selection. First, the expert must be a middle to senior-level professional with academic or industrial experience of more than ten years. Nineteen experts provided data for the first and second phases of data collection, respectively. The authors ensured that all experts have robust expertise in various managerial functions within the industry, i.e. procurement, strategic planning, risk management, coordination, etc. Before the commencement of the research, the experts were briefed on the goal and objectives of the research. The experts were also informed of how the data collected will be used. A questionnaire was developed and e-mailed to the respective experts for completion.

5.2.1 Step 1: identification of risk factors in the context of ESC

Following a rigorous and comprehensive literature review, the research identified 45 specific risk factors grouped into two main categories, five subcategories and 13 risk types to develop an initial hierarchy risk taxonomic diagram. Next, the research designed an online questionnaire survey to validate the identified risk factors and ensure the risk taxonomic diagram was appropriate for the context. Through an online link to access the survey, experts were required to indicate the likelihood of each specific risk factor based on a five-point Likert scale. Appendix 1-2 presents a sample of the questionnaire used. The survey remained open for three months. Twenty-two fully completed questionnaires were returned; however, only 19 met all-inclusivity criteria. Expert details and information are presented in Table 3. Based on the data collection, several specific risk factors were eliminated from the study, and the risk classification was modified. The experts considered only 28 specific risk factors as important. Two subcategories were eliminated: process and control risk, and the research introduced infrastructural risk. The risk types were reduced to eleven following the elimination of "decision-maker risk" and "strategic risk" and the specific risk factors.

5.2.2 Step 2: ranking the risk factors using fuzzy-analytical hierarchy process

In this step, the identified and selected risk categories, types and specific factors were analyzed to determine their priorities. Another round of data was collected from experts to inform this decision through a pairwise comparison questionnaire. Table 4 presents the expert's profile. This questionnaire involves human subjectivity and the inherent uncertainty in the process. Thus, the fuzzy-AHP methodology is adopted, which involves the introduction of linguistic terms to provide flexibility for the experts making judgments. This methodology will reduce the bias, vagueness and uncertainty present in the conventional AHP methodology that requires expertise to suggest specific values in a pairwise comparison. A sample of the questionnaire is presented in Appendix 3.

5.3 Development of the final hierarchical structure

Based on the initial phase of data collection that involved the consultation of 19 experts in both academic and industrial fields, a final hierarchical structure was formed (see Figure 5). The final hierarchical structures cover five levels; Level 1 is the goal of analyzing risks in the emergency supply chain. Levels 2 and 3 encompass the two main categories and four subcategories, respectively. The 11 risk types present at Levels 4 and 5 consist of the 28 specific risk factors likely to disrupt the effective functioning of the emergency supply chain.

5.4 Determining the weights of the risk factors

In this paper, 19 experts were presented with a fuzzy linguistic scale to make informed judgments concerning relative importance. As Saaty (2001) noted, just a small sampling size is needed provided the data obtained are taken from experienced experts; hence, the number of replies was regarded suitable for this study. This is because experts are more likely to hold

Table 3 Experts' profile for risk identification

Expert	Organization	Work experience	Country of operation	Job title
Expert 1	Relief organization	6–10 years	Global	Operations Director
Expert 2	Academic	11–15 years	UK and France	Professor
Expert 3	Academic	>20 years	USA	Professor
Expert 4	Other	>20 years	Global	Disaster Response and Recovery Adviser
Expert 5	Government	11–15 years	UK	Emergency Response Project Manager
Expert 6	Academic	>20 years	Australia	Professor
Expert 7	Nongovernmental organization	>20 years	Global	Partner Portfolio Manager
Expert 8	Academic	>20 years	Thailand	Asst. Professor
Expert 9	Nongovernmental organization	11–15 years	Global	Emergency Response Director
Expert 10	Nongovernmental organization	>20 years	Thailand	Supply Chain Specialist
Expert 11	Nongovernmental organization	11–15 years	Singapore	Emergency Logistics Expert
Expert 12	Other	>20 years	Global	Retired Humanitarian leader
Expert 13	Other	>20 years	Australia	Disaster Relief Team Manager
Expert 14	Nongovernmental organization	6–10 years	Nigeria	Humanitarian Affairs Officer Monitoring and Reporting
Expert 15	Academic	>20 years	United Kingdom	Associate Professor
Expert 16	Nongovernmental organization	6–10 years	South Sudan	Head of Programme Support
Expert 17	Nongovernmental organization	16–20 years	Mexico	Regional Logistics Manager
Expert 18	Academic	11–15 years	Finland	Professor
Expert 19	Nongovernmental organization	11–15 years	DKI JAKARTA	Senior Logistics Officer

