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Application of a Blockchain Enabled Model in Disaster Aids Supply Network Resilience

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APPLICATION OF A BLOCKCHAIN ENABLED MODEL IN DISASTER AIDS SUPPLY NETWORK RESILIENCE

by

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ABSTRACT

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The disaster area is a dynamic environment. The bottleneck in distributing the supplies may be from the damaged infrastructure or the unavailability of accurate information about the required amounts. The success of the disaster response network is based on collaboration, coordination, sovereignty, and equality in relief distribution. Therefore, a reliable dynamic communication system is required to facilitate the interactions, enhance the knowledge for the relief operation, prioritize, and coordinate the goods distribution. One of the promising innovative technologies is blockchain technology which enables transparent, secure, and real-time information exchange and automation through smart contracts. This study analyzes the application of blockchain technology on disaster management resilience. The influences of this most promising application on the disaster aid supply network resilience combined with the Internet of Things (IoT) and Dynamic Voltage Frequency Scaling (DVFS) algorithm are explored employing a network-based simulation. The theoretical analysis reveals an advancement in disaster-aids supply network strategies using smart contracts for collaborations. The simulation study indicates an enhance in resilience by improvement in collaboration and communication due to more time-efficient processing for disaster supply management. From the investigations, insights have been derived for researchers in the field and the managers interested in practical implementation.

This dissertation is dedicated to my family.

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CHAPTER 1

INTRODUCTION

At the heart of any disaster relief system is a disaster, an event that forms the focal point around which all the supply chain management activities are organized. Disaster relief supply chain management is defined as the system responsible for designing, deploying, and managing the required processes to deal with current and future disaster events, and managing the coordination and interaction of the processes with other competitive or complementary supply chains. Moreover, it is responsible for identifying, implementing, and monitoring the achievement of the desired outcomes which the processes are intended to achieve. Finally, it is responsible for evaluating, integrating, and coordinating the activities of the various parties that emerge to deal with the events (Day et al., 2012). Disaster supply chain management is characterized by large-scale operations, unusual constraints, irregular demand, and unreliable or non-existent supply and transportation information. The engineering of a distribution network is challenging because of the nature of the unknown (locations, type, spread, and magnitude of events, politics, and culture). The flow of resources in the phases of disaster relief are a) assessment b) deployment c) sustainment d) reconfiguration (Balcik & Beamon, 2008). Hence, a multidisciplinary research approach is required to address unique challenges of emergency logistics with a focus on a) large volume of supplies b) short time frame for response to prevent losses c) significant uncertainties about the needs and availabilities in the affected areas (Holguín-Veras et al., 2007). The disaster might still be evolving when the response operations start, which makes the emergency logistics time-sensitive operations. The lack of vital information about available infrastructure, supplies, and demands in the initial phase of a disaster may greatly complicate the dynamic environment. Equity and fairness among aid recipients are also other essential aspects that require more consideration (Cavdur et al., 2016; Tierney, 2012). To consider the need for dynamic, reliable, and transparent tracking of the supply chain, Betti et al. (2020) combined blockchain technology and the Internet of Things (IoT). The integration of physical internet and hyperconnected logistics provide more efficient supply management. On the other hand, time is a critical resource in disaster management. The information and demands need to be delivered to the affected area in the least possible time. This study proposes a model based on the combination of IoT and blockchain technology (Betti et al., 2020) and fast secure transaction mechanism ((Pérez-Solà et al., 2019)) to monitor the demand provision, response time, and enhance the efficiency of the disaster management.

Disaster management is a vast field. This study focuses only on the information and communication influences on disaster governance, and the scheme of the study is on the following aspects:

- Recent disaster illustrates the complexity, uncertainty, and ambiguity of disaster nature in social mobilization which requires resilient disaster governance.
- By analyzing the whole spectrum of disaster propagation and ecosystem, with the advent of blockchain technologies, IoT, and modeling and simulation are an opportunity to redefine the new architecture of emergency awareness governance.
- New techniques such as blockchain technology, IoT, and modeling and simulation, etc. are proved to be of support for dealing with biological, technological, and natural disasters.
- Decentralized distributed system (cloud computing, IoT, etc.) are hoping to be integrated tools for addressing the ecosystem of disaster governance.

PROBLEM STATEMENT

The dynamic nature of disasters increases the complexity level of response operations due to the lack of vital information about available infrastructure, supplies, and demands in the initial phase of the disaster. Glenn Richey Jr (2009) argues that the main cornerstones of a disaster supply chain are collaboration, communication, and contingency planning. Different parties pursue several distinct and, in some cases, conflicting strategic goals in contributing to disaster response. Hence, this study focuses on the communication and collaboration of the participants in disaster response by considering them in a distributed and decentralized network. For this purpose, the presented major challenges of disaster supply network and the proposed solutions in the literature were reviewed. As the results the core challenge of disaster supply network is categorized in four main groups to be address with blockchain technology (Apte & Petrovsky, 2016; Colicchia & Strozzi, 2012; Garcia & You, 2015; Kleindorfer & Saad, 2005):

- *Network Communication and Collaboration:* (1) Analog gaps between victims and relief teams, (2) Lack of information sharing among all involved participants, (3) Lack of an integrated global view concerning the dynamic of the disaster.
- *Transparency and Swift Trust:* (1) Lack of traceability of the flow of the process, (2) Limited visibility concerning how and where aids are sourced, made, and stored.
- *Data and Information Management*: (1) Lack of accurate and reliable data for analytics (3) Excessive redundancy and crosschecking (4) Various and independent data sources of different parties.
- *Humanitarian Aids*: (1) Lack of clear definitions of roles (2) Lack of coordination due to geographical dispersion (3) Lack of systemic governance.

The integration of supply chain management concepts into the disaster-aids complex system is not yet completely understood. The complexity stems from different factors such as uncertainty, time pressures, and the involvement of many stakeholders. An integrated framework can improve some of the challenges arising from such complexities. This study will be limited only to how communication and information flow challenges can be handled through the proposed framework.

RESEARCH PURPOSE

A disaster poses severe logistical challenges to emergency response due to the disruptions and the potential of creating chaos (Holguín-Veras et al., 2007). The critical difficulties responding to disasters are coordination, sovereignty, and equality in relief distribution. Hence, to design a reliable disaster supply aids system, knowledge about disaster supply chain operation and interaction, and methods to analyze and coordinate the flows of priority goods are required (Holguín-Veras et al., 2007). The research purposes for this study to develop an integrated blockchain empowered platform to make disaster aids management more resilient, effective, and efficient, and to tackle some of the limitations and challenges within the current disaster aids supply network.

Blockchain technology can provide an effective solution to disaster supply network resilience, due to its three foundational tenets stated by Liang et al. (2017). 1) data in a blockchain is stored in a shared, distributed, and fault-tolerant database that every participant in the network can have access to them. Blockchain technology provides the ability to nullify adversaries by harnessing the computational capabilities of the honest nodes and hence making information exchange resilient to manipulation. 2) Blockchain has a decentralized architecture that makes it robust against any failures and attacks. 3) Blockchains rely on public key infrastructure, which allows the contents to be encrypted in a way that is expensive to crack. With blockchain-enabled supply network architecture, all data operations are recorded transparently and permanently. Thus, trust can be established among all stakeholders.

The proposed model provides a useful decision support tool for disaster management. The blockchain approach can help with transparency and trust in information management. The modeling and simulation approach leads to appropriate data standards, understanding the system, and processes for developing and operating the platform for disaster aids supply management.

RESEARCH QUESTIONS

Research Question 1: How can the blockchain-enabled model enhance the disaster supply network performance?

Hypothesis 1: The level of real-time information sharing in the platform is positively related to the response time.

Hypothesis 2: The level of real-time information sharing in the platform is positively related to delay in demand provision.

Research Question 2: How can the blockchain-enabled model enhance the disaster supply network resilience?

Hypothesis 1: The blockchain-enabled model has a positive impact on disaster complexity management.

Hypothesis 2: The blockchain-enabled model has a positive impact on monitoring the disaster supply network.

SIGNIFICANCE

This study aims to accomplish two objectives. First, identify the disaster aids network management challenges and map the blockchain features to address the gaps. Second, develop an integrated blockchain-based model to make disaster aids management more resilient, efficient, and effective. For this purpose, two research questions and hypotheses are identified that are described in the next section.

To accomplish the goals, first a systematic literature review to identify the main challenges of current disaster supply networks, improvement opportunities in disaster supply network models, and the application of blockchain technology in the field is conducted. The results aim to provide the basis of solutions to some of the challenges in the area. Second, a model is developed using integrating blockchain technology and IoT with the support of a DVFS algorithm to measure the resilience of the proposed model by simulating the results and compare them to a valid applied model.

Some of the contributions of this study are a) disaster supply chain ontology of blockchain b) the relationship of blockchain technology with the existing interaction among institutions (smart contracts) c) contribute to the voluminous literature on the disaster supply chain. In addition, based on our knowledge, this is the first study that has applied the DFVS-algorithm integrated with blockchain technology to improve disaster management complexity and reduce the energy consumptions of implementing such methods.

The structure of the dissertation is as follows. Chapter Two describes the literature review with a focus on definitions, backgrounds, theories, and applied technologies to the disaster management domain. Chapter Three includes the methodology of the study that explains the research design, model structure, algorithms, and functions. Chapter Four consists of the results of the simulation analysis and discussions on the output of the simulation run followed by the research limitations and future research possibilities. The study ends in Chapter Five with a conclusion on the relation of the identified challenges with the proposed model and the implication possibilities of the model.

CHAPTER 2

LITERATURE REVIEW

The unwanted impacts of disasters all around the globe have increased regarding the increases in populations, infrastructure complexities combined with the fast and unplanned urbanizations (Cavdur et al., 2016; Tierney, 2012). A single disaster can cause losses of thousands of lives and billions of dollars. The several late disaster observations such as the 2005 Hurricane Katrina, the 2010 Deepwater Horizon oil spill, Japan's 2011 earthquake and tsunami, etc. As a result of such facts, illustrate that more research is required to develop solution approaches for the current challenges. In the time of a disaster, the delivery of critical supplies is a challenging task because of possible damages to the infrastructures (physical and virtual) and transportation capacity limitations in the affected areas. Multidisciplinary research approaches are required to address the unique challenges of emergency logistics with the focus on a) large volume of supplies b) short time frame for response to prevent losses c) significant uncertainties about the needs and availabilities in the affected areas (Holguín-Veras et al., 2007). This chapter includes the fundamental concepts related to the disaster supply chain and a mapping system of how research in this field was generated, developed, and improved within time.

HISTORICAL BACKGROUND

This section describes the basis for disaster supply management. First, the fundamentals of hazards, risk, disaster, and disaster supply chain are defined. Second, the concept of risk management, disaster management, and disaster supply network management are described. Third, the most important theories and approaches in the literature regarding disaster supply chain management with a focus on collaboration and communication are determined. Fourth, the results of a systematic literature review on the concept of a disaster supply network are used to identify the most critical challenges and the knowledge gaps in the field.

Hazard

Hazard is defined as a “source of danger that may or may not lead to an emergency or disaster” (Haddow et al., 2008, p. 27). Each hazard carries an associated risk representing by the likelihood of the hazard and the consequences of that event. The realized hazard risk can produce an emergency event that is characterized as a condition displaying adverse effects (Haddow et al., 2017). The consequences require efforts to manage emergency services.

When the requirements to respond to an emergency event exceed the capabilities of the existing emergency services, the event is classified as a disaster. The basis of all emergency management activities is *hazard identification.* The knowledge derived from the identified hazards would be the foundation of preparedness and mitigation actions in disaster management (Haddow et al., 2017). The goal of hazard identification is to establish an exhaustive list of hazards to perform analysis on them. Table 1 shows six categories of hazards. The magnitude and existence of hazards should be identified through historical and scientific data interpretation using multiple sensing devices and models. Communication technologies have a crucial role in hazard-specific detection and monitoring (Samarajiva, 2005).

Table 1

Types of Hazards

Type	Hazard
Natural Hazards	Flood Earthquakes Hurricanes Storm Surges Tornadoes Wildfires Mass Movements Tsunamis Volcanic Eruptions Severe Winter Storms Drought Extreme Temperatures Coastal Erosion Thunderstorms Hail
Technological Hazards	Structural Fires Hazardous Materials Incidents Nuclear Accidents Dam Failures Terrorism
Chemical Biological Radiological Nuclear Hazards	Chemical, Biological, Radiological, and Nuclear devices (CBRN) Incidents

Risk Management

Risk management is the process of assessing the identified risks and designing strategies and procedures to mitigate the risk factors. The process contains the following steps:

1. Hazard’s identification
2. Risks assessment for each of the identified hazard
3. Hazards risks analysis concerning one another
4. Hazard risk treatment according to prioritization

In the risk evaluation process, each hazard should be identified, described, mapped, and analyzed according to the likelihood of occurrence and the consequences of a disaster. The two primary approaches evolving in risk management are qualitative and quantitative. Any risk assessment outcome validation and utilization is defined by the quality and availability of data (Haddow et al., 2017).

Disaster

There are several definitions for a disaster including the followings:

- The World Health Organization (WHO) defines a disaster as any occurrence that causes damage, destruction, ecological disruption, loss of human life, human suffering, deterioration of health, and health services on a scale sufficient to warrant an extraordinary response from outside the affected community (Mid-Atlantic Universities Transportation Center, 2009).
- The American Red Cross defines a disaster as an occurrence or situation that causes human suffering or creates human needs that the victims cannot alleviate without an assistant (Mid-Atlantic Universities Transportation Center, 2009).
- The Center for Research on the Epidemiology of Disasters (CRED) is a collaborating center with the WHO and the United Nations (UN). CRED defines a disaster as a situation of event that overwhelms local capacity, requires a request to national or international level for external assistance, an unforeseen and often sudden event that causes significant

damage, destruction, and human suffering (Mid-Atlantic Universities Transportation Center, 2009).

- The official definition of disasters in the United States has presented in *The Stafford Act* (1988) (Act, 1988). "any natural catastrophe (including hurricane, tornado, storm, high water, wind-driven water, tidal wave, tsunami, earthquake, volcanic eruption, landslide, mudslide, snowstorm, or drought) or, regardless of cause, any fire, flood, or explosion, in any part of the United States, which is the determination of the President causes the damage of sufficient severity and magnitude to warrant major disaster assistance under this Act to supplement the efforts and available resources of States, local governments, and disaster relief organizations, in alleviating the damage, loss, hardship, or suffering caused thereby."
- The International Strategy for Disaster Reduction describes disaster as "severe disruption of the functioning of society, posing a significant, widespread threat to human life, health, property, or the environment whether caused by accident, nature, or human activity, and whether developing suddenly or as a result of complex, long-term processes (Day et al., 2012, p. 24).
- The Federal Emergency Management Agency (FEMA) defines *disaster* as: "An occurrence of a natural catastrophe, technological accident, or human-caused event that has resulted in severe property damage, deaths, or multiple injuries. A "large-scale disaster" exceeds the response capability of the local jurisdiction and requires State and potentially Federal involvement" (FEMA Glossary, p.GLO-1).

Table 2

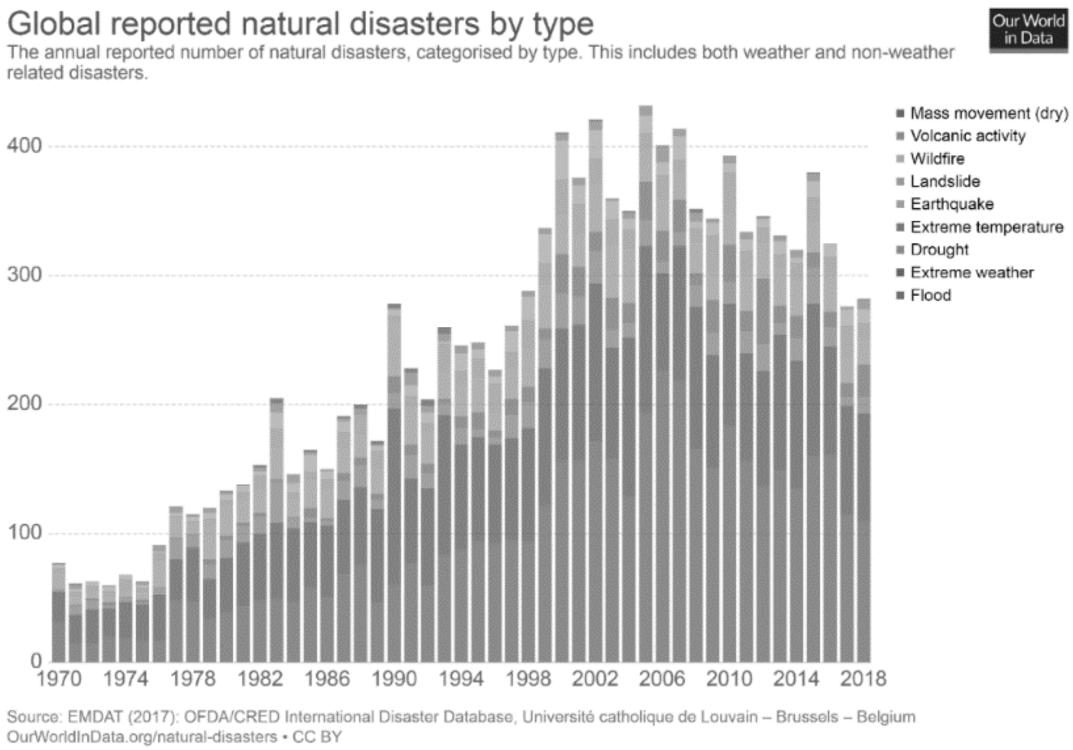
Affected People by Natural Disaster in 2018

Event	2018	Average (2000-2017)
Drought	9,368,345	58,734,128
Earthquake	1,517,138	6,783,729
Extreme temperature	396,798	6,368,470
Flood	35,385,178	86,696,923
Landslide	54,908	263,831
Mass movement (dry)	0	286
Storm	12,884,845	34,083,106
Volcanic activity	1,908,770	169,308
Wildfire	256,635	19,243
Total	61,772,617	193,312,310

The frequency of disasters happening in recent decades illustrates the importance and role of a resilient disaster management framework. In 2018, the SwissRe Institute estimated that more than 11,000 people were victims of disaster events, and the economic losses were estimated to be USD 155 billion. Figure 1 depicts the number of disaster events from 1970 to 2017. The total number of people affected by natural disasters is shown in Table 2 (CRED, 2018).

Figure 1

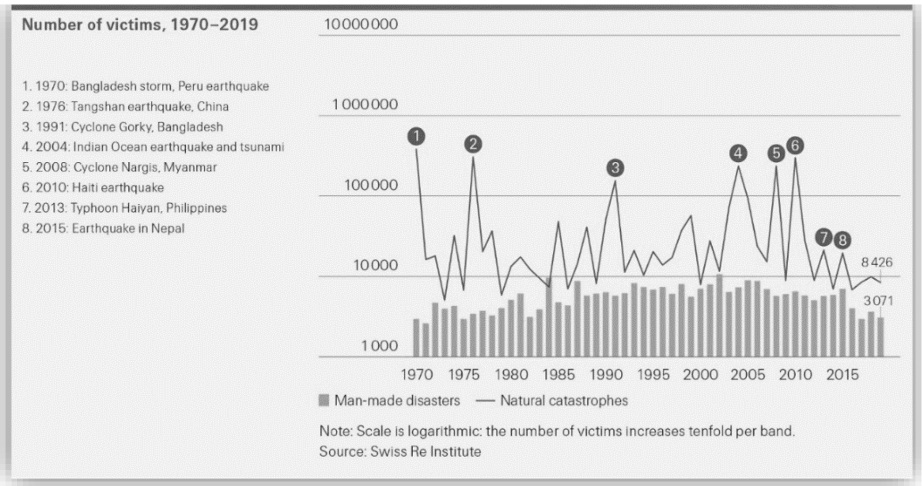
Global Reported Natural Disasters by Type (1970 – 2018) (Ritchie & Roser, 2018)



Disaster types have three categories of natural, human-made, and hybrid disasters. Natural disasters are catastrophic events that are developed from natural causes such as earthquakes, hurricanes, etc. Manmade disasters are devastating events that are generated from human decisions, including warfare, structure collapse, etc. Hybrid disasters are catastrophic events that are developed from both human error and natural forces, such as clearing of jungles, causing soil erosion (Shaluf, 2007). The global annual deaths from catastrophes, differentiated by the type, in the period of 1970-2019 is illustrated in Figure 2 (SwissRe Institute, YEAR).

Figure 2

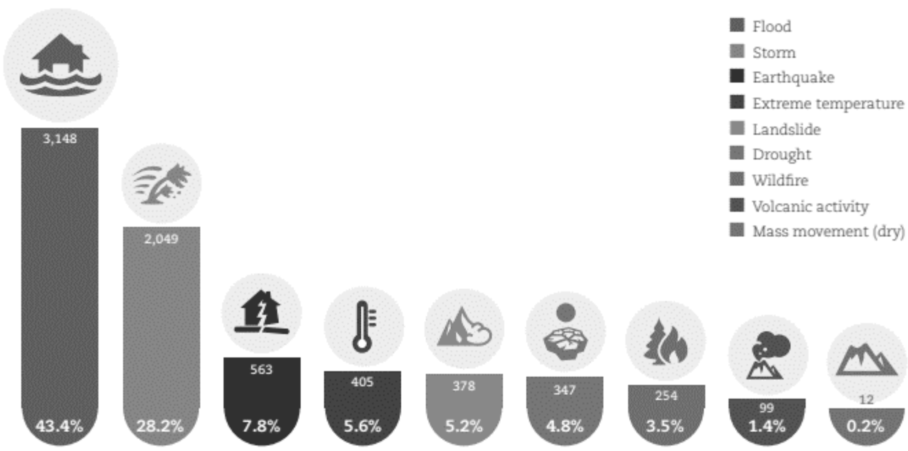
Number of Victims (1970-2019) Retrieved from SWISSRE Report



The number of disasters per type from 1998 to 2017 is depicted in Figure 3 (Mizutori & Guha-Sapir, 2018). Based on the indicated definitions, the threshold for determining what constitutes a disaster is depended upon two factors. First is the availability of resources, and second is the capabilities of the community to respond.