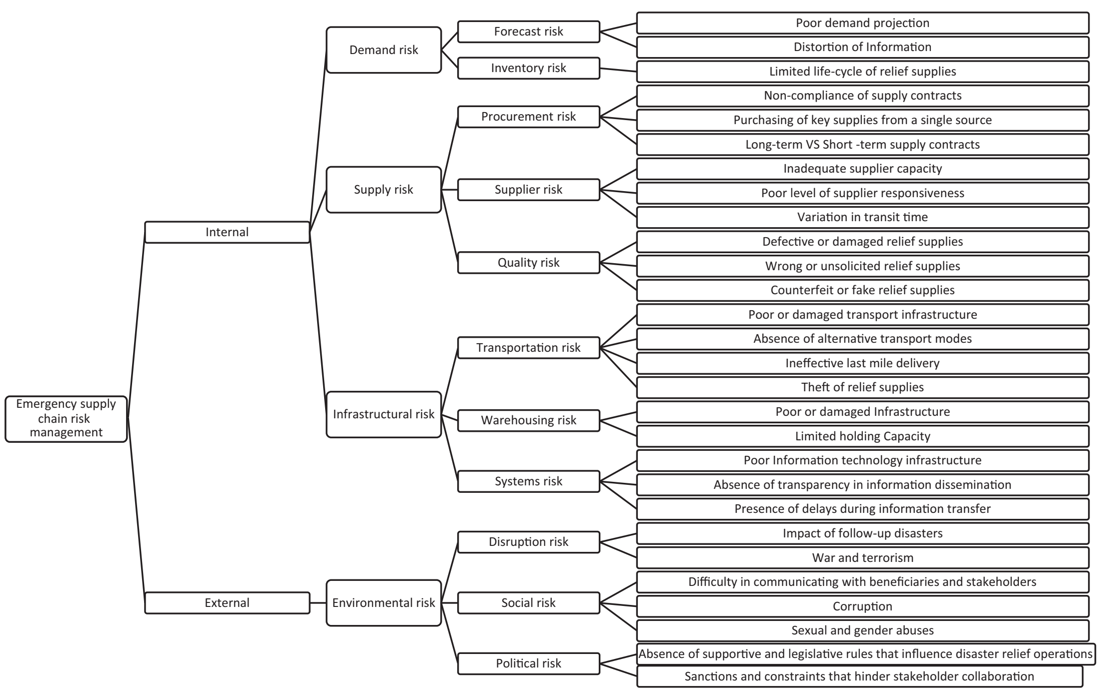
Source: Author

Table 4 Experts' profile for risk evaluation

Experts	Type of organization	Job title	Years of experience
1	Nongovernmental organization	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	Nongovernmental organization	Project Coordinator	6–10 years
7	Academic	Professor	20+ years
8	Nongovernmental organization	Operations Manager	16–19 years
9	Nongovernmental organization	Supply Chain Specialist	11–15 years
10	Other	Logistics Associate	16–19 years
11	Relief organization	Supply Chain Manager	20+ years
12	Nongovernmental organization	Country Director	20+ years
13	Nongovernmental organization	Country Director	20+ years
14	Nongovernmental organization	Director Public Health	16–19 years
15	Academic	Professor	20+ years
16	Other	Supply Chain Specialist	20+ years
17	Nongovernmental organization	Regional Emergencies Supply Chain Officer	11–15 years
18	Nongovernmental organization	Regional Supply Chain Manager	11–15 years
19	Nongovernmental organization	Emergency Logistics Officer	6–10 years

Source: Author

Figure 5 Risk hierarchical structure



similar opinions, reducing the need for a massive data set. The fuzzy linguistic scale includes linguistic expressions, such as equally important, weakly more important, moderately more important, strongly more important and absolutely more important, to compare the various risk categories, types and factors for the effective functioning of the emergency supply chain. The arithmetic mean of these values is computed to obtain the aggregated pairwise comparison matrixes. Table 5 presents the aggregated pairwise comparison matrix of supply risk for brevity.

After examining all aspects, the research adopted Chang's Extent Analysis method to calculate the respective weights of risk categories, subcategories, types and specific risk factors, which are given in Table 6. These respective weights support

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Table 5 Aggregated pairwise comparison concerning supply risk

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

Source: Fuzzy-AHP analysis

experts in prioritizing the respective categories, subcategories, types and risk factors that require imminent attention to guarantee the effective functionality of the emergency supply chain so that the vulnerable can receive the required assistance at the right time.

6. Results and discussions

6.1 Research results and managerial applications

Determining the most important risk factor that will most likely impede the smooth operation of the emergency supply chain can be challenging but using the fuzzy-AHP methodology to prioritize the risk factors will ensure the process is comprehensive and systematic. Adopting the fuzzy AHP will improve risk management in the emergency supply chain, enhancing its effectiveness and efficiency in disaster relief operations. Risk sources associated with the emergency supply chain are categorized into two main categories; internal and external risk; four subcategories; demand, supply, infrastructural and environmental risks; 11 risk types and 28 specific risk factors.

Concerning 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 result 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, myriad actors differing in local presence, size, mandate and structure are present. These differences can affect response times, delimit operational possibilities and hinder collaboration since these actors are not familiar with or have mere 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 subcategory of external risk. These adverse events are beyond the control of organizations. 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 subcategories of risk make up 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 among other subcategories 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 organization. This subcategory concerns the risk of an organization's 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 nonexistent without these supplies. Without critical supplies, no assistance can be provided for the vulnerable population in dire need. 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 risk is associated with an organization experiencing demand that it has not anticipated and provisioned for through its chain to satisfy 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 or insufficient infrastructure is considered a critical and fundamental challenge of any immediate response operation (Kovács and Spens, 2009; Chari *et al.*, 2019). This result suggests that stakeholders need to put targeted endeavors to lessen the consequences of this manner of risk and its associated concerns to the effectiveness and efficiency of the emergency supply chain. The difference between these results is minimal, reflecting all risk factors' importance.

6.1.1 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 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 result will ensure a better strategic partnership and enables the emergency supply chain to achieve its objectives. The supplier risk type consists of three specific factors: inadequate supplier capacity, poor 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 can adapt swiftly to changes in demand, particularly in delivery, volume and modification (Chirra and Kumar, 2018). Therefore, stakeholders are advised to choose suppliers that