Figure 3

Number of Disaster per Type 1998-2017



Disaster Management

Disaster management provides the possibility to prepare for, respond to, and recover from disasters and minimize destruction. Emergency management is a discipline that involves preparing for disasters before the occurrence, responding to disasters immediately, and supporting and rebuilding societies after the catastrophe (Mid-Atlantic Universities Transportation Center, 2009). Emergency management is integral to everyone's security and should be integrated into daily decisions, not just considered in case of a disaster. Emergency management roots in ancient history. The account of Moses parting the Red Sea to control floods could be considered as the first attempt in emergency management (Haddow et al., 2017). As there have been disasters, people have tried to find ways to fix them. The evolution of emergency management was during the 1950s, the Cold War era. In 1961, the Office of Emergency Preparedness was created in the White House to deal with natural disasters. Federal Emergency Management Agency (FEMA) was established 1978. To eliminate the conflicts facing FEMA, the new concept of the Integrated Emergency Management System (IEMS) was developed. The approach of this system was on all types of hazards, including direction, control, and warning, as functions common to all emergencies. The emergency management system had a major evolution during the 1990s. FEMA launched a national initiative called Building-Resistant Communities to promote a new community-based approach. In this new approach, all the stakeholders, including the business sector, were involved in identifying risks and establishing plans to reduce them. This approach would promote sustainable economic development, protect and enhance natural resources, and ensure a better quality of life for the citizens (Haddow et al., 2017). The strategic goals of FEMA explained by Mid-Atlantic Universities Transportation Center (2009) are to fulfill the following objectives:

1. Lean an integrated approach that strengthens the nation's ability to address disasters, emergencies, and terrorist events.
2. Deliver easily accessible and coordinated assistance for all programs.
3. Provide reliable information at the right time for all users.
4. FEMA invests in people, and people invest in FEMA to ensure mission success.
5. Build public trust and confidence through performance and stewardship.

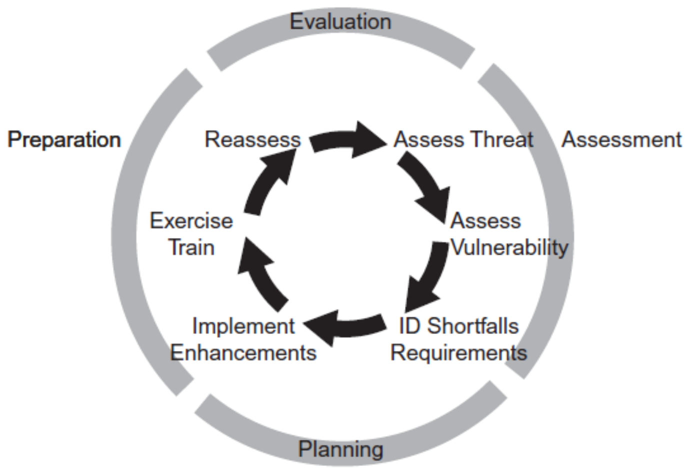
There is no global formula for disaster management capacities development in different countries. The most significant overall move to the centralized safeguarding of citizens was in the civil defense era. Modern disaster management emerged in the mid-20th century. Most nations established legal frameworks to guide and maintain disaster management systems through the passage of the law, the creation of national defense organizations, and the allocation of funding and personnel. Disaster management is the process of developing and implementing policies that are concerned with all the phases of a disaster:

- Mitigation is defined as sustained action to reduce risks to people and property from the hazards and their effects. The essential part of any mitigation strategy is analyzing all the potential hazards in a particular area (Haddow et al., 2017). Mitigation is deciding on actions where the risk to the health, safety, and welfare of society has been determined to exist; and implementing a risk-reduction program (Petak, 1985).
- Preparedness is defined as a state of readiness to respond to a disaster, crisis, or any other type of emergency. Studies in the 1970s depicted the importance of preparedness in emergency management (Haddow et al., 2017). The heart of preparedness is planning, training, and exercising to develop the capacity to respond and recover from emergency and disasters. Preparedness is preparing a response plan and training to save lives and reduce disaster damage, including the identification of critical resources and the development of necessary agreements among responding agencies (Petak, 1985).

- Response is defined as the immediate actions to save lives, protect property, and meet basic human needs. Responding to disaster events is the most visible activity of emergency management. Clear lines of communication and coordination of numerous agencies are required to have a successful response, a strong command, and a control system (Haddow et al., 2017; Petak, 1985).
- Recovery is defined as a complex set of issues and decisions relative to rebuilding homes, replacing property, resuming employment, restoring businesses, and permanently repairing and rebuilding infrastructure. The recovery process requires long-term goals to be defined for reducing vulnerability. An active recovery aims to bring all the players together to plan, finance, and implement a recovery strategy that will rebuild the affected area safer and more secure as quickly as possible (Haddow et al., 2017; Petak, 1985).

Figure 4

Preparedness Planning Cycle



The national preparedness directorate of FEMA developed a systematic approach toward a cyclical process to establish and improve preparedness (Haddow et al., 2017).

- Step 1: Preparing a plan: this phase includes planning for the protection of the citizens, property, and essential services after a disaster and ensuring the viability of the community to be sustained despite the existing hazard risks (Figure 4).
- Step 2: Acquiring equipment: actual possession and access to the required equipment are the limiting factors in this phase. Some of the main requirements are Personnel Protective Equipment (PPE), communications equipment, and proper search and rescue equipment.
- Step 3: Training to the plan: all the key stakeholders operating in the community are required to participate in emergency response training.
- Step 4: Exercise the plan: through different types of exercise, a better understanding of the realities of response can be achieved. Also, the shortfalls or failures in the previous steps can be identified.
- Step 5: Evaluation and improvement: the lesson learned is documented to be applied for further iterations. This step is the product of two sources. One is the exercise step and the results of the actual disaster experience.

An effective disaster preparedness needs the capacity to receive and convert the information from the hazard detection and monitoring system to a credible, accurate, and timely warning and alert. Media plays a crucial role in distributing warnings to the first responders (Samarajiva, 2005). The Incident Command System (ICS) developed in the 1970s establishes a set of planning and management systems to help to respond to disaster coordination in a systematic approach to maintain efficient leadership during the disaster. The management system includes five sections of command, operations, planning, logistics, and finance.

In the recovery phase, some key factors are concerned in the recovery programs:

- Identifying needs and resources.
- Providing accessible housing and promote restoration.
- Addressing the care and treatment of affected persons.
- Informing residents and preventing unrealistic expectations.
- Implementing additional measures for community restoration.
- Incorporating mitigation measures and techniques.

In developing a recovery plan, decision-makers should consider the policy areas, including land-use planning techniques, zoning, building codes, financial, information, and oversight. The purpose of a long-term recovery plan is to identify the impacts of a disaster on the area and develop a process and procedures to ensure rebuilding a safer and more reliable community. Conducting a long-term recovery plan provides the following benefits (Haddow et al., 2017).

- Most vulnerable areas can be identified.
- Funding for rebuilding in the post-disaster environment can be accelerated.
- Regulatory and environmental requirements for rebuilding can be compensated.
- Economic and social disruption is minimized.

The area of disaster recovery has received the least attention in the literature (Chang, 2010). The key concerns in this phase include the operational problems of damage assessment and cleanup, and the key characteristics of food and monetary aid collection, allocation, and distribution. Comprehensive emergency in terms of four programmatic phases is described in Table 3.

Table 3

Disaster Operation Management Activities (Altay & Green, III, 2006)

Phase	Description	Operation Activities
Mitigation	Employing measures to prevent hazards or decrease their impacts in case of occurrence	• Barrier construction to defect disaster forces • Active preventive measures to control the developing situation • Risk analysis to measure the potential for extreme hazards • Insurance to reduce the financial impact of disasters • Zoning to prevent the occupation of high hazard areas
Preparedness	Determining activities and procedures to prepare the community for responding to a disaster	• Emergency planning • Development of communication systems • Training response for personnel and citizens • Maintaining emergency supplies • Construction of an emergency operation center
Response	Using resources and procedures to preserve life, property, environment, and social, economic, political structures	• Activating the emergency operations plan • Evacuation of threatened populations • Emergency rescue and medical care • Emergency infrastructure protection and recovery • Opening of shelters and provision of mass care
Recovery	Specifying long-term actions after the immediate impact of the disaster to stabilize the community and restore some aspect of normalcy.	• The rebuilding of roads, bridges and essential facilities • Full restoration of lifeline services • Financial assistance to individuals and governments • Disaster debris cleanup

Governments have a significant role in each phase of a disaster. To have a practical mitigation strategy, besides the technical knowledge, other factors including historical occurrence, public education, and media attention are required to make recognition of the vulnerabilities of each community. To enhance the mitigation programs, the government should offer political visions and both incentives and penalties for not taking the actions. Moreover, a community partnership should be built, and the steps would be communicated with all the stakeholders. The preparedness phase should not only focus on the protection of the citizens, property, and essential services after a disaster, but it also should ensure the viability of the community to be sustained despite the existing hazard risks. In the planning phase, planners can understand the reasons for disasters by the vulnerabilities. The vulnerability assessment includes assessing the current preparedness levels to determine the resources and capabilities required in case of an emergency.

All nations face risks of natural and technological hazards and might become victims of disasters. The response capacity of each nation is linked to several factors, including a propensity for disaster, local and regional economic resources, government structure, and availability of technological, academic, and human resources. As the nation's response capacities fail in facing large-scale disasters, international assistance is required. As the response capacity of a nation's emergency management structure is overwhelmed, the event becomes a global disaster (Haddow et al., 2017). The size and scope threshold of a disaster to become an international disaster are different for each country. Numerous factors are driving the limit including the severity of hazards and consequences, the availability of economic resources, the comprehensiveness and appropriateness of responder training, the built-in resilience of infrastructure, the actual ability and the public impression of the government's ability to manage the situation, and the availability of specialized assets, etc. The participants in international disaster management include victims, local first responders, the government of the affected countries, international organizations, international financial institutions, regional organizations and associations, nonprofit organizations, private organizations – business and industry, and local and regional donors (Coppola, 2006).

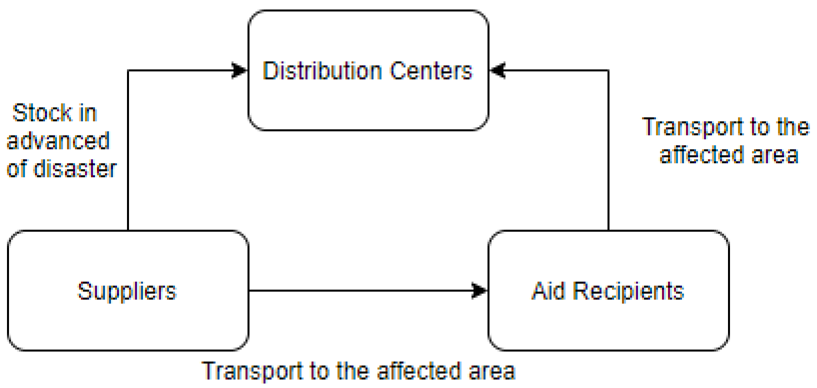
The critical challenges responding to international disasters are *coordination, sovereignty, and equality in relief distribution*. The Inter-Agency Standing Committee (IASC), established in 1992 under the UN, serves as a platform within which the board range of humanitarian partners may come together to address the humanitarian needs resulting from a disaster with the following objectives:

- Develop and agree on system-wide humanitarian policies.
- Allocate responsibilities among agencies in humanitarian programs.
- Develop and agree on a shared ethical framework for all humanitarian activities.
- Identify areas where gaps in mandates or lack of operational capacity exist.

There is no global stock positioning system that offers information regarding quantity, quality, geographical location, and ownership of stocks. Hence, a systematic approach and supporting infrastructure for relief chain design is required to facilitate response capacity and performance. Balcik and Beamon (2008) provide an analytical approach to make effective and efficient facility location and stock pre-positioning decisions to assist decision-makers. The flow of resources in disaster relief is depicted in Figure 5.

Figure 5

Relief Chain Retrieved (Balcik & Beamon, 2008)



Several organizations with different tasks and responsibilities are involved in disaster management. There is an inevitable need to work together to one degree or another while responding to a disaster. The challenge is how they can work together as effectively as possible (Scholtens, 2008). A lack of knowledge about constitutes strong collaboration is existing in many countries. A nongovernmental organization (NGO) is an organization with no affiliation with a government of any nation other than the support from government sources. NGOs are considered as information gathering bodies and are vital in establishing accuracy in the development of damage and needs assessments. They can provide specific technical skills to allow reaching a larger population with a more excellent capability in less time. Moreover, their fundraising abilities bring more significant cash amounts to address the needs of victims. For example, in the 2004 Asian Tsunami, more than 40 countries and 700 NGOs assisted (Balcik et al., 2010).

Several studies in the disaster management literature offer models, guidelines, and procedures for more effective disaster plans. The traditional approach toward disaster management is addressed from a single government's perspective (Luna & Pennock, 2018). Much of the research in the disaster management field is targeted to public servants, government agencies, and insurance firms charged with responding in times of crisis (Hale & Moberg, 2005). Decision-making in case of a disaster is usually very tense. Dealing with a complex, unpredictable, and dynamic emergency responding environment pressure the central management with a degree of personal danger of the responsibility, the sight of causalities, along with time pressure, and communication. Paton and Flin (1999) examined the stress in making-decision in response to a disaster categorized in environmental, organizational, and operational sources. Different tools and approaches have been applied to improve the decision-making process in case of a disaster. For example, Gunes and Kovel (2000) built a database in a Geographic Information System (GIS) framework to help integrating emergency management in decision making. Sahebjamnia et al. (2017) developed a hybrid decision support system framework to respond to large-scale disasters consisting of a knowledge base and a ruled-based simulator.

Disaster operation management is multi-organizational by the nature. However, the organizations are loosely connected which leads to ambiguity of authority and confusion in management. Effective emergency response should include and integrate the two stages of pre-event and post-event response. Pre-event tasks consist of prediction and analysis of potential hazards to developing the required mitigation action plans. Post-event challenges are locating, allocating, coordinating, and managing available resources (Altay & Green III, 2006). Altay and Green III (2006) argue disaster operation management lacks widely accepted measures of productivity and efficiency. A rapid initial assessment is vital in few hours after the strike of a disaster to provide the following:

- Anticipate the needs of survivors.
- Prevent avoidable mortality.
- Identify areas where services were deficient.
- Establish priorities and determine the best location for the resources to satisfy the survivors' immediate needs (Akbari et al., 2004).

Limitation in the understanding of resources and types of critical data shows the requirement for theory development and hypothesis testing which requires an understanding of models' inputs and the event characteristics to develop new solution methods. In disaster management, it should be recognized that whether the social interactions are helping or hindering people in reducing the vulnerability to hazards (Haddow et al., 2017). Due to the nature of disasters, multiple agencies need to work together to monitor the response and manage a large number of people responding to the affected area. An integrated system of all agencies is required to operate under one overall response management system. Duplication of efforts, lack of coordination, and communication problems hinder the involved parties from responding to a disaster (Haddow et al., 2017).

The first step in any emergency response is to assess the extent and impact of the damage caused by the disaster and the capacity of the affected population to meet its immediate survival needs (degree of vulnerability). Although the impact may vary considerably from one disaster to another, based on the International Federation of Red Crescent Societies (IFRC) typical needs that arise include: food, shelter, essential items (blankets, heaters, water containers, etc.), medical care, sanitation, and waste disposal, psychosocial support. Generally, problems of the public sector are not well-defined while they have high behavioral content and are overlaid with strong political implications which are not recognized in the literature. Therefore, new network and organizational structures are required to facilitate communication and coordination in the resolution of disasters (Altay & Green III, 2006).

Disaster Management Complexity

Disaster management is a complex and multifaceted system (Fogli et al., 2017). The disaster management domain is facing an increase in complexity and a decrease in the predictability of operational scenarios (Gunes & Kovel, 2000). The newly emerging science of complexity enables a precise understanding of the likelihood of disasters (Casti, 2001). The essential purpose of unraveling the complexities of disaster management is to recognize the interdependencies between response agencies and the other involved agencies and how they intersect to promote resilience before, during, and after a disaster. O'Sullivan et al. (2013) explore the complexity of disasters empirically to determine levers for action where interventions can be executed to facilitate the collaborative effort. Limitations or deficiencies in any of the organizational, institutional, and behavioral area makes disaster management more difficult (Gerber, 2007). This study aims to tackle some level of complexities by facilitating communication and collaboration among the aids network participants and providing real-time information from the affected area of the disaster.

Disaster Management Communication

The United Nations (UN) has a leadership role and a pre-described procedure in case of a major international disaster. Still, the role of the government must be recognized, since all the global actions are based on their request. There must be a commitment of the participants to identify the needs and to accept to appeal to the affected area. For coordination, a vital and immediate component due to the sheer number of responding agencies is required. Each agency has a particular skill or service to offer. Successful coordination and cooperation can lead to the great success of the disaster response. The sovereignty of the state should be based on the recognition of political authority characterized by territory and autonomy. For equality in relief distribution, the challenge is that sometimes a particular group of needs of aid is favored over others, based on two primary reasons. First is discrimination (e.g., gender bias), and second is the class of bias. For capacity building and linking relief with development, disasters present an opportunity to rebuild old, ineffective structures and develop policy and practice toward a more resilient community. Linking relief and development should not be a deviation from the missions of the agencies. In the reconstruction phase, training and information exchanges are essential to mitigate repeat disasters and increase the likelihood of a nation being developed sustainably.

Information technologies can support communication challenges throughout a disaster response focusing on *interactions* between different agencies with multiple developers or vendors that operate different software. Papadopoulos et al. (2017) categorized the main types of organizations involved into a disaster response on a five-point Likert scale depicted in Table 4. To facilitate the communication among the entire network, a solution is mentioned by Imran et al. (2015) to use machine-understandable ontologies that can define, categorize, and maintain a relationship between several concepts to be able to facilitate mutual understanding and integrated communication.

Table 4

Relief Participants

Types of Organization	Approximation
Infrastructure development companies	6
Transporters	30
Warehousing	18
Army logistics	2
Border road organization	1
NGOs	12
Medical aid agencies	30

The public information should be coordinated and integrated across all the involved parties. Communication is a critical function in emergency management. The information communication regarding preparedness, prevention, and mitigation can promote actions that reduce the risk of future disasters. The communication of the participating agencies is imperative to share information and responsibilities.

An efficient disaster management operation requires all the policies, goals, and priorities to be communicated to staff, partners, and participants. Manoj and Baker (2007) identified three main communication challenges in the disaster responding system in three categories of technological, sociological, and organizational. These are the key factors to develop and maintain a healthy and effective disaster communication system. The responding organizations make interagency communication. Without appropriate communication, decision-makers will not be able to gain an accurate picture of events to make decisions or to execute them properly (Cartier, 2009). Good quality communication is essential for ensuring that appropriate information is available and delivered promptly (Paton & Flin, 1999). Cooperation is necessary to achieve the desired results in all phases of disaster management (Hu et al., 2018). Smith and Dowell (2000) studied interagency coordination in response to disasters. Waugh Jr and Streib (2006) developed an effective collaboration and leadership strategy in case of catastrophe. The critical factors that describe communications in planning are channels of communication, the sources of the communication, and message distribution or delivery strategy. The two main elements of disaster risk communication are understanding and working with the media (Glik, 2007). The disaster communication system must include the followings (Haddow et al., 2017):

- Definition of an effective disaster communications strategy.
- Examination of several forms of historically used media and the new forms of media that can share the information with the public.
- Specification of the communication elements that comprise effective disaster communication in the future.

Communication is involved in all four main phases of emergency management (Haddow et al., 2017). The communication role in each stage is described as following:

- Mitigation – to promote the implementation of strategies, technologies, and actions that will reduce the loss of lives and property.
- Preparedness – to communicate preparedness messages to encourage and educate the public in anticipation of disaster events. .
- Response – to provide notification, warning, evacuation, and situation reports on an ongoing disaster.

- Recovery – to provide registration information and to receive disaster relief to the affected individuals and communities.

Due to the importance of communication and the leadership's commitment, a communication specialist needs to be included in the emergency management team. Therefore, all the communication issues would be considered in the decision-making processes. There are two types of coordination in the relief chain. Vertical coordination is about the coordination of upstream and downstream activities. The horizontal coordination occurs among the organizations at the same level (Gerber, 2007). The primary audiences for emergency management communication are shown in Table 5.

Table 5

Communication Audience

Disaster Aids Communication Primary Audience
1. General public
2. Disaster victims
3. Business community
4. Media
5. Elected officials
6. Community officials
7. First responders
8. Volunteer groups

The elements required for effective disaster communication are as follows (Haddow et al., 2017):

1. A communication plan: In the planning phase includes the protocols for collecting information from a variety of sources, analyzing the data to identify the needs and match the available resources to those needs, disseminating information of current conditions and actions to the public through media. In the response phase, the plan includes protocols for monitoring the media, identify new sources, and evaluate the effectiveness of disaster communications. In the recovery phase, the focus would be on available resources to help in rebuilding.
2. Information coming into the system: all possible sources of information should be identified, and working relationships be developed during non-disaster periods.
3. Information going out: discover the best media to deliver preparedness and hazard mitigation messages and communicate in response and recovery phases with the targeted audiences.
4. Messengers: the authority figure that informs the decisions to the public and the media. It should be determined what types of information will be delivered by which messenger prior to a disaster.
5. Staffing: the involved organizations in emergency management should establish an ongoing communication staff capability. Staff will be required to establish and maintain working relationships with media sources.
6. Training and exercises: the staff and messengers should be well-trained o have effective disaster communication operations. The training includes media relations, new media, and marketing.
7. Monitor, update, and adapt: staff should routinely monitor the media outlets to identify problems and issues early in the process and shape communication strategies to address them. The regular monitor helps in identifying rumors and misinformation and speed

corrections. The collected information from monitoring can be used in updating communication plans, strategies, and tactics.