Table 6 Ranking of the specific factors in the emergency supply chain

Main category	Main category weight	Subcategory	Subcategory ratio weight	Risk type	Risk type ratio weight	Specific risk factors	Risk factor ratio weight	Final weight	Ra nk
Internal	0.502	Demand	0.332	Forecast	0.494	Poor demand projection	0.507	0.041742332	9
						Distortion of information	0.493	0.040589684	10
				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
						Variation in transit time	0.31	0.01798407	19
		Supply	0.346	Procurement	0.333	Noncompliance of supply contracts	0.341	0.019723248	13
						Purchasing key supplies from single source	0.334	0.019318372	16
						Long-term vs short-term contracts	0.325	0.018797817	22
				Quality	0.332	Defective or damaged relief supplies	0.347	0.020010013	14
						Wrong or unsolicited relief supplies	0.329	0.01897203	18
						Counterfeit relief supplies	0.324	0.018683701	20
				Transportation	0.348	Damaged transport infrastructure	0.253	0.014231784	25
						Absence of alternative transport modes	0.251	0.01411928	26
						Ineffective last mile delivery	0.251	0.01411928	26
						Theft of relief supplies and resources	0.245	0.013781767	27
		Infrastructural	0.322	Warehousing	0.323	Damaged warehousing facilities	0.515	0.026888671	11
						Limited holding capacity of facilities	0.485	0.025322341	
				Systems	0.328	Poor I.T infrastructure	0.331	0.017549366	12
						Absence of transparency in information dissemination	0.347	0.018397674	23
						Presence of delays during information transmission	0.321	0.017019173	21
									24
				Disruption	0.354	Impact of follow-up disasters	0.486	0.085677912	3
						War and terrorism	0.514	0.090614088	1
External	0.498	Environmental	1	Social	0.325	Poor communication	0.337	0.05454345	6
						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

Source: Fuzzy-AHP analysis

can appropriately meet the vast ever-changing demands of beneficiaries and incorporate multiple suppliers into the network to satisfy these diverse demands (Olanrewaju *et al.*, 2020).

Quality risks include defective or damaged relief supplies, wrong or unsolicited and counterfeit relief supplies. Defective or damaged relief supplies emerged as the most important risk factor, with a weightage 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 weightage 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 recommends quality and standard specifications for developing 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 noncompliance with supply contracts, purchasing critical supplies from a single source and long-term vs short-term contracts. The analysis reveals that noncompliance with supply contracts is the most significant risk factor, weighing 34.1% of 0.332. Stakeholders and relief actors purchasing key supplies from a single source is this group's next most important risk factor, with a weightage of 33.4% of 0.332. Long-term vs short-term contracts come third, weighing 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 providing relief supplies. For example, the contracts might not be initiated due to high expenses related to the nonusage of critical supplies committed in contracts. Thus, stakeholders in the emergency supply chain are usually advised to carefully examine procurement contracts before entering one (Olanrewaju *et al.*, 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 reemphasized the need 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 achieve the supply chain objectives (Zhang *et al.*, 2019).

6.1.2 Demand risks

Next in line is demand risk. This subcategory includes two risk types: forecast and inventory risks. In this group, inventory risk comes first and attains the highest priority with a weight 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. The 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 a high chance of critical supplies being held for long periods before a disaster strikes and can be distributed to the affected population. Some of these supplies may have expired or are 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 subcategory with a weight of 49.4% of 0.332 and receive the lowest priority. This type of risk encompasses three specific risk factors: poor demand projection and distortion of information. Poor demand projection is the risk factor, with the highest weight 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 an 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 critical needs of the vulnerable population.

6.1.3 Infrastructural risks

The infrastructural risks include transportation risks, warehousing risks and systems risks. From the analysis, transportation risks have the highest priority, with a weightage of 34.8% of 0.322. Systems and warehousing risks follow, respectively, weighing 32.8% and 32.3%. These results indicate that transportation is more significant and challenging in any disaster relief operation (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 depends on transportation-related infrastructure, which is often destroyed (Balcik *et al.*, 2010). Thus, relief organizations are urged to develop advanced transportation and logistics networks to provide 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 weighing 25.3% of 0.3489 ranks as the most significant in this group. Absence of alternative transport modes and ineffective last mile delivery comes 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 abstract the best means of transport or resources needed to mobilize supplies from Point A to Point B. In addition, relief organizations 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 using a variety of means of transport including land, air or water to deliver these supplies from 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 weighing 51.5% of 0.323 is ranked as the most important risk factor, and limited holding capacities come next with a weightage 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 disaster frequently occurs. However, relief organizations struggle to locate warehouses out of the reach of the demolishing impact of the disaster while at the same time being 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 must 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 organizations are advised to develop their capabilities and capacities, including expanding the current warehouse networks (Azmat and Kummer, 2020).