Collaboration and coordination are essential for disaster management. In the response phase of a disaster, the organizational structure for disaster management has been divided into three levels of coordination to shape multidisciplinary collaboration (Scholtens, 2008):

1. Administrative coordination.
2. Operational leadership.
3. Presence and operations at the place of the disaster.

New technologies have changed the collaboration and distribution methods. These technologies modified the flow of information, replaced the centralized, top-down model, and create ad-hoc distributive information networks. Risk communications that advocate for disaster preparation should be imminent to be successful in motivating behavior change. Inconsistency happens when the event is evolving, but the information is not updated regularly (Glik, 2007). To transmit social information, the classical communication model of source, channel, message, receiver, effect, and feedback is the basis. Based on the New York Times (2005), during hurricane Katrina, the communication capabilities became so weak that officials had to use human couriers to transmit messages (Majchrzak et al., 2007). The lack of interaction and institutional overlap among involved communities generate conflicts (Schipper & Pelling, 2006). This study aims to provide a platform that can facilitate collaboration among the entire network and provide real-time information.

Disaster Governance

One single entity cannot command compliance among all participants in a governance system. Such systems rely on the development and diffusion of many norms, state regulations and self-regulation, mechanisms of the market, and other processes (negotiation, participation, and engagement) that facilitate collective decision-making and activities. Disaster as a complex social problem does not fit precisely within the scope of an organization. Governance through networks of collaboration and diverse entities yields to address the issues due to flexibility, adaptability, and mobilization capabilities of various resources. Disaster governance is defined as "the interrelated sets of norms, organizational and institutional actors, and practices that are designed to reduce the impacts and losses associated with disasters" (Tierney, 2012, p. 344). Since governments are not on a global scale, transnational governance processes are required to provide coordination mechanisms in the case of a disaster. Many of the disaster risk reduction attempts are dependent on cross-border collaboration and complex governance arrangements. Disaster governance is tied to risk, environmental, and earth governance (Tierney, 2012).

Disasters are becoming less deadly but more costly. The number of catastrophes and the number of people affected by disasters is rising. Developing countries are disproportionately affected by disaster consequences. Under the traditional approach, decision-making, and communications are centralized (Luna & Pennock, 2018). Birkmann and von Teichman (2010) suggest that disaster challenges can be broken down into issues regarding scales, knowledge, and norms in a centralized knowledge database. The application of a central command and control system within a dynamic organization will lead to insurmountable restrictions (Scholtens, 2008). It is impossible to provide an optimized decision-making process because a full range of information is never available in a dynamic disaster management organization. In such conditions, a distributed decision-making approach will be more efficient within complex and dynamic organizations (Scholtens, 2008).

In summary, some of the critical challenges that disaster management is faced are summarized as 1) the access to accurate information of the affected areas (Lin et al., 2011), 2) limited communication (Manoj & Baker, 2007), 3) lack of efficient coordination of different agents and transportation (de la Torre et al., 2012), 4) decisions load constraints (Cartier, 2009;

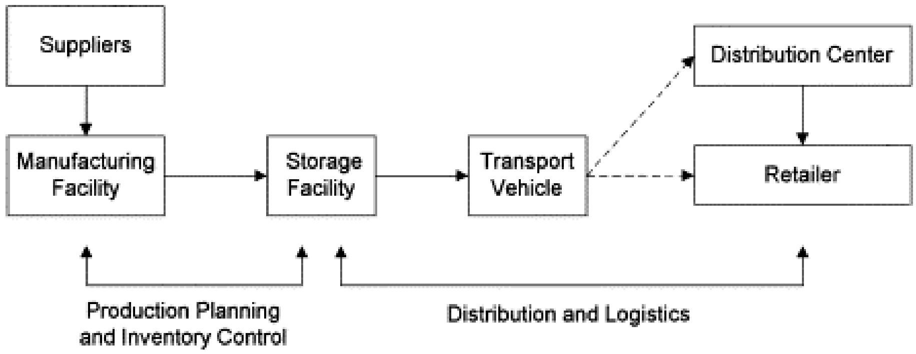
Paton & Flin, 1999). Disaster management is an extensive area; for this research, the challenges regarding disaster supply management are only considered. Based on the FEMA professional approach that emergency management is *a decentralized network* of organizations that collaborate to mitigate the impacts of disasters (Luna & Pennock, 2018), this study proposes a blockchain-enabled disaster aids supply management approach.

Supply Chain

A supply chain is defined as an integrated process that various business entities work together in an endeavor to acquire raw materials, convert them to specified final products, and deliver the final products to retailers. The chain is characterized by a forward flow of materials and a backward flow of information (Beamon, 1998). The history of the supply chain initiative can be traced in the textile industry with the quick response program. Later, the grocery industry used efficient consumer response. A supply chain analysis was commissioned by Kurt Salmon Associates in 1985. The outcomes of the study illustrated a long delay in warehouse or transit which resulted in major losses to the industry by the inventory costs and lack of having the right product in the right place at the right time (Lummus & Vokurka, 1999). A supply chain is comprised of two basic and integrated processes depicted in figure 6 as the production planning and inventory control process, the distribution and logistics process (Beamon, 1998).

Figure 6

Supply Chain Process (Beamon, 1998)



Interest in the concept of supply chain management has steadily increased since the 1980s by the benefits managers achieved from collaborative relationships within and beyond their organizations. There are several definitions of supply chain management or the activities in different fields in the literature. The Supply Chain Council defines it as “every effort involved in producing and delivering a final product from the supplier’s supplier to the customer’s customer. Four basic processes of the plan, source, make, and deliver define these efforts including managing supply and demand, sourcing raw materials, manufacturing and assembly, warehousing and inventory tracking, order entry and order management, distribution across all channels, and delivery to the customer” (Lummus & Vokurka, 1999). Several definitions on the concept of supply chain management were described in the study by Lummus and Vokurka (1999) and summarized as “all activities involved in delivering a product from raw material through to the customer including sourcing raw materials and parts, manufacturing and assembly, warehousing and inventory tracking, order entry and order management, distribution across all channels, delivery to the customer, and the information systems necessary to monitor all of the activities”. Croom et al. (2000) highlight a sample of definitions related to the concept of supply chain management in the literature and are shown in Table 6.

Harland (1996) describes supply chain management as managing business activities and relationships within the followings:

- Internally within an organization.
- With immediate suppliers.
- With first and second-tier suppliers and customers along the supply chain.
- With the entire supply chain.

Supply chain management aims to identify the most important sets of outcomes and articulate them. The articulation is achieved using metrics and performance measurement systems. Then systems need to be designed and implemented that make the outcomes inevitable (Day et al., 2012). Supply chains are dynamic due to changes in the environment, technology, customer, and corporate strategy. Supply chain management starts with the extraction of raw materials through the manufacturers, wholesalers, retailers, and the final users, and in some cases includes recycling or re-using the products or materials (Mid-Atlantic Universities Transportation Center, 2009). Croom et al. (2000) conduct a literature analysis on supply chain management and argue that there are more empirical-based studies than theoretical work in the field and the theoretical development is critical to the establishment and development of supply chain management study.

Table 6

Definitions of Supply Chain Management

Authors	Definition
Tan et al. (1998)	Supply chain management encompasses materials/supply management from the supply of basic raw materials to the final product (and possible recycling and re-use). Supply chain management focuses on how firms utilize their suppliers' processes, technology, and capability to enhance competitive advantage. It is a management philosophy that extends traditional intra-enterprise activities by bringing trading partners together with the common goal of optimization and efficiency.
Berry et al. (1994)	Supply chain management aims at building trust, exchanging information on market needs, developing new products, and reducing the supplier base to a particular OEM (original equipment manufacturer) to release management resources for developing meaningful, long-term relationships.
Jones and Riley (1985)	An integrative approach to dealing with the planning and control of the materials flow from suppliers to end-users.
Saunders (1995)	External Chain is the total chain of exchange from the source of raw material, through the various firms involved in extracting and processing raw materials, manufacturing, assembling, distributing, and retailing to ultimate end customers.

Table 6 (continued).

Ellram (1991)	A network of firms interacting to deliver product or service to the end customer, linking flows from raw material supply to final delivery.
Christopher (1992)	Network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer.
Lee and Billington (1992)	Networks of manufacturing and distribution sites that procure raw materials, transform them into intermediate and finished products, and distribute the finished products to customers.
Kopczak (1997)	The set of entities, including suppliers, logistics services providers, manufacturers, distributors, and resellers, through which materials, products, and information flow.
Lee and Ng (1997)	A network of entities that starts with the suppliers' supplier and ends with the customers' custom the production and delivery of goods and services.

One of the related ones to this research is the collaboration of several leading manufacturers with the National Institute of Standards and Technology (NIST) and create the National Initiative of Supply Chain Integration (NISCI) to improve and standardize communication and business processes through manufacturing supply chains and to share the results (Lummus & Vokurka, 1999).

Supply chain management and logistics are often viewed as overlapping. The Council of Logistics Management (CLM) defines logistics as "the process of planning, implementing, and controlling the efficient, effective flow and storage of goods, services, and related information from the point of origin to the point of consumption to conform to customer requirements" (Lummus et al., 2001). The distribution and logistics process determines how products are retrieved and transported from the storage warehouse to retailers. The process also includes the management of inventory retrieval, transportation, and final product delivery. The interacting of these processes produce an integrated supply chain (Mid-Atlantic Universities Transportation Center, 2009). A key point in supply chain management is that the entire process must be viewed as one system. The concept of integrated supply chain management was stated by Monczka and Morgan (1997); it is about going from the external customer and then managing all the processes that are needed to provide the customer with value in a horizontal way". According to the coordination theory, the horizontal and vertical dimensions used for logistics are shown in Table 7 (Jahre & Jensen, 2010).

The performance of any entity in a supply chain depends on the performance of others, and the ability and willingness to coordinate activities within the supply chain. An important component in the design and analysis of the supply chain is the establishment of appropriate performance measures that can be used to determine the efficiency and effectiveness of the existing system or make a comparison to the competing alternative systems. The performance measures can also be used to design proposed systems by determining the values of the decision variables which yield the most desirable levels of performance.

Table 7

Logistics Coordination

Dimension/Type of Coordination	Horizontal	Vertical
What to coordinate	Actors, activities, resources at strategic, tactical, and operational levels in information, money, and material flows for companies at the "Same" stage in the supply chain Focus on the companies and their specific tasks	Actors, activities, resources at strategic, tactical, and operational levels in information, money, and material flows for companies at the "Different" stage in the supply chain Focus on the customer and synchronization
Why coordinate	To achieve economies of scale and to reduce costs for the individual company To have access to more physical resources, information, and competence	To reduce overall supply chain costs but can increase costs for some actors To improve customer service through smoother flows

There are a variety of performance measures including the followings (Beamon, 1998):

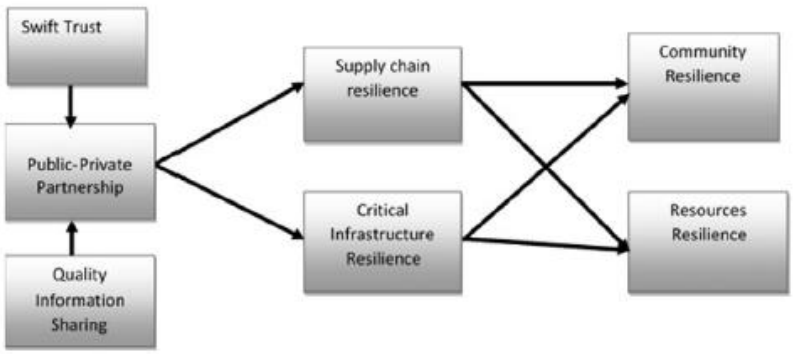
- Qualitative performance measures
    - Customer satisfaction

    - Flexibility
    - Information and material flow integration
    - Effective risk management
    - Supplier performance
- Quantitative performance measures
    - Based on cost and profit objectives
        - Cost minimization
        - Sales maximization
        - Profit maximization
        - Inventory investment minimization
        - Return on investment maximization
- Based on customer responsiveness objectives
        - Fill rate maximization
        - Product lateness minimization
        - Customer response time minimization
        - Lead time minimization
        - Function duplication minimization

The sources of risks relevant to supply chains can be organized into three categories (Brindley, 2017): external to supply chain, internal to supply chain, and network-related. Modern supply chains are vulnerable to a variety of risks due to complex networks which are stretched over multiple geographical locations (Aqlan & Lam, 2015). The core factors of supply chain profitability are responsiveness, efficiency, and reliability. Supply chain resilience is defined as the property of a supply chain network that enables it to regain its original configuration soon after disruption from disasters (Papadopoulos et al., 2017). According to the Business Continuity Institute in 2017, 65% of companies experienced at least one supply chain disruption which led to a loss of productivity, decrease in customer service, and loss of revenue. During the past two decades, supply chain disruptions caused by natural and manmade disasters occurred more frequently and with greater intensity, and had severe consequences (Ivanov et al., 2017). The disruptive risks are distinguished by rare occurrence and high-performance impact which disturb network structure and critical performance metrics. An important phenomenon connected to disruption is the ripple effect. The absence of capacity or inventory at the disrupted facility may lead to a lack of material in the affected area. Resilience in supply chain networks is shown in Figure 7 (Papadopoulos et al., 2017).

Figure 7

Supply Chain Network Resilience



Disaster Supply Chain

At the heart of any disaster relief system is the disaster which is an event that forms the focal point around which all the supply chain management activities are organized. Transient supply chains are finite-life supply chains that are regularly deployed in response to a specific event. Accordingly, all the supply chain life cycle stages need to be considered in a relatively short period (Day et al., 2012). Embracing supply chain management as a core function of disaster response is a process that began in humanitarian agencies in the last decade (Tomasini

& Van Wassenhove, 2009). The difference between supply chain management and a disaster relief operation is the involvement of the intermediate channels (Kumar & Havey, 2013). Several studies emphasized that some supply chain concepts share similarities to emergency logistics, therefore the tools and methods developed for commercial supply chain can be successfully adapted in emergency response logistics. However, the strategic goals of the commercial supply chain are different from disaster response logistics.

Table 8

Research on Supply Chain Techniques in Disaster Management

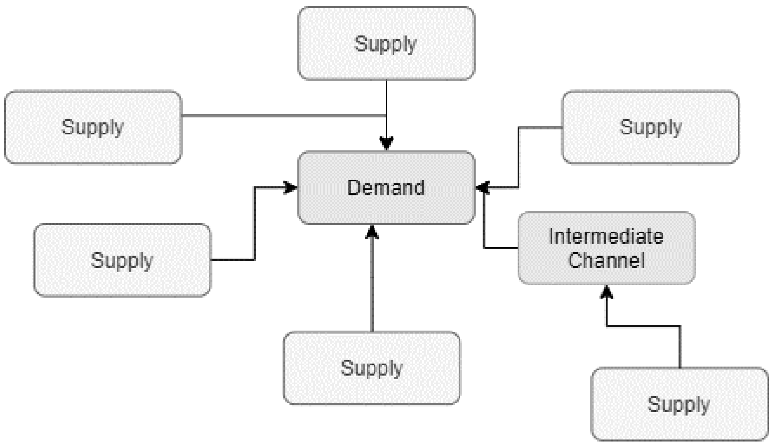
Author	Problem Statement	Findings
Beamon (2004), Thomas and Kopczak (2005)	Supply chain management capabilities within humanitarian organizations	The strategic advantages extensive research in the area of supply chain and logistical analysis, but rarely applied to disasters humanitarian operations
Altay et al. (2009)	Strategic planning for disaster relief logistics	Improvements are required in communications with both internal and external parties, invest in long-term relationships, develops cross-functional teams, and promote trust and commitment in the logistics chain
Ransikarbum (2015)	Humanitarian logistics in relief operations	
Ivanov et al. (2014)	Ripple effect in supply chains	
Tatham and Christopher (2018)	The need for developing appropriate performance metrics for humanitarian operations that capture aid recipients' viewpoint	
Nahum et al. (2017)	Evacuation routes issues in both multi-objective and stochastic	A positive correlation between cost and flow as well as between the flow and the evacuation time

The main goal in the commercial supply chain is to minimize the cost or maximize the profit of operations. While in disaster response the goal is to save victims' lives and minimize the pain and suffering. Using commercial supply chain techniques in disaster management is still in its infancy (Mid-Atlantic Universities Transportation Center, 2009). Table 8 illustrates some of the studies in this regard.

The disaster relief supply chain is shown in Figure 8. Disaster relief logistics is defined as the process of planning, implementing, and controlling the effective, cost-efficient flow and storage of goods and materials as well as related information, from the point of origin to the point of consumption to meet the end beneficiary’s requirements.

Figure 8

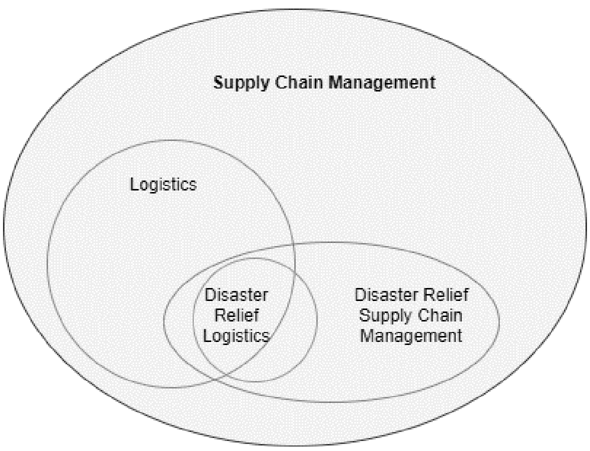
Disaster Relief Operation Supply Chain Configuration (Kumar & Havey, 2013)



Disaster relief supply chain management is defined as the system responsible for designing, deploying, and managing the required processes to deal with current and future disaster events, and managing the coordination and interaction of the processes with other competitive or complementary supply chains. Moreover, it is responsible for identifying, implementing, and monitoring the achievement of the desired outcomes which the processes are intended to achieve. Finally, it is responsible for evaluating, integrating, and coordinating the activities of the various parties that emerge to deal with the events (Day et al., 2012). Disaster relief logistics is more tactical, operational, and execution-oriented comparing to disaster relief supply chains. The relationship among supply chain management, disaster relief logistics, and disaster relief supply chain management is depicted in Figure 9 (Day et al., 2012). Disaster supply chain management is characterized by large-scale operations, unusual constraints, irregular demand, and unreliable or non-existent supply and transportation information. The engineering of a distribution network is challenging because of the nature of the unknown (locations, type, spread, and magnitude of events, politics, and culture). Disaster management organizations need to deal with zero lead time in their supply chain. Agile capabilities are very important in this aspect. Collaboration is very important in disaster management since no single entity has sufficient resources to respond (Scholten et al., 2014).

Figure 9

Supply Chain Management and Disaster Relief Relationship (Day et al., 2012)



A disaster relief operation supply chain is like a commercial supply chain in several ways such as effective delivery, complex supply network, uncertainty, and visibility. However, there are many differences including the followings (Pujawan et al., 2009):

- The number of involved parties: in case of a disaster, most of the relationships are developed promptly. Many parties are voluntary, and their participation is without any evaluation. The contribution of parties to the activities is different.
- Configuration of the supply network: disaster relief supply chain has only one demand point and is achieved from multiple sources of supply. Configuration is unstable and most of the suppliers only supply once during the relief operation.
- The pattern and uncertainty of demand: the demand is largely unpredictable, short-term in nature, very unstable with time, very limited past data can be used to evaluate the level of demand.
- The pattern and uncertainty of supply: it is not possible to limit supplies from certified suppliers. The amount of supply would not reflect the demand since the supplies come from different aid agencies. Therefore, excess non-essential supplies and shortages of critical items are the cases in most relief operations.

Table 9

Comparison of Commercial - Humanitarian Supply Chain

Characteristic	Commercial Chain	Humanitarian Relief Chain
Strategic goals	Typically to produce high-quality products at low cost to maximize profitability	Minimize loss of life and alleviate suffering
Distribution network configuration	Well-defined methods for determining the number and locations of distribution centers	Challenging due to the nature of the unknowns (locations, type, and size of events, politics, and culture)
What is "Demand"	Products	Emergency Supplies, equipment, and Personnel
Lead time	Lead time determined by the supplier-manufacturer-DC-retailer	Zero time between the occurrence of the demand and the need for the demand
Inventory control	Utilizes well-defined methods for determining inventory levels based on the lead time, demand, and target customer service levels	Inventory control is challenging due to the high variations in lead times, demands, and demand locations
Information System	Generally well-defined, using advanced technology	Information is often unreliable, incomplete, or non-existent

Some issues make each disaster relief supply chain unique including, the command and control issues, supply chain formation, donor independence, high levels of uncertainty, shifting overall priorities, changing operational needs, self-initiated participants, a large number of players, press coverage, and publicity, and post-disaster relief activities. Beamon (2004) made a comparison between commercial and humanitarian supply chains as depicted in table 9. Pujawan et al. (2009) propose four principles for managing disaster relief operation supply chain as follows.

1. Information Visibility: visibility in disaster relief operation express that critical information is well accessible by the interested parties. In case of a disaster, there

should be information about the available items, the on-hand quantity, the supply expected days, and the location. To have this information, accurate recording of inventory transactions and regular reporting to the public, aid agencies, and major donors are required.