System risks include poor information technology (IT) infrastructure, lack of transparency in information dissemination and delays during information transmission. From the analysis, the absence of transparency in information dissemination, weighing 34.7%, is ranked as the most important in the group. Next in line is poor IT infrastructure, weighing 33.1% and delays during information transmission (32.1%). In complex environments like disaster relief operations, information sharing among 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 relief operations (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 organizations with 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 UN developed a system to improve coordination between humanitarian organizations, attempting to facilitate information exchange, improve coordination and build capacity (Kovács and Spens, 2007). Therefore, relief organizations are advised to make available and properly use 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).

6.1.4 Environmental risk

Environmental risk comprises disruption risk, social risk and political risks. Disruption risk is ranked as the most significant, weighing 35.4%. Social risks rank second, weighing 32.5% and political risk is the least important in this group, with a weight 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 organizations must develop supply chain strategies under 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 use 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 weighing 33.7%, is this group's most important risk factor. Next in line are corrupt practices and sex and gender abuses, weighing 33.3% and 33%, respectively. This result informs the need for stakeholders to make concerted efforts toward effectively collaborating with other stakeholders and local communities. Integrating local groups in the decision-making and 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 weightage of 53.7% and sanctions and constraints that hinder collaboration are the least important factor, with a weightage 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 ultimately improve collaboration. This improved collaboration will speed up certain activities, including needs assessment and distribution capacity.

6.2 Sensitivity analysis issues

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. Table 7 presents the results of the sensitivity analysis. In assessing the risk prevalent in the emergency supply chain, not all subcategories of risk were involved in the pairwise comparison process with other categories at the same level. For example, environmental risk is the only subcategory of the main category of external risk. Similarly, inventory risk type covers only one specific risk factor. Therefore, there may be concerns with this subcategory's larger weights and other associated risks. The fuzzy-AHP methodology in this research used subjective judgments from diverse experts to calculate respective weights and prioritize the specific risk factors. Hence, it is important to check the validity of the final ranking by altering the respective weights attained (Govindan *et al.*, 2014). Chang *et al.* (2007) noted that minor shifts in relative weights should result in major alterations in the final ranking. To illustrate the sensitivity analysis and for easy comprehension, the process will be conducted using specific risk factors. The process involves three steps. First, the weights are left unchanged. The second step involves multiplying a particular risk factor by the number of 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. The final step involves dividing a particular risk factor by the number of risk factors in its respective risk type. Results reveal small changes in weights; however, the analysis indicates that the top 10 risk factors remain the same, which justifies the robustness of the research model. An increase or decrease in weight reveals little changes or no considerable variation in risk results. Hence, this proves that the methodology is acceptable. Appendix 4 presents an illustrative example.

7. Research implications

The purpose of this study is relevant to the emergency relief and disaster management sector, and the findings are concerned with likely specific risk factors prevalent in the emergency