2. Coordination: regarding multiple parties involved the objectives may be conflicting in the disaster relief operation supply chain. The lack of coordination can lead to an excess of supply for some types of goods, shortage of other types, duplication of efforts, etc. The humanitarian agencies may not be aware of their counterparts' activities which may lead to duplication and low resource utilization in many supply chain decisions such as warehousing, transportation, procurement, etc. visibility of information can help in creating a better supply chain coordination.
3. Accountability: the number of parties that are directly involved in a disaster relief operation process may be very large from agencies to individual volunteers. Some other parties are involved indirectly. Significant efforts are required to make sure every contribution is distributed properly and reported transparently.
4. Professionalism: this is related to the availability of well-trained people to perform the tasks and standard operating procedure to follow. Promoting professionalism in the disaster relief operation supply chain is difficult because the turnover rate of people working in relief projects is high. Professionalism also is about enough standard operating procedures available and being compiled during the relief operation. All the involved parties should maintain the principles of equality and impartiality in delivering aids to the affected areas.

The emergency supply chain objectives for disaster management include optimal deployment of military units, resources and equipment, supply of water, food, clothing, etc., infrastructure reconstruction, and medical support (Ben Othman et al., 2017). Cost minimizing, delivery delays, the complexity of the environment (i.e., uncertainty and a large number of actors) are the relevant factors to consider in developing an automatic tool to model and optimize logistics solutions to meet the emergency needs and help decision-makers with the right choices in real-time (Ben Othman et al., 2017). Based on the study by Thomas and Kopczak (2005), the main problem in disaster relief operations is in the distribution of the items quickly and in sufficient quantity for the affected areas. The bottleneck in distributing the supplies might be from the damaged infrastructure and unavailability of accurate information about the required amounts. There might be some conditions that the oversupply of non-essential goods could make the logistical response slower. Several studies noted one of the major challenges in the disaster relief supply chain is that the resources flow once a disaster has taken place (Day et al., 2012). Convergence is the tendency of offering volunteer care and assistance to individuals or groups at or near the scene of a disaster to those physically injured or emotionally distraught. The convergence exposes the supply chain to certain unique challenges described by Day et al. (2012):

1. Incorporating groups not traditionally involved in disaster response or mitigation decision-making.
2. Setting boundaries requires determining how the convergence-driven individuals or organizations can provide the greatest assistance, and the activities and the areas that are outside of the scope.
3. Ensuring that the provided services have been brought up to current performance standards.
4. Lack of trust within the resulting supply chain relationships.

Critical areas of the disaster relief supply chain identified by experienced practitioners are categorized in four themes as following (Day et al., 2012):

1. Demand signal visibility and requirements determination.
2. Information management and relief activity coordination.
3. Disaster relief planning.
4. Managing relationships and developing trust along the supply chain.

Perry (2007) concurred that local knowledge can be very helpful in assessing the needs considering culture and traditions. Altay and Green III (2006) review the literature to identify potential directions of researching disaster operations and provide a database of practical resources. Soon after a disaster, resilience in the supply chain determines the path to normality through various actors' collaboration in the supply chain networks. Numerous studies are focusing on developing frameworks for the disaster supply chain. Ransikarbum (2015) argues that the existing models for post-disaster disruption management are limited and an integrated system view is required. The model for multi-objective integrated response and recovery (MOIRR) proposed by Ransikarbum and Mason (2016) includes three objectives that integrate the supply disruption problem that occurs during a disaster: first, provide a model to maximize equity or fairness. Second, minimize total unsatisfied demand across the demand/beneficiary nodes. Third, minimize the total calculated network cost as the fund used to restore disrupted nodes, restore disrupted arcs, and transport supply units based on origin-destination pair information. Alderson et al. (2014) illustrate how to build and solve a sequence of models to assess and improve the resilience of an infrastructure system after disruptive events. Akgun et al. (2014) develop a pre-disaster phase model to locate prepositioned supplies close to disaster-prone areas such that a reliable facility network minimizes response time to the demand points. The Cui et al. (2011) develop a GP model for a web service problem and suggest that including only real constraints is not sufficient for describing user requirements; further, there may be no way to satisfy all of the real constraints simultaneously (Ransikarbum, 2015). Jahre and Jensen (2010) have proposed the application of the cluster concept to humanitarian logistics coordination. There are also some platforms that assist in case of disasters. For example, Humanitarian Aid Distribution System is a web-based decision support platform designed to aid non-experienced users to make more effective decisions during the response phase (Vitoriano et al. 2010, Ortuño et al. 2011). However, Ben Othman et al. (2017) argue that most literature used centralized planning approaches for emergency supply chain, while a distributed planning approach can be more suitable according to the large and distributed nature of the emergency supply chain.

Trust in Disaster Supply Communication

One of the main challenges that influence collaboration and communication during a disaster is trust. There has been some research on how to improve trust in the communication process (Murayama et al., 2013). Trust plays a vital role in supply chain relationships. Trust consists of two dimensions of affective and cognitive. Affective trust is loyalty to a partner which is typically developed through firsthand experience. Cognitive trust reflects rationale choice, that the decision to trust is based on economic considerations of the partners investing in the supply chain (Day et al., 2012). Therefore, trust is critical in the disaster relief supply chain. A systematic approach is required to prioritize the needs and all the providers are aware of this periodization immediately to provide the necessary items. Swift trust has a key role in coordination improvement among humanitarian actors. Tatham and Kovács (2010) identified characteristics of swift trust as follows:

1. Information regarding actors involved in disaster relief activities
2. Dispositional trust
3. The clear rule for classification of processes and procedures
4. Role clarity
5. Category (i.e., gender, ethnicity).

A survey by Altay and Green III (2006) in the current literature of emergency disaster management concludes that most of the research in this field focuses on subjects such as disaster results, sociological impacts on communities, psychological effects on survivors or rescue teams, and organizational design and communication problems. The most used techniques for these studies are OR/MS. There is not much work on integrating the interrelated problems of a large-scale multimodal network flow problem. Nahum et al. (2017) argue that most research on emergency response operations is focused on evacuation problems from the perspective of transportation modeling such as network design and traffic assignment. Bai (2016) argues that the current literature regarding emergency supplies mainly depends on deterministic optimization methods. There are some cases that the fixed distributions cannot be determined in the problem and adopting the obtain solution is unsuitable to conduct the emergency management. One of the significant problems faced immediately after a disaster is transporting large amounts of multiple commodities including food, clothing, medicine, medical supplies, machinery, and personnel from several origins to several destinations. Transportation should be quick and efficient to maximize the survival rate of the affected population and minimize the cost of such operations.

Emergency Logistics

Emergency logistics are a set of logistics actors that interact and coordinate to accomplish emergency logistics requirements (Ben Othman et al., 2017). The main features are as follows:

- Automated emergency logistics systems are needed in the affected areas for efficient disaster relief supply and recovery.
- Supply resources and workforce assessment to adjust to the unexpected difficult circumstances.
- A decentralized system to deal with the uncertainties.

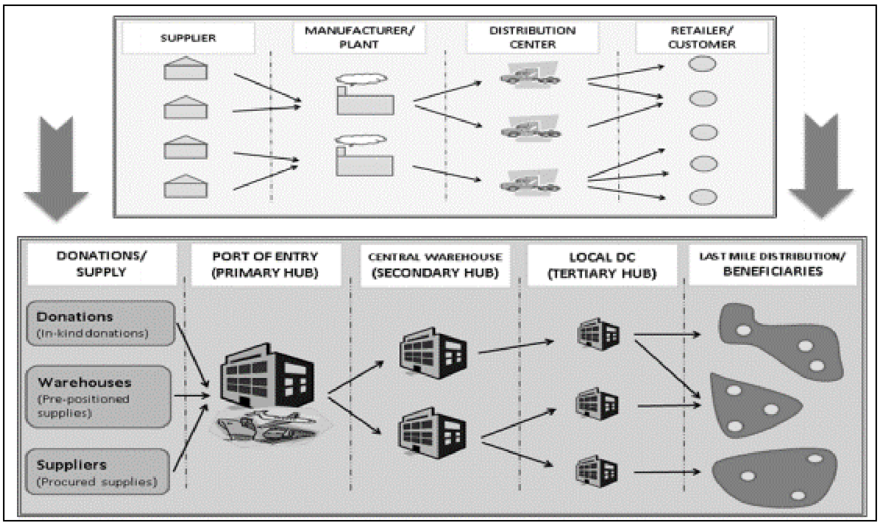
The disaster area is a dynamic environment, and it might evolve, hence emergency logistics are time-sensitive operations. The lack of information about the available infrastructure, supplies, and demands would complicate this dynamic environment even more. The high stake of life or death for victims requires a high level of accuracy and tractability. Logistics planning in emergencies includes sending several relief commodities from different sources to multiple distribution points in the affected areas through a chain structure. Deciding on the right type and quantity of relief items, the sources and destinations of commodities, and how to dispatch relief items to the recipients to minimize the pain and suffering for the disaster victims. Some of the demand items are one-time demand and some are subject to expiration. The demand information might not be completed and accurate at the beginning (Mid-Atlantic Universities Transportation Center, 2009). Logistic coordination in disasters includes the selection of sites that can maximize the coverage of affected areas and minimize the delays for supply delivery operations. Therefore, coordination and cooperation between transportation modes are required for managing the response operations.

Humanitarian Logistics

Humanitarian logistics is defined as a process of planning, managing, and controlling the efficient flows of relief, information, and services from the point of origin to the points of destination to meet the urgent needs of the affected people under emergency conditions (Ransikarbum, 2015). Based on the different types of technologies described, there are three types of activity structures or value creation models including chain, shop, and network. Network taxonomies are based on certain elements including who takes part, who controls, type of coordination, the purpose, the products, the degree of dynamic, etc. This type of network is temporary and unique that is created only for humanitarian operations. The network should be tailored based on the uncertainties about the time, needs, and available infrastructures (Tatham et al., 2009). Based on a literature review of humanitarian logistics research, Ransikarbum (2015) argues that more research is required in humanitarian logistics. The performance of humanitarian logistics is not only based on the effectiveness but the efficiency of post-disasters activities as well. Humanitarian logistics can be a key factor in devising improved ways of managing multi-stakeholder relief operations (Ransikarbum, 2015). Humanitarian organizations try to find a balance between speed and cost in their supply chain.

Figure 10

Commercial - Humanitarian Supply Chain (Beamon & Balcik ,2008)



The different characteristics between non-profit and for-profit organizations are based on revenue sources, goals, stakeholders, and performance management depicted in Figure 10. Based on Tomasini and Van Wassenhove (2009), there are three stages of ramp-up, sustain, and ramp-down in disaster response. The first few days after the strike of a disaster is covered in the ramp-up stage where speed is the main driver, lead time reduction is also important. The focus is on accessing the field and setting up operations according to the highest priority. The objective for the agencies is to get to the affected area, observe, and document damage extent, assess needs and implement urgent solutions. In the sustain stage, agencies try to implement their programs where cost and efficiencies are more concerned. The exit strategy including transferring the operations to the local actors is the focus of agencies in the ramp-down stage. Once the operation has been set up, roles have been defined, and visibility of the process to assist the beneficiaries has increased, the cost would be the adopted driver. The cost and speed balance are also important in disaster preparedness where agencies try to develop better-prepared processes and products to achieve both aims of cost and speed. In the case of a combination of specialized and independent organizations, a series of problems arise related to coordination, such as the 2005 Indian Ocean tsunami and the 2004-2005 Darfur crisis. There were overlapping in some provisions of relief, some populations were not considered properly, and prioritization of pipeline was very problematic. These facts indicate the coordination requirement in contingency planning, needs assessment, appeals, and transport management. The concern would be observing when and how the key players should collaborate and coordinate (Jahre & Jensen, 2010).

Private organizations aid in disaster relief by providing cash, goods, human resources, knowledge, and expertise. Recently private companies are opting to design their social engagement through a long-term partnership with humanitarian organizations not only from a charitable concern but also as an opportunity for learning and developing their business. On the other side, humanitarian agencies invest equal resources to try to enhance their performance and core competencies interacting with the private sector. The main benefit is back-office support for better preparation and the key asset's movement during a disaster (Papadopoulos et al., 2017). Table 10 describes the attributes, costs, and applicability of potential relief chain coordination mechanisms derived from the commercial supply chain coordination mechanisms (Balcik et al., 2010).

Table 10

Potential Relief Chain Coordination Mechanisms

Coordination Mechanism	Currently Observed	Coordination cost	Opportunistic risk Cost	Operational risk Cost	Technological Requirements for NGO	Conductive to relief environment	Implementation Potential
QR, CR, VMI, CVMI	No	Low	High	High	High	No	Higher for large NGOs, but low overall
Collaborative Procurement	Yes	Low	Low	Low	Low	Yes	High
Warehouse standardization	No	High	Varies	High	Medium	Yes	Low
Third-party warehousing (umbrella org.)	Yes	Low	Low	Low	Low	Yes	High
Third-party warehousing (private sector partner)	Yes	Medium	Medium	Varies	Low	Yes	High
Transportation: Shipper collaboration	No	High	Varies	High	Medium	No	Low
4PL	No	High	High	High	Medium	No	Low

Ransikarbum (2015) suggests the research areas needed in humanitarian supply chain and relief operations as follows:

- Distribution planning
- Information and communication system

- Sourcing and supplier management
- Performance measurement
- Transportation, mode choice, and routing.

Decision-making in humanitarian logistics operation are dynamic, applying dynamics simulations to study the effects of stakeholder on other parties can be a practical tool (Ransikarbum, 2015). To have more efficient coordination and integration within a supply chain and among multiple supply chains, using a decentralized structure for the distribution of activities and resources is an attractive part of the preparedness strategy for many multinational NGOs. The decentralized units are representing as information intermediaries between players to be activated in the response phase by instituting business relations (Tatham et al., 2009).

Theory Relevant to Research Questions

Disasters are varied in nature and reflect the influences of two factors: First is the speed of onset, second is the source of the disaster (Day et al., 2012). Besides, disasters are interrelated and compounding. The main theories that are relevant to this research are categorized into two groups of disaster management theories and disaster supply chain theories.

Disaster Management Theories

One of the significant challenges in disaster management is to plan and address disaster responses systematically. Sementelli (2007) argues that there are underlying theories and heuristics for a disaster situation regardless of the context of that disaster situation. In this study, the aim is to create a basic taxonomy of current disaster theory. The range of theories is very vast from simple approaches to complex political elements. The disaster research can be categorized into two dimensions of framing focus on process and naming with the focus on tools. For this dimension, four categories of theories are considered including decision theory, which is the largest one, leadership and management theories, social theories, and economic theories. These categories are better depicted in Table 11. In the context of social theories, ecological models and environmental elements are used for several reasons including uncovering stressors, communication, perceptions, and gender role in the disaster literature. Decision theories have top-down approaches and are data-driven. Besides considering the theories, the other categories would be focusing on vulnerability, uncertainty, and ambiguity management of disasters. Within theories, Drabek (1985) recognized coordination concerns among the participants in the context of decentralization.

Table 10

Disaster Theories Categories (Sementelli, 2007)

Categories Concerns			
	High	Decision Theories • Data-intensive approaches • Rational approaches policies • Standard operation procedures • Basic satisficing • GIS • Remote sensing	Administrative Theories • Leadership • Management • Ethics • Responsibility
Concern for tools	Low	Economic Theories • Resource allocation • Economic Impact Systems • Experiments	Social Theories • Social construction • Critical theory • Gendered approaches • Marginalization
		Low	High
		Concern for process	

Disaster Supply Chain Theories

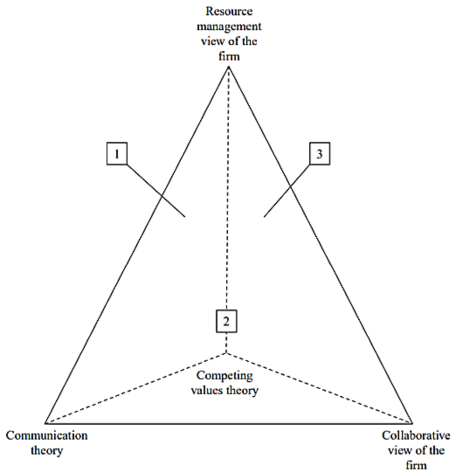
Theories have a significant role in making sense of the current complex living environment (Tabaklar et al., 2015). Tatham et al. (2009) argue that developing theories in the field of humanitarian logistics is required. As the first attempt to theoretically support supply chain disaster preparedness and recovery, Richey (2009) argues that the focus on supply chains related to disasters has been expanded recently and still a very young field. Therefore, there is little theoretical grounding in extant studies. Tabaklar et al. (2015) claims that there is a lack of research on theoretical approaches toward humanitarian supply chain management and reviewed the literature to provide a deeper understanding of the field from a theoretical view. The results indicated that humanitarian logistics is the primary discipline for the supply chain and there is a lack of other theoretical perspectives and grand theories. The three identified keystones for this discipline by Richey (2009) are communication theory, relationship management theories (collaboration), and competing value theory (contingency planning) depicted in Figure 11, and these foundations are linked with resource management. The goal is to provide interconnection among stakeholders to fulfill the following aims:

- Obtain effective partnership and develop collaborative relationships for a long-term commitment.
- Foster information development and exchange to facilitate strategic planning.
- Develop contingency programs for flexible response to the inevitable changes along with following inconsistent goals.

Even though the performance and core objectives of humanitarian supply chain management are different from the traditional view of supply chain management, the fundamental components are similar as been identified in other research (Cooper et al., 1997) and Lambert et al. (1998)) are a) supply chain network structure, b) supply chain business processes and c) management components (Tabaklar et al., 2015).

Figure 11

Disaster Pyramid Retrieved (Richey, 2009)



Resources play a vital role in disaster supply chain management. Resources can be human, financial, informational, technological, and physical. Thus theoretically, empirical models are required to manage resource employment, impact, and interaction. If the resources are matched to strategic initiatives in a disaster condition, it can be the key to initiative performance (Richey, 2009). In traditional logistics, the focus is on improving efficiency and cost reduction while in humanitarian logistics the focus is toward an innovative and responsive approach due to the highly dynamic nature of the field (Tatham et al., 2009). Usually, disasters require short-term stabilization actions followed by a mid-to-long-term recovery process. The consequences demand a lot of time, effort, and investment to overcome. Disaster supply chain management needs to proactively ensure supply chain redundancy and agility to prevent the ripple effect. A disaster supply chain is extremely uncertain and dynamic which required unique management principles. Communication is one of the most important factors in disaster relief operations due to the fast pace of disaster management. One approach that permits taking action immediately is *decentralization*. For example, Walmart took a decentralized approach that allowed providing food and water to the victims quickly and effectively in the 2005 hurricane Katrina disaster.

To improve the humanitarian logistics field, Tatham et al. (2009) suggest using the theoretical aspect of logistics and the empirical aspect of humanitarian aid operations. The study indicates three challenging dimensions for each disaster to enhance the response capabilities are as follow:

- Temporary networks
- Vertical and horizontal coordination
- Structure (centralized / decentralized).

Modeling and Simulation

Natural disasters have resulted in the mortality of almost three million people and affected the lives of 800 million people worldwide which led to diseases and serious economic losses. Modeling and simulating the rescue procedure can help to facilitate emergency management and limit the impact on society (Mustapha et al., 2013). Applying simulation as a tool to understand issues of decision-making has gained considerable attention recently. The true validation of preparedness efforts comes as the result of a response to an actual disaster event. However, simulation can be used to evaluate the efficiency and effectiveness of the plan and the components in the preparedness phase. A controlled scenario-driven simulation can be designed to demonstrate and evaluate the capability to execute the operational tasks and procedures as are outlined in the contingency plan. Ben Othman et al. (2017) team is among the pioneers who research the case of supply chain management under emergency in cooperation with Airbus Defense and Space. Simulation-based studies have been used for planning evacuation operations in several studies (Hardy et al., 2008; Hardy et al., 2009; Pidd et al., 1996; Zou et al., 2005).

Modeling can help in the commission of fundamental analysis for the strength of a particular tool and the aims of a planned analytical endeavor (Hardy et al., 2009). Simulation can be used for analyzing the different types of disaster management activities as well. Sebatli et al. (2017) provide a simulation-based approach to determine the supply demands of an affected area from a disaster. To determine the optimum decision rules on the applied method to address a specific class of disaster problems in the case that the knowledge is incomplete and the uncertainties cannot be easily resolved, Bankes (1993) suggests applying comprehensive simulation models of interdisciplinary nature to capture some aspects of the phenomena (Altay & Green III, 2006). Therefore, simulation is an effective tool for visualizing supply chain risks which deal with the stochastic nature of supply chain and risk uncertainties (Aqlan & Lam, 2015). There are not many frameworks developed that support both the design and the implementation of disaster simulation. There is some limitation for modeling natural disasters:

1. Lack of sufficient consideration of the organization.
2. Aspects of natural disasters including the structure and organizational dynamics related to behaviors associated with multiple roles.
3. Not taking into account observable and indicators specific to the organization of the disaster which is usually defined by the domain experts. These are data and inform ongoing decision processes.
4. Validation limitations -- in evacuation models, validation refers to a systematic comparison of model predictions with liable information. The lack of suitable experimental data to feed the modeling can cause challenges.
5. Weakness in the presentation of occupants in the models. Accurate occupants' representation according to comprehensive anthropometric data and human performance should be used to provide a further level of validity to the model.

6. There are limitations in the interoperability between emergency response modeling and simulation applications.
7. Data transferring between emergency response simulation software applications is very costly.

Based on Mustapha et al. (2013), there are two frameworks available. The first one is the agent-based disaster simulation environment that provides model elements and tools to support the modeling and simulation of different types of disasters which describes how agents move, attach, and interact with each other and with the environment. The second one is the dynamic discrete disaster decision simulation system that is a comprehensive decision support system to simulate large-scale disaster responses. Multi-agent systems (MAS) are a powerful modeling tool for individual interaction simulation in a dynamic system. It has a distinctive ability to simulate situations that contains unpredictable behavior. MAS is one of the methods used for natural disaster emergencies modeling and simulation, creating computer representations of dynamic events. The behavior of a set of entities can be modeled with a MAS. The application of MAS helps to experiment with all possible scenarios of a disaster and assist in the decision-making process (Mustapha et al., 2013).

Simulation models can be used to study disruption propagation and the ripple effect across multiple tiers. Simulation models allow an in-depth view of network operations considering real-time operation and situational behavior changes. A simulation model can be used to analyze the complexity of disaster supply chain risks, the development of contingency plans, and more efficient disaster management. Supply chain faces uncertainty in terms of supply, demand, and process. Swaminathan et al. (1998) applied simulation to deal with the uncertainties in supply chain management. Simulation enables the decision-makers to quantitatively assess the risks and opportunities associated with various supply chain reengineering alternatives. Simulation-based studies are commonly used for planning evacuation operations, analyzing the different types of disaster operation management including resource allocation and mass decontamination, and relief supplies distribution operations (Rodrigo et al., 2018).

New Technologies

For effective disaster management information is vital. Information systems have a great role in recording, exchanging, and processing information (Sakurai & Murayama, 2019). Even though the new information technologies have changed the situational information collection, Sakurai and Murayama (2019) argue that there are not enough discussions about the technologies implementation with certain strategies.

Table 11

Information Technology Role in Disaster Management Phases

Disaster Phase	Applicable Information Technology
Mitigation	Monitor real-time risk • Sensor network systems (vulnerability of infrastructures) • Unmanned aerial vehicles
Preparedness	Living-lab Scenario-simulation (ex: virtual reality) Messenger application and online dashboards Knowledge repository based on previous disaster experiences
Response	Provide Situational Information • Situational awareness (social networks) • Decision-making
Recovery	Manage recovery operation • Available resources coordination • Share victim data • Interactive communication and enhance collaboration with disaster relief agencies

A general disaster plan explains a chain of command in a disaster duration. However, there is no holistic strategy that indicates who should use what technology for what reason (Sakurai & Murayama, 2019). Due to the high frequency of disasters, the lack of up-to-date technology systems is one of the challenges which organizations must deal with. Moreover, the main challenge of humanitarian logistics networks is the requirement for better coordination (Tatham et al., 2009). The information technologies application in each phase of a disaster is demonstrated by Sakurai and Murayama (2019) described in Table 12.

Cloud Computing

Social media is a new source of information for disaster relief agencies that improve situational awareness and two-way communication (Sakurai & Murayama, 2019). Cloud computing has emerged as a technology and has the potential to revolutionize the information and communication landscape. Moreover, cloud computing allows the development of reliable, agile, and incrementally deployable and scalable systems at low cost and access to large shared resources on demand. Alazawi et al. (2011) proposed an intelligent disaster management system. The intelligent system is capable of gathering information from multiple sources and locations, making effective strategies and decisions, propagating the information to other nodes in real-time.

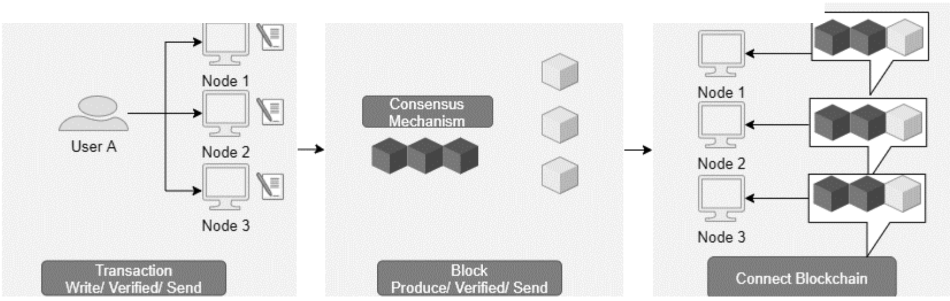
Blockchain Technology

Blockchain is considered as the fifth disruptive innovation following mainframe, personal computer, internet, mobile, and social network, and it is the fourth milestone of the credit evolution. Blockchain is predicted to remodel human society drastically and will promote the present information internet to the credit internet (R. Xu et al., 2017). The basic idea of blockchain was incepted by Harber and Stornetta in 1991 and the first version was created in 2008 with an original white paper of Bitcoin by Satoshi Nakamoro published on his internet page (Zile & Strazdina, 2018). Cryptocurrency Bitcoin was the first practical solution of applying blockchain technology and one of the main reasons for blockchain's current popularity. Based on the World Economic Forum report in 2015, blockchain has been considered as one of the megatrends that are going to change the world in the next decade (Kshetri, 2018). Blockchain technology is formally defined as a “fully distributed system for cryptographically capturing and storing a consistent, immutable, linear event log for transactions between network actors” (Risius & Spohrer, 2017, p. 386); transparency is enforced within the network with system-wide consensus on the validity of the entire history of transactions (Queiroz et al., 2019). Blockchain consists of nodes within a communication network that contains a common communication protocol. Each node stores a copy of the blockchain on the network, and a consensus function verifies transactions to preserve the immutability of the chain (Wang et al., 2019). Each block is identified through its cryptographic hash, and each block is referred to as the hash of the previous block, which creates a link between blocks that form a blockchain. The transactions of each block are hashed in a Merkle tree. The root hash and the hash of the previous block are recorded in the block header. Blockchain provides interaction between users using a pair of public and private keys (Casado-Vara et al., 2018). The hashing process transforms assets into a digitally encoded token that can be registered, tracked, and traded with a private key on the blockchain (Ivanov et al., 2019). Every blockchain network needs a distributed consensus mechanism. As the transaction is approved by the network, it will be a valid and permanent part of the database. This method can enhance the transparency, trust, and traceability of the system significantly (Tian, 2017). Users have access to the audit trail of activity. The decentralized storage of data decreases the risk of failure of any single point (Wang et al., 2019). Figure 12 demonstrates the blockchain operation.

The main characteristics of a blockchain identified through literature are decentralization, immutability, disintermediation, transaction sharing, creation, and movement of digital assets, and tamperproof (Queiroz et al., 2019; Tian, 2017). Based on the blockchain decentralization feature, the intermediaries can be eliminated with the application of a smart contract, which is an automated manner for asset transfer in case the determined conditions are fulfilled. Thus, the decentralization and disintermediation features of blockchain can support supply network management innovation and reconfiguration (Queiroz et al., 2019).

Figure 12

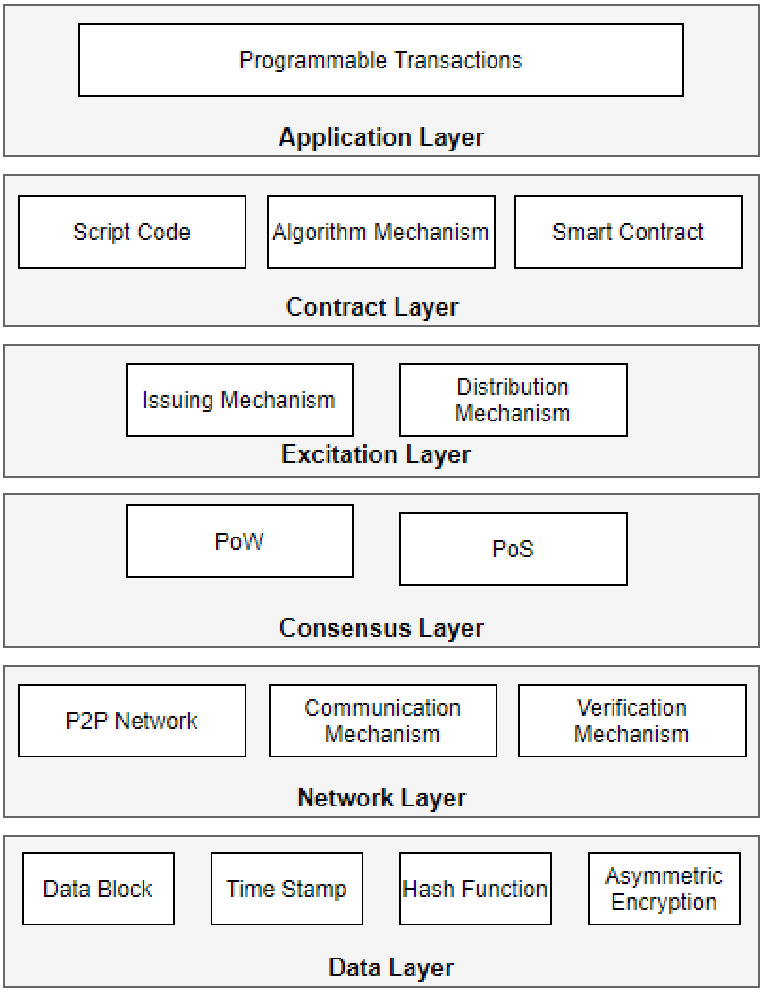
Blockchain Operation Adapted by Yoo and Won (2018)



A blockchain system consists of six layers, as shown in Figure 13. The decentralization feature forms the fundament of the blockchain-based networks which provide distributed trust and consensus. Hence, large networks have the integrity of transactions among the peers in a peer-to-peer configuration without the central mediate third party. According to the establishment of verifiable trust, the networks can be audited in a trusted and transparent manner. Blockchain facilitates operations that require interactions among several stakeholders providing transparency and trust without involving any third party (Hassan et al., 2019). The immutability, transparency, and peer-to-peer consensus features of blockchain provide a trusted audit of networked systems meanwhile the control is to the edge of a network (Hassan et al., 2019).

Figure 13

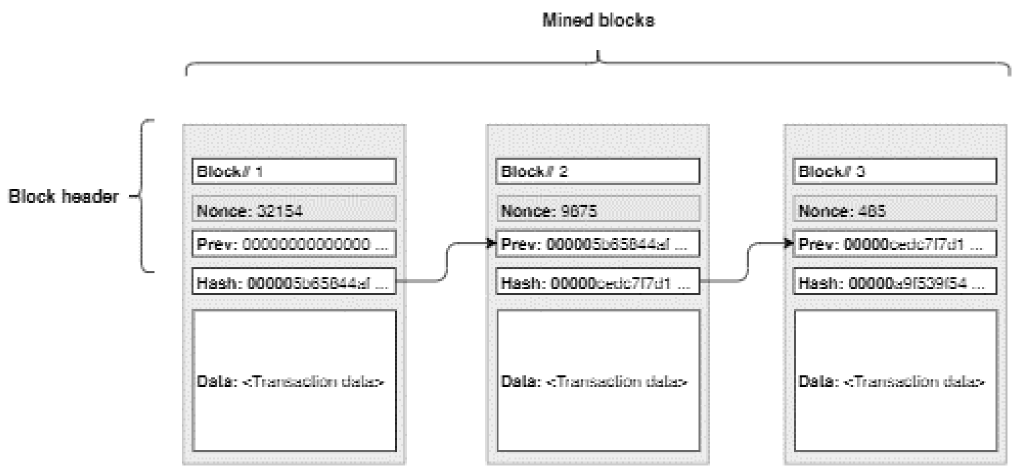
Blockchain Layers (R. Xu et al., 2017)



Transactions among the peers are stored as a record in a series of a data structured chain and every member of the network preserves a copy of this record (Hassan et al., 2019). Hash is defined as a unidirectional cryptographic function. A hash function takes an arbitrary input of an arbitrary length that generates a random fixed-length string of characters as the output. Hence, each output is unique and footprint for the input. Hash can be used to check the integrity of a piece of data. Figure 16 depicts a simple version of blockchain adopted from Hassan et al. (2019). Merkle trees are one of the essential components of blockchain that support vital blockchain functionality and enable efficient and secure verification of large data structures. Merkle tree structure is hash-based which can ensure data integrity. With any changes, the hashes on the path from the root to the changing leaves are changed (Weber et al., 2019). There are four main fields for each block (Figure 14). The first block in a blockchain is called the genesis block. The contents of a hash value include block number, previous hash, and data is recorded in the hash field. The previous hash is the most important part that contains the hash value of the previous block which will chain the blocks together. If the contents of a block change, it would be reflected in the hash of the considered block as well as the portion of the blockchains that come after that block. Hence, the records stored in a blockchain are immutable since hashing and the distribution of blockchain are copied among the peers of the network (Hassan et al., 2019).

Figure 14

Blockchain Mined Blocks (Hassan et al., 2019)



For each block to be added to the chain, all network participants must confirm the authenticity which means reaching the network consensus and being validated by all the nodes up to the point that all the nodes have an up-to-date blockchain structure (Zile & Strazdina, 2018). The peers of the blockchain network are informed of the overall state of the stored records in the blocks using the consensus engines. The consensus mechanisms such as Proof-of-Work (PoW), Proof-of-Stake (PoS), or Proof-of-Authority (PoA) coordinate the nodes and decide which block should be added to the ledger next (Lohmer et al., 2020). The main goal of the consensus mechanism is to provide a verifiable trust guarantee (nonce) to prevent the double spending of a digital asset. Finding a nonce is a computationally rigorous process called mining. A nonce is an integer that produces a hash matching a predefined pattern when hashed together with the contents of a block. As the miner finds a nonce, the network rewards the node with a set number of cryptocurrency tokens (Hassan et al., 2019).

Blockchain provides global, tamper-resistant, and append-only ledgers for a namespace system that guarantee the integrity, availability, uniqueness, and security of name-value pairs. Hence, blockchain technology provides the necessary fundament for the construction and governance of secure and distributed naming services (Hassan et al., 2019). Immutability of the recorded entries is one of the main principles of blockchain. The intended application of blockchain and the parameters including scalability and accessibility determine the mechanism of achieving immutability.

Table 12

Classification of Blockchain Types

Access to Transactions	Access to Transaction Validation	
	Permissioned	Permissionless
Public	All nodes can read and submit transactions. Only authorized nodes can validate transactions.	All nodes can read, submit, and validate transactions
Private	Only authorized nodes can read, submit, and validate transactions.	
Consortium (Verma et al., 2019)	Partially decentralized Controlled by a group of organizations that have authority to participate by running as a full node and by mining	

Data distribution is the other important part of blockchain technology (Zile & Strazdina, 2018). Permissioned and private blockchain also are available in addition to the public one. Linux Foundation's Hyperledger Fabric (HLF) popularized this concept for business use cases that requires confidentially in addition to data immutability and peer-to-peer consensus (Table 13). These two types deploy a cryptographic membership service on top of the immutable record-keeping of blockchain. Hence, each member can be identified based on the real-world identity (Hassan et al., 2019).

Table 13

Blockchain Evolution Timeline (Hassan et al., 2019)

Year	Description
2018	Blockchains potential expansions due to more investments in a vast variety of use cases
2017	Blockchain-based trade finance platform developed by several European banks in collaboration with IBM
2016	The emergence of permissioned blockchain solutions
2015	Hyperledger project was started. NASDAQ initiated a blockchain trial
2014	Ethereum project was started with crowdfunding and Ethereum genesis block was created
2013	Ethereum was proposed as a blockchain-based distributed computing platform
2012	Coinbase was started (a brokerage of Bitcoin)
2011	The emergence of some cryptocurrencies such as Litecoin. With the Bitcoin payment method, the Silk Road project was launched. BitPay was created as the first blockchain-based wallet.
2010	The first Bitcoin cryptocurrency exchange started working
2009	The first Bitcoin block was created
2008	Satoshi published Bitcoin's whitepaper

A permissionless public blockchain is the most well-known kind mostly token-based systems, rely on decentralization, immutability, auditability, and anonymity. These systems eliminate the need for a third party, open for participation either for transacting or validating, higher transaction speed and lower fees. In permissioned blockchains, the network maintenance is not primarily driven by mining, but by more efficient consensus algorithms, and the value of the stored data is dependent on the unambiguity (Ziolkowski et al., 2018). Table 14 describes the evolution of blockchain up to 2018.

Several blockchain applications have been introduced where Blockchain 1.0 is for cryptocurrencies, Blockchain 2.0 for economic, market, and financial applications, and blockchain 3.0 for applications beyond currency, finance, and markets (Rodrigo et al., 2018). Blockchain technology can be the key to the essential ingredients to confront the content distribution challenges and a more agile method for content delivery with a more trusted, autonomous, and intelligent network (Hassan et al., 2019). Blockchain can be a breakthrough invention changing daily activities and processes in different application domains. The most frequent application efforts of blockchain are in the financial sector and then government, insurance, and healthcare services (Zile & Strazdina, 2018). However, blockchain technology is still at the initial stage of adaption. Table 15 provides an overview of the most popular solutions used in blockchain.

Some evaluation models for blockchain have been developed recently as stated by Zile and Strazdina (2018). A multi-level framework created by Verma et al. (2019) can be applied to evaluate the initial suitability of blockchain. The framework reviews different technical aspects of blockchain and arrives step-by-step to decide on using the blockchain. The application of the framework on different use cases claims that blockchain is suitable for supply chain and identity data management projects (Zile & Strazdina, 2018). Effective supply chain management is challenging in every sector, but disaster management has added complexity and risk due to its direct impact on victims' lives. The ability of blockchain in receiving and recording a huge amount of data and real-time availability for every part of the process provides one of the most transparent and secure ways to deal with data and enable observing the online activities of the project (Akram & Bross, 2018). The most research focus is on designing blockchain-based systems to achieve traceability by leveraging the main properties of the blockchain as stated by Weber et al. (2019, p. 4). The capacity to utilize smart contracts to automate processes and reduce costs is a crucial mechanism that blockchain technology could support supply chain performance enhancement.

Table 14

Popular Blockchain Use Cases (Zile & Strazdina, 2018)

Category	Use Cases	
Data management	• Network infrastructure • Content and resource distribution • Cloud storage • Data monitoring • Identity data management • Contract management • Inter-organizational data management	• Tamper-proof event log and audit trail • System metadata storage • Data replication and protection from deleting • Digital content publishing and selling • IoT sensor data purchasing
Data verification	• Photo and video proofing • Document notarization • Work history verification • Academicals certification	• Identity verification • Product quality verification • Proof of origin

Table 15 (continued)

Financial	• Trade finance • Currency exchange and remittance • P2P payments • Crowdfunding	• Central bank money issuing • Stock share and bond issuing • Supply chain management • Value transfer and lending • Insurance
Other	• Predicting recording • Social voting system • Ridesharing • Domain name registration • Healthcare record storing • Software license validation • Content or product timestamping • Lottery • Property right registration • Social rating creation/ monitoring	• Voting in elections • Marriage registration • Court proceedings • Donations • Computational power • Electronic locks • Electro energy selling • Product tracing • Gaming • Reviews and endorsement

Blockchain technology can enhance supply chain management through the followings (Clauson et al., 2018):

1. Reduce or eliminate fraud and errors
2. Reduce delays from paperwork
3. Improve inventory management

4. Identify issues more rapidly
5. Minimize costs
6. Increase consumer and partner trust.

One of the main differences between blockchain and other existing technologies is the lower costs of adding new participants, data encryption, and record validation. Blockchain provides a faster transaction by reducing the required time of obtaining confirmation from multiple participants, providing reliable and verified information, and by allowing automation of some of the transaction logic through smart contracts (Babich & Hilary, 2018).

There are potential benefits of automation through blockchain. It can increase coordination through the supply chain. If the downtime of the machine is unavoidable, the customer would be informed of the potential disruption to their supply. Blockchain technology with smart contracts permits the automatic activation of the entire supply chain. The critical challenges in disasters could be addressed with superior supply chain management practices that are digitally enabled by blockchain technology (Clauson et al., 2018). A blockchain-based disaster supply chain system can enhance communication among all the stakeholders to provide receiving real-time feedback and responses. Multi-signature governance accounts provide more security by distributing transaction approval over key decision-makers that are involved in the network. Applying blockchain to the disaster response process can improve the collection and sharing of data processes. The ordering and tracking updating information will be linked in a chain that utilizes a peer-to-peer validation process to build trust within the system. All the valid participants of the network can view the changes and updates assisting to improve transparency and transaction auditability (Anand et al., 2016). Moreover, blockchains can be practical in disaster relief processes by decreasing bureaucracy and reporting requirements, provide better access to decision-makers, quicker fund availability, and long-term funding. Based on the distributed consensus verification and irreversibility feature of blockchain, stakeholders voting can be implemented (R. Xu et al., 2017).

Blockchain has been applied in the field of disaster supply chain, some of the most relevant articles to supply chain and disaster management are mentioned in the systematic literature review section. Clauson et al. (2018) provide an overview of the opportunities and challenges associated with blockchain adoption and deployment for the health supply chain. Hassan et al. (2019) used blockchain-based solutions to find common patterns, differences, and technical limitations in decision-making. Though some studies are looking at blockchain and supply chain management, there is not much research on blockchain utilization for disaster supply chain network communication.

Smart Contracts

A smart contract is a software program that stores policies and rules for negotiating terms and actions between parties (Casado-Vara et al., 2018). The smart contract concept was introduced by Nick Szabo in 1994 where the computerized transaction protocol executes the terms of a contract (Kushwaha & Joshi, 2021) intending to reduce costs and delays of traditional contracts and satisfy common contractual conditions. Smart contracts are considered as algorithmic enforcement of an agreement among, mutually non-trusting entities. The smart contract includes first the functions that receive input parameters of the contract and get invoked when the transactions are made. The second is the state variable that is dependent on the logic developed in the functions. Compilers convert the written programs into bytecode and deploy them to the blockchain network. An arbitrary value is transferred to an immutable manner that the conditional transactions are recorded, executed, and distributed across the blockchain network (Hassan et al., 2019). The transaction in the smart contract is executed independently and automatically in a prescribed way on every node of the network based on the data included in the triggered transaction (Casado-Vara et al., 2018). Smart contracts decrease the legal and enforcement expenses and the regulating authority requirement. It creates a trusted environment for the members from multiple contrasting and diverse communities (Hassan et al., 2019). Smart contracts in blockchains enable creating a self-governing partnership with enforceable rules of interactions without the need for a central authority (Ziolkowski et al., 2018). However, some benefits can be provided by blockchain technology that can be used in disaster management.