Table 7 Sensitivity analysis

Specific risk factors	Initial weight	Rank	Weight after multiplication	Rank	Weight after division	Rank
Poor demand projection	0.041742332	9	0.083484664	9	0.020871166	6
Distortion of information	0.040589684	10	0.081179368	10	0.020294842	7
Limited life-cycle of relief supplies	0.084331984	4	0.084331984	8	0.084331984	1
Inadequate supplier capacity	0.020652674	13	0.061958022	11	0.006884225	13
Poor level of supplier responsiveness	0.019376385	16	0.058129155	14	0.006458795	16
Variation in transit time	0.01798407	22	0.05395221	23	0.00599469	22
Noncompliance of supply contracts	0.019723248	15	0.059169743	13	0.006574416	15
Purchasing key supplies from single source	0.019318372	17	0.057955115	15	0.006439457	17
Long-term vs short-term contracts	0.018797817	19	0.05639345	19	0.006265939	19
Defective or damaged relief supplies	0.020010013	14	0.060030039	12	0.006670004	14
Wrong or unsolicited relief supplies	0.01897203	18	0.05691609	17	0.00632401	18
Counterfeit relief supplies	0.018683701	20	0.056051103	20	0.0062279	20
Damaged transport infrastructure	0.014231784	25	0.056927136	16	0.003557946	25
Absence of alternative transport modes	0.01411928	26	0.05647712	18	0.00352982	26
Ineffective last mile delivery	0.01411928	26	0.05647712	18	0.00352982	26
Theft of relief supplies and resources	0.013781767	27	0.055127068	22	0.003445442	27
Damaged warehousing facilities	0.026888671	11	0.053777342	24	0.013444336	11
Limited holding capacity of facilities	0.025322341	12	0.050644682	27	0.012661171	12
Poor I.T infrastructure	0.017549366	23	0.052648098	25	0.005849789	23
Absence of transparency in information dissemination	0.018397674	21	0.055193022	21	0.006132558	21
Presence of delays during information transmission	0.017019173	24	0.051057519	26	0.005673058	24
Impact of follow-up disasters	0.085677912	3	0.171355824	3	0.042838956	4
War and terrorism	0.090614088	1	0.181228176	1	0.045307044	2
Poor communication	0.05454345	6	0.16363035	4	0.01818115	8
Corrupt practices	0.05389605	7	0.16168815	5	0.01796535	9
Sexual and gender abuses	0.0534105	8	0.1602315	6	0.0178035	10
Absence of legislative and supportive rules that influence relief operations	0.085843746	2	0.171687492	2	0.042921873	3
Sanctions and constraints that hinder stakeholder collaboration	0.074014254	5	0.148028508	7	0.037007127	5

Source: Author

supply chains. This study identified and evaluated the likelihood and severity of diverse specific risk factors related to the emergency supply chain during disaster relief operations. The implications of this study are discussed below.

7.1 Theoretical implications

This study makes several theoretical contributions; first, through the identification and evaluation of risk factors in emergency supply chains, this study contributes to the theoretical understanding of disaster relief operations and emergency supply chains. Only by efficiently carrying out the tasks along the emergency supply chain can critical relief be provided for the vulnerable population. Although disaster relief operations rely heavily on emergency logistics and supply chain systems, these systems are not infallible because they are carried out in unsafe conditions and face a number of risks. One must be aware of the variables that can have a negative impact on disaster relief activities to make sense of the observed disparity. Consequently, this relevance of this study. Second, this study develops a system to classify the risks faced by emergency supply chains. There is too much room for error in the emergency supply chain; thus, it is essential to have a firm grasp on the many nodes throughout the chain from which possible risks may arise. Third, this research aimed to develop a fuzzy-AHP approach for ranking potential threats to emergency supply networks. It is important to note that the supply chain is vulnerable to a number of different risks, and that their effects vary greatly. It is crucial that you are aware of the most significant risk factor. In conclusion, this research gathered empirical data from practitioners through the use of high-level surveys. Just knowing what those risks are, in theory, won't cut it when it comes to managing the emergency supply chain. It is crucial to collect useful information from experts in the subject if the study is to produce reliable results.

7.2 Managerial implications

This research used empirical insights to validate the developed fuzzy-AHP methodology. Hence, several managerial implications are presented: The findings can be used by practitioners and policymakers to define the significant risk factors that are likely to disrupt the supply chain's activities while disaster relief operations are being carried out. Categorizing emergency supply chain-specific risk indicators will make it possible for practitioners and policymakers to immediately identify the part of the emergency supply chain that has been interrupted. This research can serve as a standard for practitioners and policymakers to use when developing and implementing emergency supply chain policies to reduce the risk variables identified in this study. The fuzzy-AHP methodology can be used by practitioners and policymakers from different sectors, including the health sector, to find the essential risk factors that are likely to disturb the regular running of their supply chain systems.