1. Smart contract functionality. The disaster management policy can be scripted with the smart contract to provide the requirements of the disaster which enables all stakeholders to approve on milestones. Damage can be logged, and costs can be estimated early in the recovery process.
2. Distributed funding: payments can be made to service providers based on the smart contract milestones. Responsibility in overruns is shared by all and payment is based upon the performance of agreed-upon requirements.
3. Multi-party validation: all stakeholders can validate the parameters in the progress of the project. The oversight committee would increase the effectiveness and value of performing an audit.

Smart contracts can be used to ensure data security and confidence in data quality (Akram & Bross, 2018). Collecting information across multiple organizations would be easier through blockchain technology. The aggregation of information can be done selectively and just the required information for improving system efficiency is shared. The aggregated information can be used synergistically and improve the performance of the system and reallocate benefits among participants. Smart contracts can automate actions based on aggregate information, decrease the lead time, and generate markets that non-standardized resources are traded (Babich & Hilary, 2018).

The decision-making process throughout a disaster response varies significantly from conventional decision-making. The challenges are that the important attributes of the problem are uncertain, the nature of the problem is dynamic and uncontrollable, the decision should be made in a very short time with the lack of unreliable information, and some critical decisions might be irreversible in disaster emergency response situations (Altay & Green III, 2006). Therefore, communication among all the parties within disaster phases plays a significant role in achieving the objectives. Constructing a common operational structure is necessary for communication and coordination of activities among emergency response organizations which requires an appropriate level of shared information and participation in the disaster operation at multiple locations. All actors should be aware of all the limits in the possible combination of collaborations and support under a set of conditions. There will be more challenges when a range of heterogeneous organizations are included in the operations. Communication in emergency management includes the capacity to build shared meanings among the involved participants while the focus has been more on the interoperability of the mechanical devices (eg., radio, cellphone, etc.). This process requires the capacity of resonance between the organization and the environment for innovation or new ways to solve the problem (Comfort, 2007). A white house homeland security report based on the lesson learned noted, “The lack of communication and situational awareness had a debilitating effect on the federal response.” (Haddow et al., 2017). Adding cognition to emergency management would include systematic means of adapting to the dynamic and uncertain conditions of a disaster evolvement.

The other aspect is coordination which is dependent on communication. The other component is control which in emergency management is the capacity to keep actions focused on the mutual objectives of saving lives, properties, and maintaining continuous operations. This requires maintaining shared knowledge, skills, reciprocal adjustment of actions to suit the needs of the dynamic situation (Comfort, 2007). All of these capacities have relied on a well-designed information structure which can facilitate the processes of communication, coordination, control, and cognition among the participating actors in emergency response (Comfort, 2007). Information structure is very important since it can construct a human capacity to learn and use technology to monitor performance, facilitate detection, and correction of errors and increase creative problem-solving capability (Comfort, 2007).

Internet of Things (IoT)

IoT provides new types of services to improve daily life where big data, cloud computing, and monitoring can take part. A wireless sensor network is a subset consist of small sensing devices with few resources wirelessly connected. Nodes can communicate with the internet. Sensory features collect information from the environment through specific sensors then process and transmit to the internet (Plageras et al., 2018). The IoT-based sensors provide efficient monitoring of the processes. The IoT-generated sensor data have the characteristics of real-time, large amounts, and unstructured type (Syafrudin et al., 2018).

IoT technology can play a critical role in developing effective monitoring infrastructure and information sharing in disaster management systems. Recently, innovative real-time monitoring and disaster warning systems are developed based on the IoT paradigm where objects are globally interconnected. Wireless sensors network (WSN) is a part of IoT that has been widely used for monitoring natural disasters in remote and inaccessible areas. WSNs are based on autonomous sensor nodes that have monitoring and recording capability of the surrounding environment with low energy (Adeel et al., 2019).

Dynamic Voltage Frequency Scaling (DVFS) Algorithm

Dynamic voltage and frequency scaling (DVFS) was proposed by Gu et al. (2014). DVFS is a sorting process embedded in the server which enables analyzing the disaster management complexity. DVFS is a tool that can be used to analyze the maximum level of disaster management complexity. When there is an awkward request from one of the nodes of the network, which can be an army of clients in case of a disaster, can be detected with the sorting feature of DVFS. The attacked host within the network can be identified. The attacks from the clients can be stored on the server and manage by the disaster based on real-time information. Using two types of immigration algorithm (local and external), the stored information can be linked to it which enables the management of the enforced traffic on the network from the disaster node. Employing DVFS can support managing the vast input data from the disaster and the processing costs. By sorting data on servers and evaluate the transaction power, the nodes that disaster is occurred on can be identified due to the high rate of data added to that node. In the token-based blocks in the network, the information will be rewritten once. When the existing blocks on the disaster location servers are rewritten, the cost of monitoring would be decreased to zero.

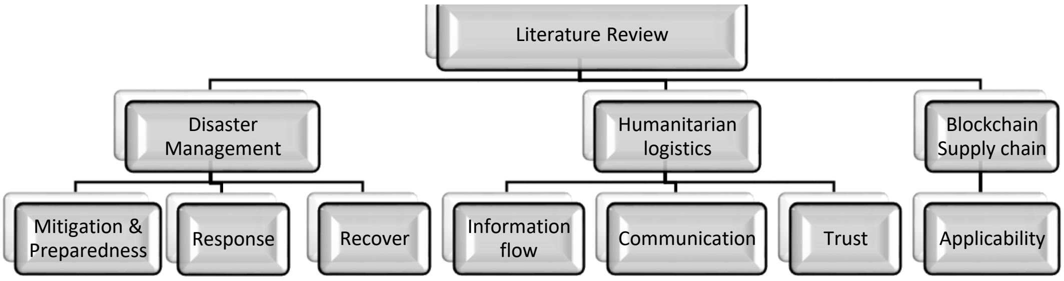
The concept of DVFS has been applied in the literature as a means to reduce the energy consumptions of the proposed applications. Calheiros and Buyya (2014) targeted the energy-efficient execution of cloud models in the disaster management domain, applied DVFS to enable deadlines for the execution of urgent CPU-intensive jobs with less energy consumption. Hosseini Shirvani et al. (2020) emphasized the need for studying virtual machine migration and DVFS techniques on disaster-resilient fault-tolerant systems.

SYSTEMATIC LITERATURE REVIEW

This section explains a systematic literature review on the disaster supply network. The scheme of the literature review is in three different aspects disaster management, humanitarian logistics, and blockchain supply chain (Figure 15).

Figure 15

Literature Review Scheme



The scope of the literature review is shown in Table 16. In literature, numerous endeavors have been done on the analysis and visualization of many different types of bibliometric networks. The most frequently studied types of bibliometric networks are based on citation relations. The value of direct citation networks for studying the history and development of research fields which is referred to as algorithmic historiography needs to be emphasized.

Table 15

Scope of Literature Review

Analysis Items	Categorical Values
Disaster Phases	Preparedness, Planning, Response, Recovery
Application Domain	Emergency Management
Impact on Disaster	Response pace and quality
Impact on victims	Equity, fairness, communication
Assessment layers	Four phases of a disaster
Data Collection	Historical data, simulation data
Phases of the study	Simulation, case study
Method of the study	Algorithmic historiography

A new java-based software tool developed for analyzing and visualizing direct citation networks is introduced by van Eck and Waltman (2014). The software offers sophisticated functionality for drilling down into citation networks dealing with a specific topic of interest.

A systematic literature review is a specific methodology that reviews the existing articles, evaluates the contributions, and analyses and synthesizes data (Etemadi et al., 2021). In the first phase, the disaster supply network articles are reviewed with a focus on disaster network communication. The principal components of disaster supply chain within the literature is shown in Table 17.

Table 16

Principal component bodies of disaster supply chain literature

Analysis Items	Categorical Values
Partnerships	Trust
Strategic networks	Commitment
Supply network design	Partnership performance, information flow
Distribution base integration	Time compression
Contract view	Distribution channel management
Communication	Organizational structure
Knowledge transfer	Technology transfer

The Web of Science database was used as the search query and the keywords combinations are shown in Table 18. The protocols followed for this systematic literature review include a) determining the Web of Science database as the main research database in the duration of 2000-2020, b) only the English language within Journal publications was considered for this review.

Table 17

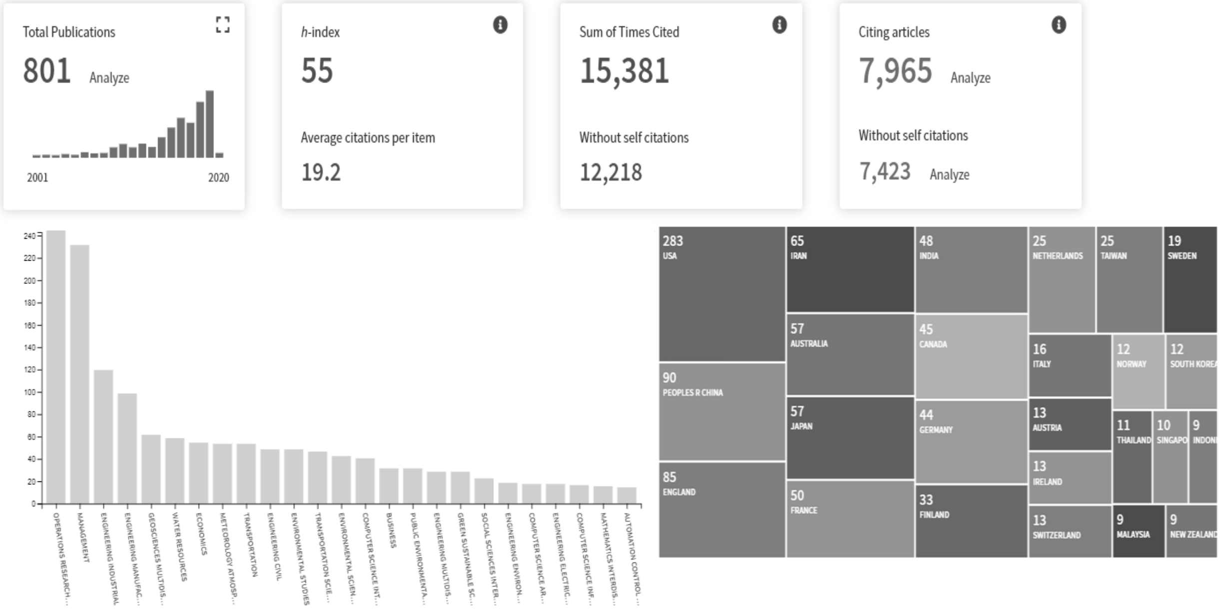
Literature Review Based on the Keywords

Search Query (Article)	Web of Science	
Language (English)	Search Result (1999 – 2021)	Sum of Times Cited
“Disaster” AND “Supply Chain”	618	10883
“Disaster” AND “Supply Network”	44	759
“Disaster” AND “Blockchain”	16	148
“Blockchain” AND “Humanitarian”	14	59
“Blockchain” AND (“Disaster” AND “Supply Chain”	7	85

The citation network in CiteNetExplorer is acyclic due to the visualization of the citation flow. The CiteNetExplorer is applied to find the citation mapping system for the significant papers to find the roots and paths of methods related to the disaster supply network.

Figure 16

Disaster Supply Chain Publications Tree Map



research. At the first point, the search key was the disaster supply chain. The visual tree map of the search results is shown in Figure 16. The citation visualization of supply chain management in disaster response is depicted in Table 17 using CitNetExplorer. The results depicted that the USA was the first leader of research followed by China and England (Figure 18). However, the topic is narrow down to more specific areas. The search on the topic of supply chain management in disaster response shows 148 publications with 272 citation links with 91 core publications in the duration of 2007-2019, shown in Figure 19.

Figure 17

Keyword "Supply Chain Management in Disaster Response "Citation Visualization

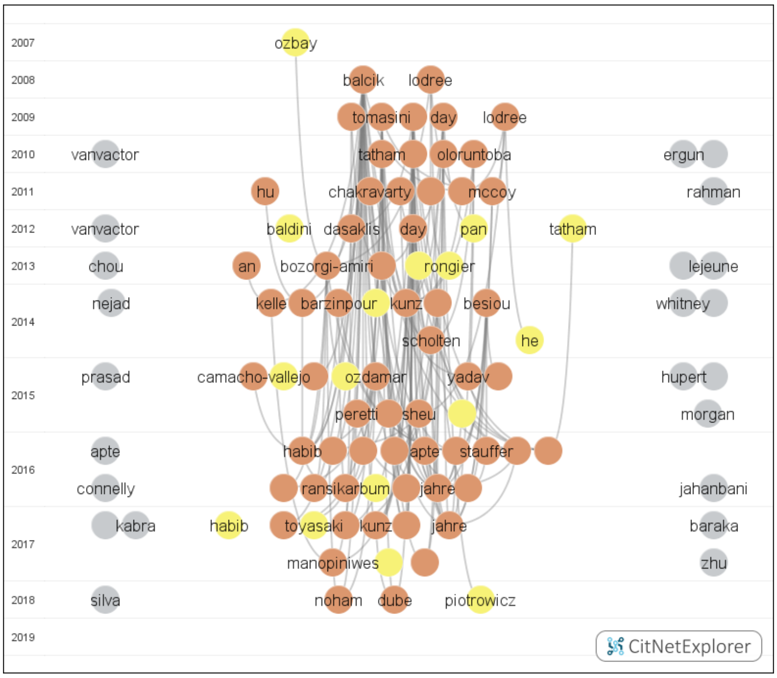
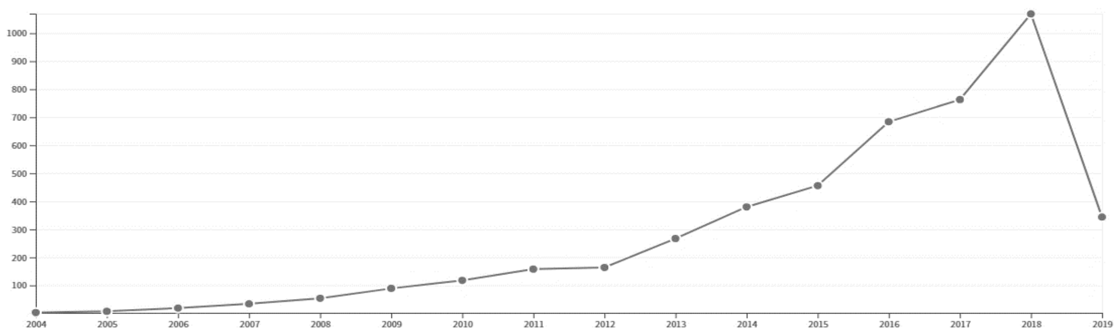


Figure 18

Sum of Times Cited per Year



The main topic for this research to focus on is the "disaster supply network". The results from the software show 253 publications on this topic in the duration of 1993-2019 with 3525 citing articles (Figure 19). The next search topic is blockchain technology in the supply chain and the results are 58 publications in the period 2017-2019 and are shown in Figure 20.

Figure 19

Disaster Supply Chain Citation Network – Blockchain Links

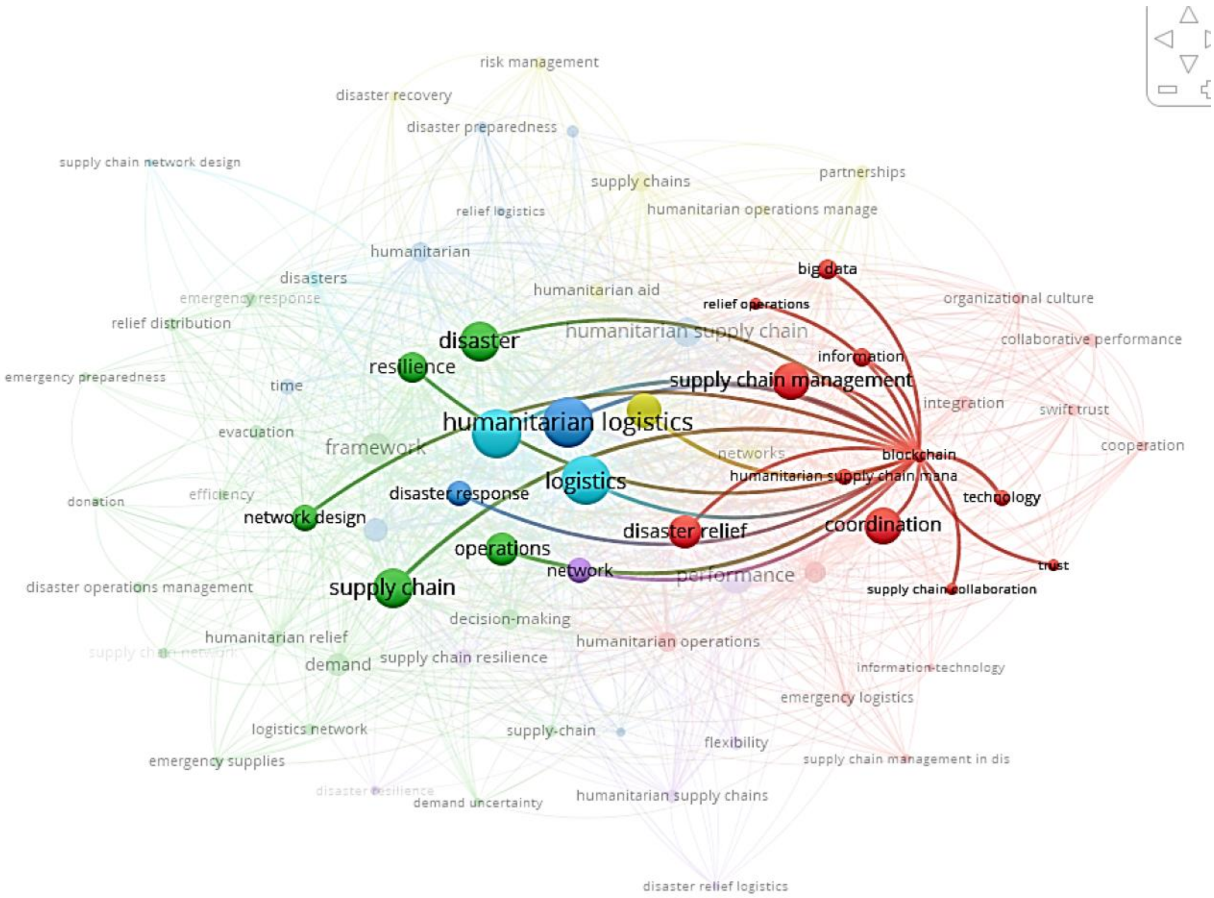


Figure 20

Blockchain in Disaster Management Critical Keywords Links

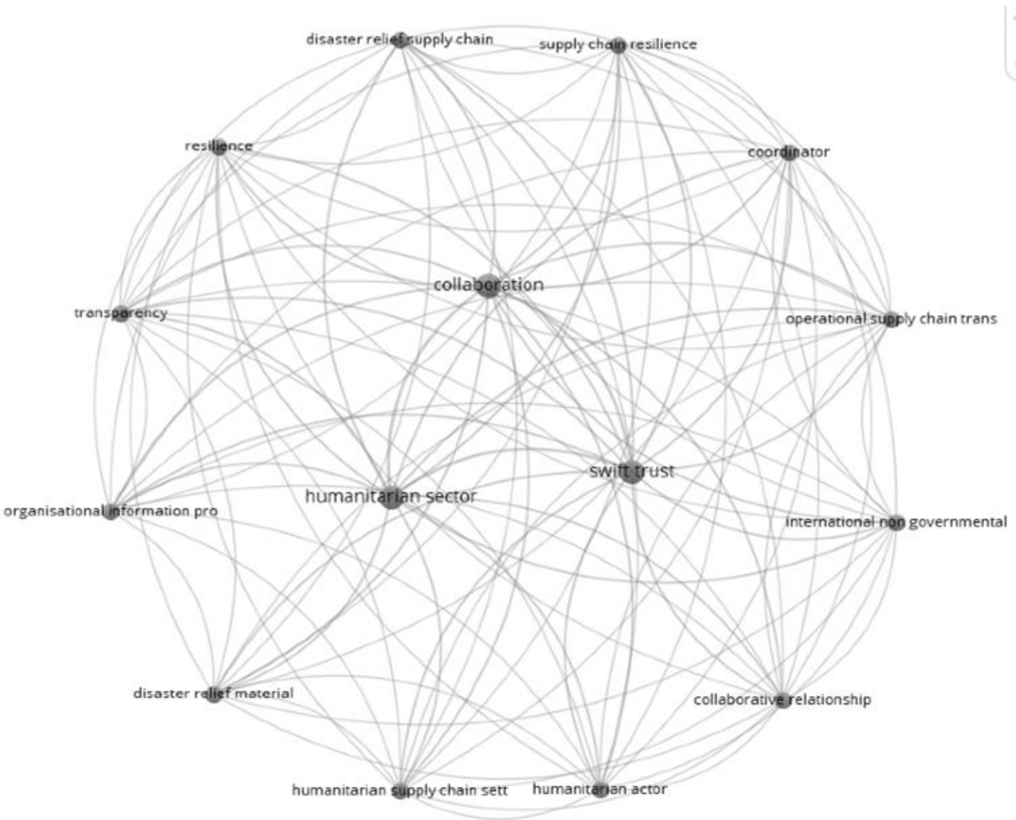


Table 18

Articles Related to the Keywords

Articles	Disaster Management	Humanitarian Aid	Blockchain Technology
Coordinating expertise among emergent groups responding to disasters (Majchrzak et al., 2007)	●		
Post-disaster humanitarian logistics (Holguín-Veras et al., 2012)		●	
Processing social media messages in mass emergency (Imran et al., 2015)	●		
Crisis management in communication (Comfort, 2007)	●		
Humanitarian logistics network design under mixed uncertainty (Tofighi et al., 2016)		●	
Leveraging public-private partnerships to improve resilience in times of disaster (Stewart et al., 2009)	●		
Mitigation processes - antecedents for building supply chain resilience (Scholten et al., 2014)		●	
Big data role in disaster supply chain resilience (Papadopoulos et al., 2017)		●	
Coordination in humanitarian relief chains (Balcik et al., 2010)		●	
Facility location in humanitarian relief (Balcik & Beamon, 2008)		●	
Humanitarian aid logistics (Van Wassenhove, 2006)		●	
Last-mile distribution in humanitarian relief (Balcik et al., 2008)		●	
Coordination in humanitarian logistics (Jahre & Jensen, 2010)		●	
Disaster relief operations supply chain (Maon et al., 2009)		●	
Humanitarian logistics (Tomasini & Van Wassenhove, 2009)		●	
Humanitarian relief supply chains (Day et al., 2012)		●	
Blockchain role supply chain management (Kshetri, 2018; Saberi et al., 2019)			●
Blockchain and foreign aid governance (Reinsberg, 2019)			●
Blockchain technology for a humanitarian supply chain (Dubey et al., 2020)			●

Interestingly, there are 4781 journal publication with the keyword of “Blockchain” within the chosen search query while only seven of them is related to disaster supply chain and are only in 2020 and 2021. Since there are not many articles published in the field, the focus is to find the main keywords that cooccurred in the published articles to illustrate the current approaches of blockchain technology applications in the field of disaster management. The main keywords within the articles with 105 links from the 18 published using the VOSviewer tool (Figure 20).

The next step is reviewing papers with the relevant keywords manually. According to the authors' keywords’ co-occurrence network of citations based on VOSviewer results, the keywords that have the most weights within the citation network are depicted in Table 19. As can be seen in Figure 21, the keywords of collaboration, humanitarian sector, and swift trust have the most weight within the citation network. Table 20 includes the extracted articles that have the most critical keywords and are related to the current study.

Table 19

Categories of Articles Based on the Most Critical Keywords

Authors	Collaboration	Coordination/ Communicatio	Swift Trust	Transparency	Information Sharing	Humanitarian Aid
Dubey et al. (2020)	*		*			*
Rodríguez-Espíndola et al. (2020)	*					*
L'Hermitte and Nair (2020)	*		*			*
Ozdemir et al. (2020)			*			*
Reinsberg (2019)						*
Madianou (2019)				*	*	*
Seyedsayamdost and Vanderwal (2020)			*			*
Rejeb and Rejeb (2020)			*			*
Fu et al. (2020)	*	*	*	*	*	*
Patil et al. (2020)	*					*
Sahebi et al. (2017)			*			*
Khan et al. (2021)	*		*			*
Altay et al. (2009)	*		*			
Ransikarbum (2015)						*
Tatham and Christopher (2018)						*
(Balcik et al., 2010))	*					
Sakurai and Murayama (2019)						
Aranda et al. (2019)	*		*			*
Yang et al. (2013)			*			*
Samir et al. (2019)	*	*	*	*	*	*

Systematic Literature Review Results

Since the literature of blockchain application on disaster supply networks is in the early stage, this study reviews also the most cited papers in blockchain application in supply chain management to provide a better understanding of how blockchain features can address the current challenges in the field. In the next step, the most important and relevant papers from the literature are selected papers for manual review to extract the main challenges in the disaster supply chain identified in the literature and the results are shown in Table 21. Table 22 includes the main contributions of studied articles to the disaster supply network using blockchain technology.

New technologies have changed the news gathering and distribution methods. These technologies altered the flow of information, replaced the centralized, top-down model, and create ad hoc distributive information networks. Inconsistency happens when the event is evolving, but the information is not updated regularly (Glik, 2007). The lack of interaction and institutional overlap among involved communities generate conflicts (Schipper & Pelling, 2006). Usually, the provided aids are based on the organization's decisions not exactly the needs of the recipient.

Table 20

Main Challenges of Disaster Supply Chain

Authors	Topic	Identified Challenges
Day et al. (2012)	Disaster Response Supply Chain	Lack of demand visibility, information, coordination, trust
Tomasini (2009)	Disaster Response Supply Chain	Importance of roles in humanitarian logistics
Maon et al. (2009)	Disaster Response Supply Chain	Lack of coordination in relief sectors
Jahre et al. (2010)	Disaster Response Supply Chain	Challenges in coordination and collaboration in the relief sector
Balcik et al. (2008)	Humanitarian Aid	Lack of right communication in relief sectors
Van Wassnhove (2006)	Humanitarian Aid	High level of complexity disaster relief collaboration
Balcik & Beamon (2008)	Humanitarian Aid	Need of effective and efficient network in disaster response
Balcik et al. (2010)	Humanitarian Aid	Lack of systematic relief chain coordination
Papadopoulos et al. (2017)	Disaster Supply Resilience	Importance of swift trust, information sharing, and partnerships in supply network resiliency
Majchrzaj et al. (2007)	Communication in Disaster Response	Communication difficulty due to geographical dispersion Lack of swift trust
Dubey et al. (2020)	Humanitarian Blockchain	Lack of technology-enabled swift trust and transparency
Reinsberg (2019)	Humanitarian Blockchain	Lack of systemic governance to make informed policy decisions
Saberi et al. (2019)	Blockchain Supply Chain	Categorize barriers in blockchain adoption in the supply chain: inter-organizational, intra-organization, technical, and external

Communication is one of the most important factors in disaster relief operations due to the fast pace of disaster management. One approach that permits acting immediately is decentralization. For example, Walmart took a decentralized approach that allowed providing food and water to the victims quickly and effectively in the 2005 Hurricane Katrina disaster. Ben Othman et al. (2017) argue that most literature used centralized planning approaches for emergency supply chains, while a distributed planning approach can be more suitable according to the large and distributed nature of the emergency supply chain. This study aims to adapt an integrated framework that enables a decentralized network structure to overcome the mentioned challenges.

Some recent studies focused on using new technologies to tackle the challenges of humanitarian communication. A wide range of solutions have been proposed using computer models, artificial intelligence, and satellite images to leverage accurate and reliable information and make appropriate decisions. Distributed ledger yechnology (DLT) can address some of the challenges of disaster supply networks including transparency, efficiency, scale, and sustainability (Coppi & Fast, 2019). DLT can update the ledger with consensus, share the transaction database, and record the ledger with timestamped and tamper-proof auditable history (Rajan, 2018).

The most application of DLT in humanitarian support is more focused on improving the transparency of donations, reducing fraud, tracking support from multiple sources, micro-insurance, cross-border transfer, grant management, and organizational governance. Blockchain technology can improve efficiency in financing aspects and tackle challenges to alleviate losses from disasters more effectively. Coppi and Fast (2019) argue that the current projects are more limited to accountability and protection framework that is based on humanitarian principles and there are some gaps around DLT for humanitarian purposes. Table 23 shows different types of DLT applications in the humanitarian sector (Coppi & Fast, 2019).

Table 21

Articles' Contribution to the Field

	Identified Challenge	Contribution
Dubey et al. (2020)	Lack of trust and collaboration	A blockchain-based theoretical model to enhance swift trust and collaboration among relief actors
Reinsberg (2019); Seyedsayamdost and Vanderwal (2020)	Lack of aid governance	Examine the applicability of blockchain technology in enhancing the foreign aid governance
Khan et al. (2021)	Lack of transparency and trust, and coordination	Integration of blockchain technology and IoT to improve the humanitarian logistic performance
L'Hermitte and Nair (2020)	Lack of communication and trust	Blockchain-based platform to enable communication and share real-time information to facilitate interactions and enhance trust
Patil et al. (2020) Ozdemir et al. (2020) Sahebi et al. (2020)	Lack of cooperation between blockchain technology developers, donors, and aid sectors	Identify potential barriers to adopt blockchain technology to disaster supply chain
Rodríguez-Espíndola et al. (2020)	Lack of accountability and poor communication	Integrate blockchain technology, IoT, and 3d printing to improve the flow of information, financial resources, and products in the humanitarian supply chain

Chapter Conclusion

To answer the research questions, firstly a systematic literature review was conducted on the development of the supply chain in disaster management and then the role of blockchain technology within disaster supply networks. The method is investigating international electronic databases including Web of Science within the time frame 2000-2021, English language, journal papers. The search terms and strategies were applied to multiple keywords. The extracted data were analyzed in terms of types of methodology, domain, and indicators. The results were identifying initially more than 600 publications and the final analysis was conducted on 70 full articles. However, blockchain technology is still in the early stage of research in the field. So far, some of the limitations of blockchain technology in various industries have been identified. The blockchain technology potential barriers to be applied in the disaster supply chain are summarized in 14 categories (Ozdemir et al., 2020; Patil et al., 2020; Sahebi et al., 2020) as shown in Table 24.

Table 22

DLT Applications in Humanitarian Sector

Organization	DLT Application	Benefits
World Food Program	Blockchain technology (Ethereum) for voucher-based cash transfer	Enhance efficiency, transparency, security, and collaboration
Start network	Ethereum-based pilot programs	Increase humanitarian community comfort with the technology
Helperbit	Bitcoin network to create a decentralized and peer-to-peer insurance service and donation system	Provide multi-signature e-wallet to enhance humanitarian assistance before and after an emergency
Sikka	An Ethereum-based platform for digital assets transfer	Address challenges of financial access during a disaster for in-need communities
IFRC and Kenya Red Cross	Multichain-based blockchain	Increase transparency and accountability of cash transfer programs

Table 23

Blockchain Application Barriers in Disaster Supply Chain

Number	Barriers
1	Data privacy, ownership, and security
2	Compatibility and scalability
3	Cost complexities
4	Legal and social frameworks
5	Interoperability and collaboration among stakeholders
6	Lack of awareness and understanding among the participants
7	Lack of engagement
8	Technological complexities
9	Interorganizational complexities
10	Operational restrictions
11	Value proposition uncertainty
12	Infrastructural challenges
13	Media backlash risk
14	Limited management support

This analysis revealed the framework which attempts to explain resilience in disaster supply networks. This study offers two main contributions to the blockchain and disaster supply chain networks literature. First, the article argues that blockchain technology can be used to enhance the resiliency of disaster supply networks. Second, an integrated blockchain-based platform is developed for disaster supply network resiliency and efficiency. By the study, some of the research gaps and future directions for managing disasters using blockchain technology are identified. There is still a need for more research on how to manage disasters, reduce lead time, and lead to more resilience aids supply networks.

On the other hand, there exist several limitations for applying blockchain technology into disaster supply networks such as high-energy consumption, lack of clear understanding of the applications, etc. that can be a future path of research for the field.

CHAPTER 3

METHODOLOGY

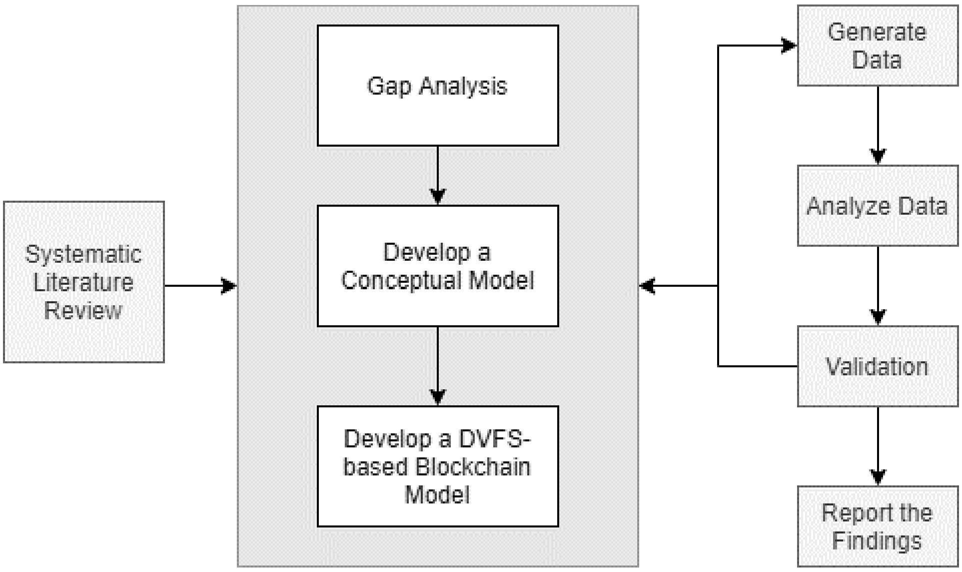
This chapter discusses the design of the research, the proposed model structure, and the development of the conceptual model. The objectives of this study are to support monitoring the supply network progress and enhance disaster management resilience by combining blockchain technology with IoT to develop a model which can reduce the response time and monitor the transaction records within the network.

RESEARCH DESIGN

Based on Whyte (1984) argument, research must be guided by good ideas of the focus of the study and analyze those data. In this study, we follow this approach to provide a framework related to key objectives of disaster supply chain management. To model the objectives of this study, the core agents of disaster management networks are needed to be defined. The study aims to use the Zero-confirmation transactions to consider smart contracts-enabled simulation for hyperconnected logistics and handle them through a blockchain platform. This simulation can be applicable for all the defined agents in any condition. It can play an important role in demand provision in the network. To use a synchronized combination of blockchain technology and IoT and enable tracking within the model, the DVFS algorithm is used.

Figure 21

Research Design



The research design for this study is shown in Figure 21. This study is based on a systematic literature review. The review recognized the root and paths of research development in the field of the disaster supply chain. The review of the literature supports analyzing gaps in this field. Based on the determined challenges and gaps, this study developed a conceptual model for the study. In the next step, the model is simulated. Data is generated using the model with several scenarios. By analyzing the data, the expected outcomes would be responses to the research questions. The model is validated compared to other valid published research; the last step is reporting the findings of the research.

Tools are required for the emergency teams to make efficient interventions. Simulations can help to analyze the behavior of the model through a large number of iterations. For this study, a systematic approach is used including modeling the disaster communication networks, impacts of the proposed model on the disaster management resilience, and facilitate identifying the possible solutions to optimize the disaster aids management.

DISASTER SUPPLY CHAIN MODEL

Disaster supply chains are complicated networks due to high vulnerability and risks. A deep understanding of supply chain risks and managing methods keeps the system dynamic, efficient, and resilient. Collaboration is the glue that holds organizations together in case of a disaster (Glenn Richey Jr, 2009). Organizations pursue several different and, in some cases, conflicting strategic goals regardless of the situation. This study proposes a decision management framework for a disaster relief supply chain that considers the complexities of disasters. The proposed model is developed based on the literature review, Blockchain technology for decentralized network brainstorming (mind mapping), and simulated stream of data. As argued by Thomas and Kopczak (2005), one of the main challenges in the disaster supply chain is the distribution of items quickly and in a sufficient quantity to the affected population. The logistical response can get slower if non-essential goods are oversupplied. Therefore, there is a need for a systematic approach to prioritizing the needs, including all the participants with enabling swift trust to provide collaboration channels.

Information technology can support each phase of disaster by providing real-time monitoring, online dashboards, interactive communication, and collaboration (Imran et al., 2015). One of the approaches supporting acting quickly is decentralization. The DLT has been applied in the field of disaster management in the literature for transparency, efficiency, scale, and sustainability (Coppi & Fast, 2019). To serve and monitor the disaster network, numerous data centers are required that are independent on hardware, infrastructure, implementation, and sharing resources which users can request demands to different data centers in a cloud datacenter. Cloud computing is one of the solutions to provide service for a wide range of users with less cost (Javadpour et al., 2018). Since the disaster network needs a distributed computing, networking, and services, virtual machines can enhance the performance without interruption in transferring to other nodes and dynamically change the resource amounts allocated to a client. The cloud data center can reduce the operational cost and improve service quality. Applying a load balancing technique helps to optimize the load distribution among various hops and eliminates overloading processing on one of the hosts (Javadpour et al., 2018). One of the tools that can be applicable is DVFS as C. Xu et al. (2017) used for the robust blockchain-based decentralized resource management framework to reduce the energy cost. Therefore, this study develops a blockchain-based disaster management model which employs the DVFS algorithm to prevent overloading on one hop, reduce the energy consumption and time of whole system processing.

BLOCKCHAIN-ENABLED DVFS-BASED MODEL

A critical review of several recent disasters by Kumar and Havey (2013) concludes that there is a need for a network authority to organize the relief supply chain. Developing a robust communication plan and the system can help coordinate all teams' efforts and responses. All the involved parties are offered an opportunity to be responsible for their domain expertise to participate in a disaster relief operation effectively for a sustainable duration. The network can include NGOs, military, industry, and government agencies to have better management and coordination of relief efforts. Constructing a reliable disaster management system that can be practical is a complex process and has multiple challenges including the extraction of demand requests of the victims, establishing a framework to address time-sensitive needs and allocation for the decision-making, etc. New data-driven methods have the potential to tackle such challenges. Modern technology utilization has enabled multi-directional communication among parties and provides a contemporary means of interfacing (Schempp et al., 2019).

In the proposed model, the first part includes a set of transactions (C1, C2, etc.) that are applied from a set of clients. The clients are the IoT nodes that represent the enforced flow of the disaster. The nodes along with some servers are included in a network. The round-robin (RR) algorithm on virtual machines in the IoT format is executing and assigned to the virtual machines randomly. The study aims to use the algorithms to calculate how to manage the resources. By embedding the DVFS algorithm, the online data streams can be sorted and allocated to the most prepared server to minimize the failures of the tasks.

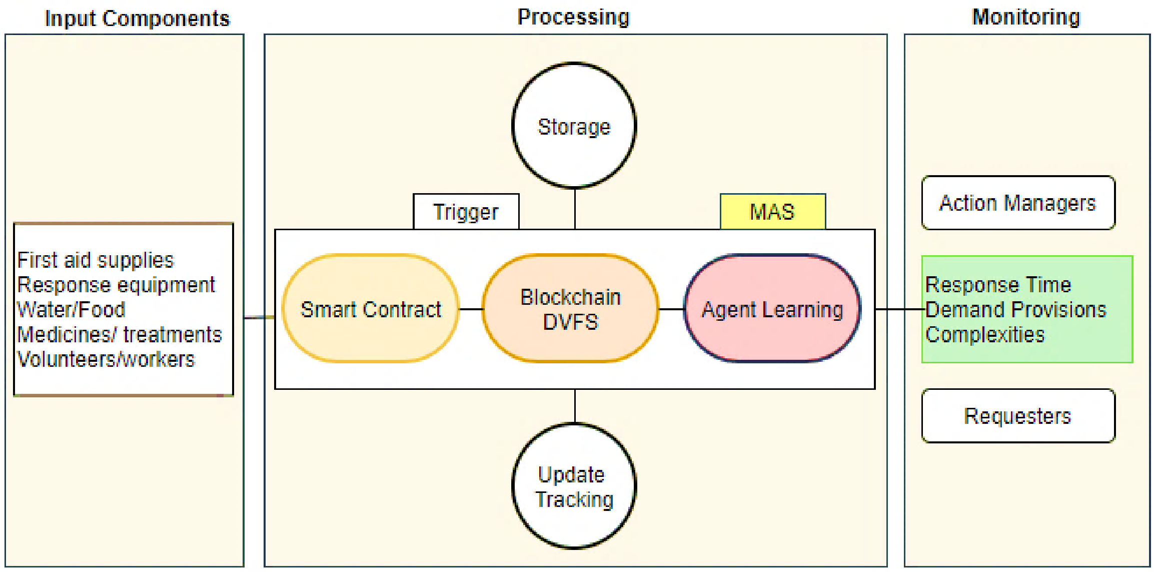
A matrix is created that can generate flows in various conditions and simulate the disaster. The matrix considers the supply chain process for the set of clients. The model aims to allocate the inputs of the clients in a chain system and manage the disaster data in the least time with high performance to enhance efficiency. The tasks are a high load of stream data entered the network. The model aims to handle those tasks efficiently. The tasks will be added to blocks and pass the chain stage. The highlight of the model is to determine which server in which virtual machine is the best to run the chain and how the virtual machines should be sorted.

The second part describes the blockchain calculation mechanism within various chains where DVFS is applied on each of them to analyze and sort the waiting queue of processes. Different physical and virtual machines are used within the queue to update the calculations. DVFS is used to identify the location within the network that the disaster is occurred due to the huge rate of requests from the clients in the transaction section. Therefore, using DVFS provides a queueing algorithm that can be processed and determine where the demands are stored and enable monitoring them. Hence, the whole network is transparent and can be monitored by the entire network. The results of this tracking and monitoring will be represented in the variables of response time, delay, throughput, and successful immigration.

The conceptual model includes three phases (Figure 22). Numerous components are considered as inputs to the network and at the same time, the updating and tracking of the network should be applied. The data are stored in the storage component activated with a trigger and review by the agents. The binary Agent-based condition considers the relation between the blockchains and the DVFS. Smart contracts are sorted using DVFS and then analyzed. When the agent is activated, a relationship is considered between the update tracking and action management. The MAS enables interactions among the entities within the network. The summation of these three steps would be the disaster management stage which can monitor the affected area and the response team.

Figure 22

Conceptual Model



The process of generating encrypted information through cryptography is very important. The science of using mathematical rules for the cryptography of the known data is based on encryption. When the shortest path is identified by the safe node, the public keys of the middle layer nodes are collected through blockchain encryption. A package through encryption and blockchain technology using private keys for all the middle nodes is applied. To execute the model two equations are proposed. The indexes intended and used in the equations are shown in Table 25. The execution of the proposed model is demonstrated in Figure 23.