8. Conclusions

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 integral to disaster relief operations. The topic is gaining more attention and continues to be discussed in the literature. However, the volume of research on risk management in the emergency supply chain is limited, and clear categories of risks and uncertainties encountered along the emergency supply chain remain to be empirically determined and analyzed (L'hermitte *et al.*, 2015). In this respect, this research attempts to contribute to the literature by presenting a systematic framework for identifying and 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; they 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 global supply chain risks will minimize the disaster impact. Therefore, this study develops a comprehensive risk database for stakeholders in disaster relief operations. Experts provide subjective judgments and, most often, are uncertain when providing evaluation scores. Hence, performing the AHP technique in a fuzzy environment aided in reducing the bias. The literature review and inputs from experts yielded 28 specific risk factors grouped into 11 risk types, four risk subcategories and two main categories. This risk classification would certainly support stakeholders in understanding the theory of risk in emergency supply chains. The research used a fuzzy-AHP approach to derive the respective priorities. 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 critical risk factor that is likely to disrupt the effectiveness of the emergency supply chain. Though internal risk emerged as the most critical risk category, most of these 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 formulate 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 to 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.

8.1 Limitations and future research

Several specific risk factors can disrupt the emergency supply chain. A fuzzy AHP-based framework has been developed to analyze the 28 specific risk factors identified from the literature review and inputs from experts. The identified risk factors have been prioritized to support decision-making and enhance the effectiveness of the emergency supply chain. However, the authors acknowledge that the research contains several limitations. First, the research provides a general perspective and is not limited to a particular context. Another limitation concerns the experts that participated in the research; only a restricted number participated and the views of government officials are missing. In the future, since disasters are unique, studies can focus on a particular type of disaster and use this research as a starting point. Another research can adopt other

MCDM techniques like fuzzy ANP or Vikor under a fuzzy environment. The research provides a foundation for further studies focused on identifying and evaluating relevant supply chain strategies that can be used to mitigate emergency supply chain-specific risk factors.

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Appendix 1

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,

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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

(*continued*)

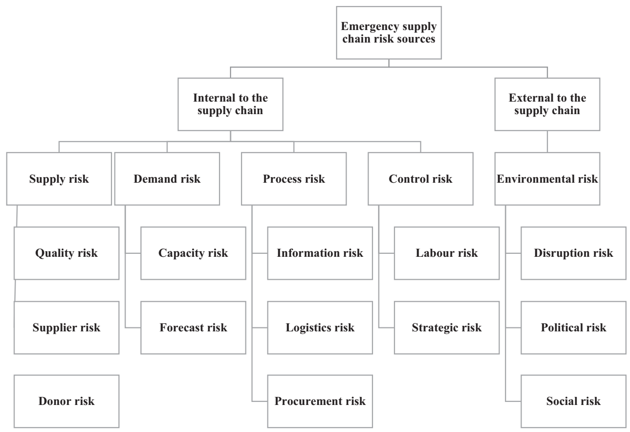
Questionnaire

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).



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

(*continued*)

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

(*continued*)

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

(*continued*)

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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

(*continued*)

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

(*continued*)

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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			

(*continued*)

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

…………………………………………………………………………

…………………………………………………………………………….

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………………………………………………………………………………………..

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

Appendix 2

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 ama 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 operation s.

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 whethe r 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 que stionnaire 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.

(*continued*)

Ethical Approval

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

Principal Researcher's Contact Details

Onyeka John Chukwuka

Department of Maritime and Mechanical Engineering

Faculty of Engineering and Technology

Room 2.29, James Parsons Building, Byrom Street, Liverpool, L3 3AF Liverpool John Moores University

Email: O. J. Chukwuka@2019.ljmu.ac.uk

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.u.k) 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…………………………………………………….

(*continued*)

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 r esources 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' repre sents '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 coversthe 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 increasein 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 fulfillment errors					
Wrong choice in supply partners					
Inadequate capacity from suppliers					
Lack of competitive pricing					
Poor level of responsiveness from suppliers					
Variation in transit time					

(*continued*)

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(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					

(*continued*)

(C) Warehousing risk: relates to the challenges faced by the supplyholding 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 behaviorof 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					

(*continued*)

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(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?

……
……
……
……
……

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

Appendix 3

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 transpo rt". 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 op erations. 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 o rganization.

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

(*continued*)

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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 favor one over another
Strong Importance (ST)	Experience and Judgement strongly favor one over another
Very strong Importance (Vs)	An activity is favoured very strongly over another
Absolute strong Importance (As)	The evidence favoring 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.

(*continued*)

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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 i mportance 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.

(*continued*)

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?

(*continued*)

	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

(*continued*)

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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 areexacerbated 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 4

Sensitivity Analysis

Thisresearch performed a sensitivity analysis to examine the effects of changes in the final ranking of the specific risk factors of the emergency supply chain. 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 external risk. Similarly, inventory risk covers only one specific risk factor. Therefore, there may be concerns in relation to the larger weights obtained by these respective forms of risk. Hence, it is important to check the validity of the final ranking by altering the respective weights attained (Govindan *et al.*, 2014) since 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. Chang *et al.,* (2007) noted that minor shifts in relative weights should result in major alterations in final ran king. To illustrate the sensitivity analysis and for easy comprehension, the process will be conducted us ing specific risk factors. The process involves three steps. Firstly, the weights are left unchanged. The second step involves multiplying a particular risk factor by the number of 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. The final step involves the division of a particular risk factor by the number of risk factors in its respective risk type. Results reveal small changes in weights; however, the analysis indicate that the top 10 risks fa ctors remain the same, which justifies the robustness of the research model. Increase or decrease in weights reveals little changes or no considerable variation in risk results. Hence, this proves that the methodology is acceptable . Table 7 presents the results of the sensitivity analysis.

Illustrative Example

For brevity and illustration, the authors will only present the sensitivity analysis of d isruption risk type. Its specific risk factors include “impact of follow-up disasters” and “war and terrorism”. The table below presents information of the first step of the sensitivity analysis.

Step 1: Weight Unchanged

Specific risk factors	Weight	Rank
Impact of follow-up disasters	0.085677912	3
War and terrorism	0.090614088	1

Step 2: Multiplication

Since disruption risk type covers two specific risk factors, each risk factor will be multiplied by 2. Similarly, each specific risk factor will be multiplied by the total number of risk factors in its respective risk type . The table below presents informa tion of this step.

Specific risk factors	Weight Unchanged	Rank	Weight After Multiplication	Rank
Impact of follow-up disasters	0.085677912	3	0.085677912*2=0.171355824	3
War and terrorism	0.090614088	1	0.090614088*2	1

After this step, the specific risk factors retained the same priorities similar to that of the first step ; Weights unchanged.

Step 3: Division

Since disruption risk type covers two specific risk factors, each risk factor will be divided into 2. Similarly, each validated specific risk factor will be divided by the total number of risk factors in its respective risk type . The table below illustrates the process of the final step

(*continued*)

Specific risk factors	Weight Unchanged	Rank	Weight After division	Rank
Impact of follow-up disasters	0.085677912	3	0.085677912/2 = 0.042838956	4
War and terrorism	0.090614088	1	0.090614088/2 = 0.45307044	2

After this step, the re appears to be a slight variation in the ranks of these specific factors . This result agrees with the postulations of Chang et al. (2007) that states that minor shifts in relative weights should result in major alterations in the final ranking. Hence, this validates the results and outcomes of the fuzzy -AHP analysis The table below presen ts a compilation of the processes and results of all the steps in the sensitivity analysis.

Specific risk factors	Weight Unchanged	Rank	Weight After Multiplication	Rank	Weight After division	Rank
Impact of follow-up disasters	0.085677912	3	0.085677912*2=0.171355824	3	0.085677912/2 = 0.042838956	4
War and terrorism	0.090614088	1	0.090614088*2	1	0.090614088/2 = 0.45307044	2

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