Table 24

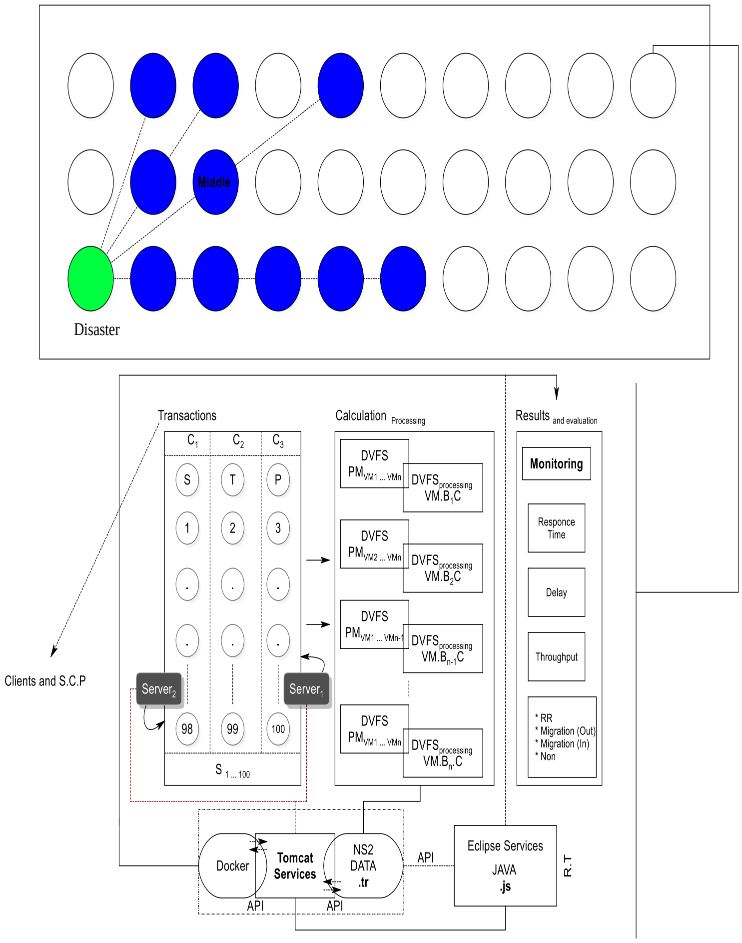
The Model Indexes

Index	Definition
e	The rate of stream entrance to the network
e_k	The rate of external transaction entrance
Y_k	Indicates the number of requests to clients
i	Confirmation request rate (number of confirmations)
t	Initial waiting time
C_{ai}	Square index for the external variety
C_{si}	Square index for the internal variety
P_i	Work traffic coefficient
m_i	The required queue time
W	Weight
$Total\ W_i$	Total weights applied to the network
Pq_i	Probability of waiting in the queue
N_i	The number of transactions in the queue

The control stage would be based on the agreements on the server. In this phase, the transactions would be reviewed with DFVS, and a specific space is allocated for each of them and added as a block to the chain. Based on Pérez-Solà et al. (2019), this method includes two phases of queue development and the phase of coding and mining. This would be based on packages labeled *Hello* to the distributed transactions but waited to be added to the blockchain.

Figure 23

Model Execution - Blockchain-Enabled DVFS-based Disaster Management



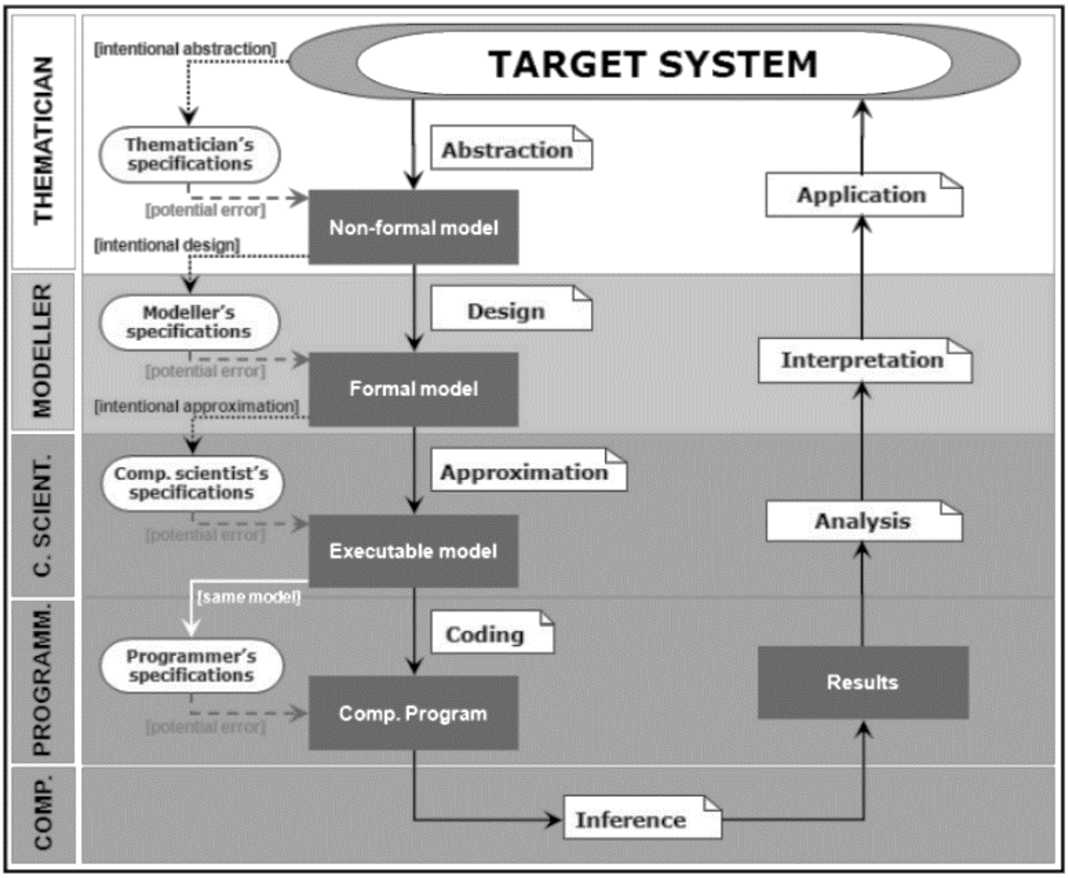
AGENT-BASED MODELING (ABM)

ABM is a modeling paradigm that defines the behavior of the system by the entities and their interactions. Modeling with ABM includes some advantages such as a transparent description of the targeted system, provides heterogenic models, facilitate representation of the environment and interactions, enables studying the bidirectional relations of entities (Galán et al., 2009).

An agent-based simulation is a practical technique to model systems that facilitate a more direct correspondence between the model entities and the targeted system with enhancing transparency, soundness, descriptive precision, and consistency of the modeling process (Galán et al., 2009). Figure 24 depicts the stages of ABM. “Running an ABM is a computer provides a formal proof that a particular micro-specification is sufficient to generate the global behavior observed during the simulation” (Galán et al., 2009).

Figure 24

Different Stages of ABM



Agent-Based Modeling Simulation (ABMS) is practical where the individuals and their interactions are the critical aspect of the system (Collins et al., 2020). MAS offers a natural metaphor for meta-scheduling function implementation. Agents cooperate to improve the performance of the entire system. MAS is an effective tool applicable for cases that a large number of dynamic interacting entities should be modeled by enabling modeling the collaboration among the teams of agents (Buford et al., 2006). The agents use their knowledge to make decisions and perform actions on the environment to solve the allocated tasks. The MAS is practical for cloud computer networks (Dorri et al., 2018). The main features of MAS are efficiency, low cost, flexibility, and reliability. In MAS, the agents and their relations are modeled using graphs where each vertex represents an agent, and the communication is indicated by the edge between two agents. The tasks are allocated to autonomous entities (agents). Each agent decides on a proper action to solve the task based on the aim of the system and by the use of multiple inputs, action history, and interactions (Dorri et al., 2018).

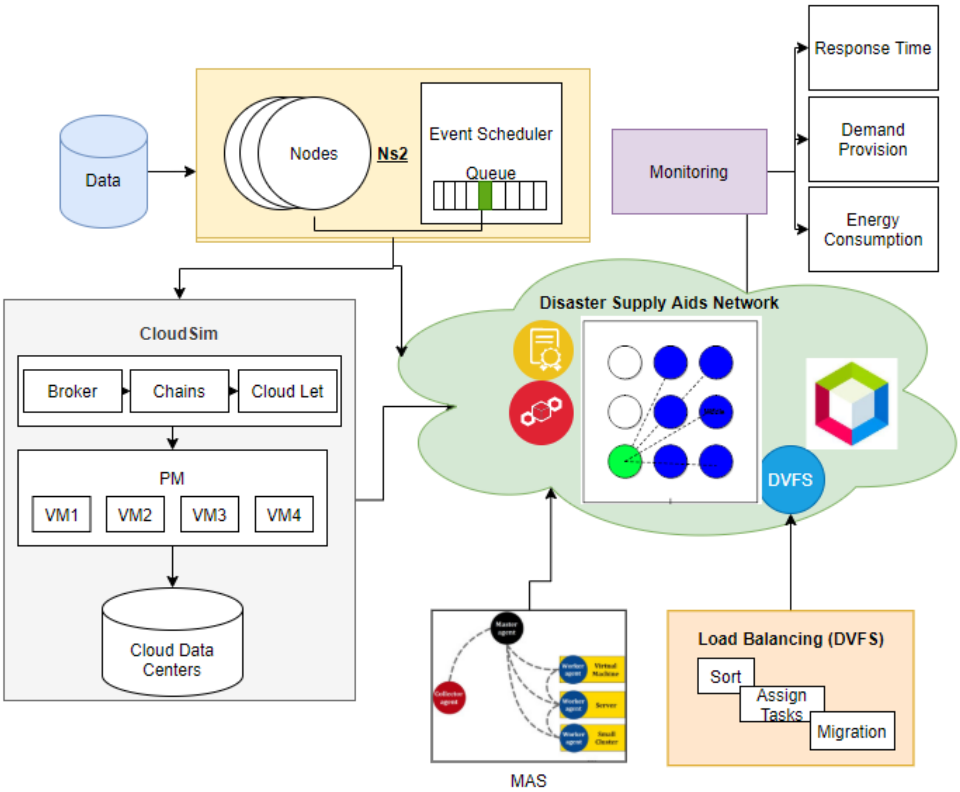
CHAPTER 4

RESULTS

In this section, the results of 100 iterations of simulating the model using a stream of data are presented. The simulation structure and the applied tools to represent the model components are illustrated in Figure 25.

Figure 25

Simulation Description



For this study, data are generated to run the simulation based on that. A list of items that are considered as the critical demands in case of a disaster is created to be used as input to the system. Table 26 explains how the data are generated randomly using a normal distribution function with a mean of 40,000 and a standard deviation of 10,000. The most critical demands in disaster response are shown in Figure 26 (Liberatore et al., 2013).

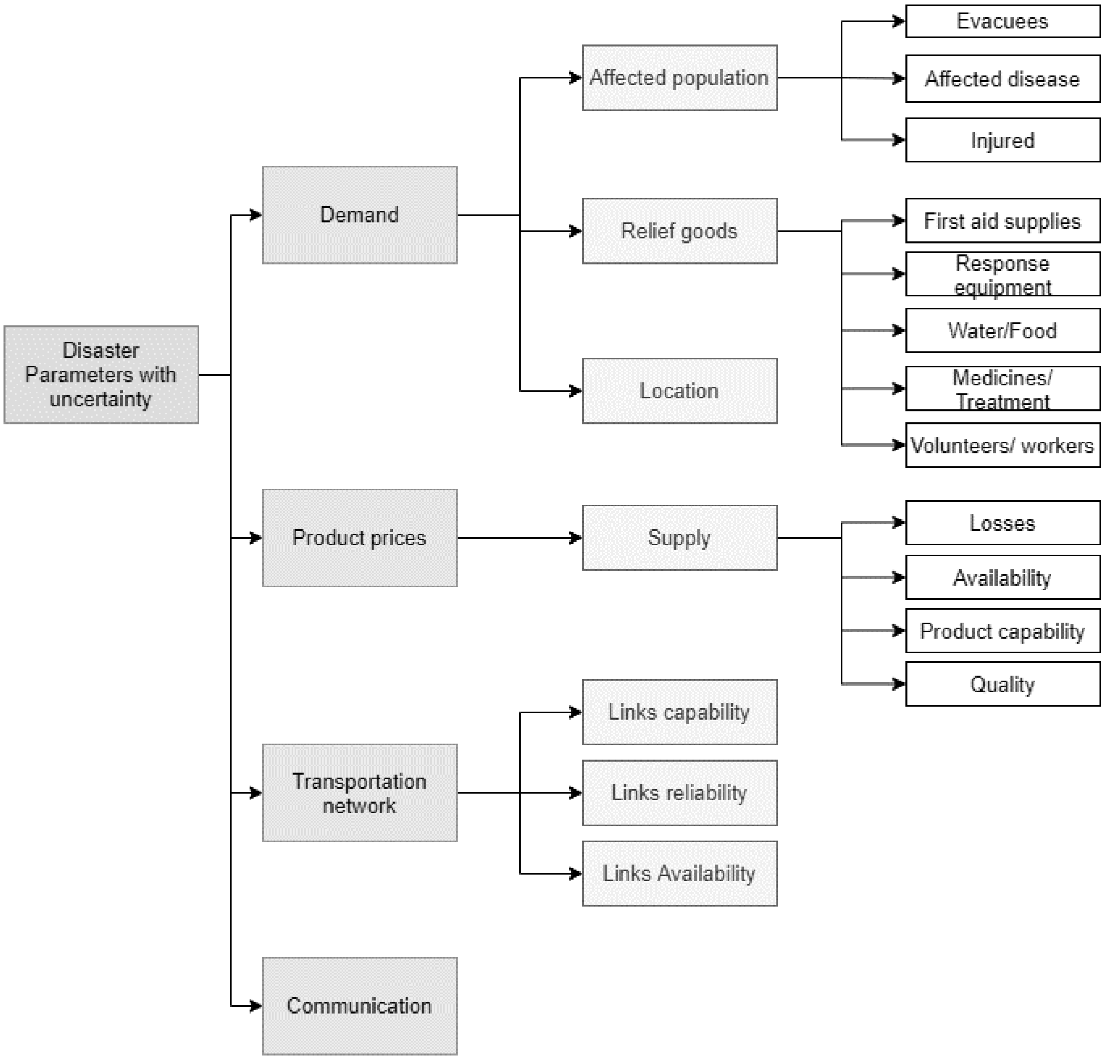
Table 25

Input Tasks Specification for Simulation

Index	Million Number of Tasks (Estimation of The Processing Time for Each Task in Cloudlet)	Input Data Size	Output Data Size	Input Time
I	A random number of normal distribution function with a mean of 40,000 and standard deviation of 10,000	3000 KB	3000 KB	A random number of inverses of Poisson aggregation distribution function with value $\lambda = 100$

Figure 26

Disaster Supply Chain Critical Demands



MODEL DESCRIPTION

Modeling is the process to conduct an abstraction of a system for a particular aim (Galán et al., 2009). Computational modeling is a formal representation animated by the computer to generate the model's outcome in a form of a computer program, algorithm, equations. A computer simulation is an interference tool that enables going beyond mathematical tractability (Galán et al., 2009).

The algorithm of how to address the challenge and provide the solution is depicted in table 27. The conducted network consists of various entities which are responsible for disaster response. Each entity is capable of exchanging data with other entities of the network.

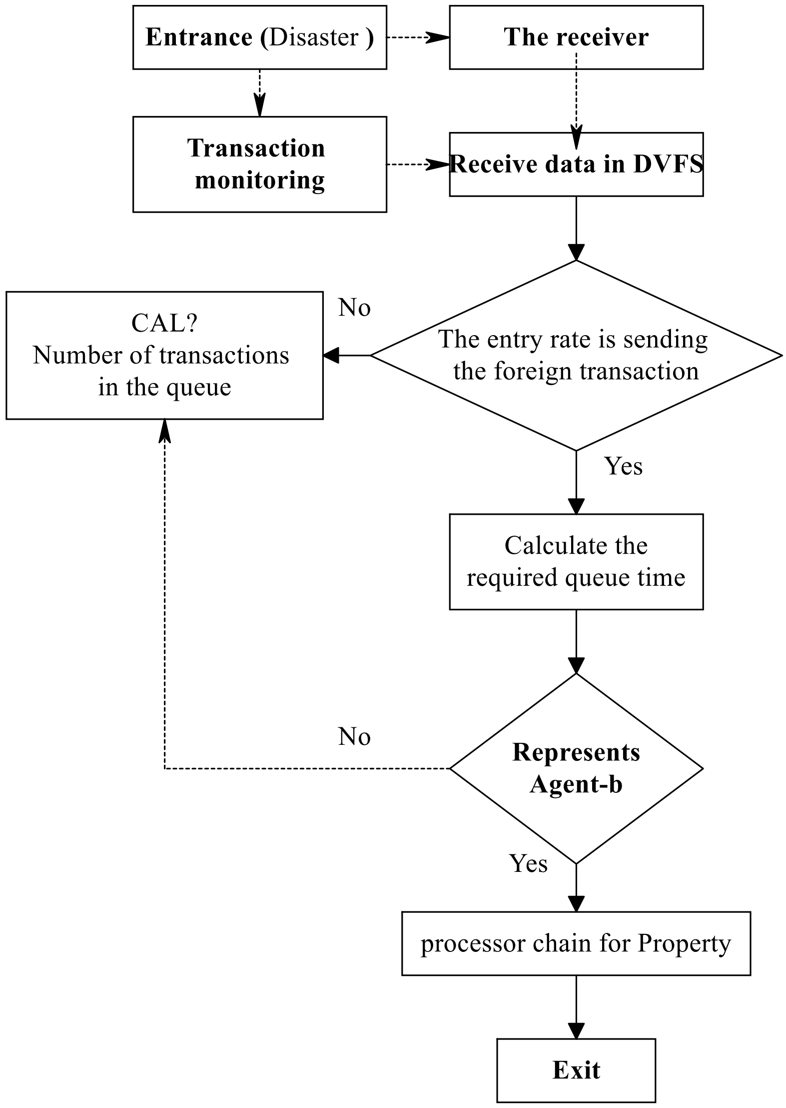
Having access to reliable information in case of a disaster is necessary to improve disaster management. Big data describe a large amount of data in the networked information-driven environment (Iglesias et al., 2020). For the data generated during a disaster by the active participants, stream big data processing frameworks are required to support disaster management. The flowchart of how to execute the proposed conceptual model is illustrated in Figure 27.

The concept of MIPS is applied for analyzing and approximately measure the processing power of the device. Datasets are added using BigData, CloudSim, and BChainCloudSim libraries. In the first step of the model, the CloudSim library is introduced which includes libraries for the cores, and the entities. The model regarding the chain's policies is provided within this library which is based on First In First Out (FIFO), and all the inputs to the system would be recorded. The CloudLet, which is used as a subset of the blockchain library, is a cloud data center to support interactive applications of devices with less amount of delay. CloudLet is used based on various information represented with UserId and the required RelocationId for the allocated tasks in each of the virtual machines to consider and record the BChain data in the datacenter. To do the simulation, a Docker model is required to store the data within it.

The API (Application Programming Interface) is the link between the network code and Docker. A Tomcat service is needed to consider the web-based API. Besides, Java is used to enable the execution of the requests (tasks) in blockchain format.

Figure 27

The Model Execution Flowchart



The model algorithm is as follow:

Start

Entrance (Disaster with Stream Data)
Check: The receiver
Check: Transaction monitoring
Check: Receive data in DVFS

Run: Distributed transactions

$e = \sum_k^1 e_k$

$Y = \sum_k^1 Y_k e_k$

represents a crisis in level K with the entrance rate variant of $i = \{1,2,3,\ldots\}$T = $\sum_i^1 e_i$ represents waiting time for monitoring transactions in each workstation

if C_{ai} (square index for external variety) and C_{si} (square index for the internal variety, then

P_i is the work traffic coefficient

m_i is the required queue time

$$Total\ W_i = \left(\frac{C_{ai} + C_{si}}{2}\right)\left(\frac{p_i^{\sqrt{2(m_i+1)-1}}}{m_i(1-p_i)}\right)$$

$$P_{q_i} = P(N_i > m_i) = \frac{(m_i p_i)^{m_i}}{m_i!\,(1-p_i)}\left(\frac{(m_i p_i)^{m_i}}{m_i!\,(1-p_i)} + \sum_{j=0}^{mi-1} \frac{(m_i p_i)^i}{j!})^{-1}\right)$$

If ===> "entry rate is bigger than foreign transaction" > 0

Yes: Calculate the required queue time

Then:

Represents Agent-based

No: CAL

Number of transactions in the queue

Run: Trigger for Agents (Selections)

CheckOutData (Disaster with Stream data)

Check: The receiver

Check: Transaction monitoring

Check: CheckOutData data in DVFS

End

In the function, λ is the input processing time which is considered as a stream type in the network and can support space and time complexity for the virtual machines. Since the input data are followed by the normal distribution, the outputs can be plotted in a range of (0-1). The applied function to the simulation is based on Equations 1 and 2.

$$f(x;\ \mu,\sigma^2) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-(\frac{x-\pi}{2\sigma^2})}, x \epsilon \mathbb{R} \qquad \text{Equation 1}$$

$$f(k;\lambda) = \frac{\lambda^k e^{-\lambda}}{k!} \qquad \text{Equation 2}$$

DESIGN OF THE SIMULATION STUDY

To run the model simulation, this study used the Ns2 simulator for the following reasons:

1. Includes blockchain library
2. An open-source tool that is not costly
3. Capable of testing complex scenarios
4. Capable of obtaining results quickly and test more ideas in a smaller time frame.

To run Ns2, Ubuntu terminal version 18.04, Docker, and Tomcat version 7 are required. To run the datacenter, with the command of ".run", the run file of the datacenter is implemented, the visualization gets started. It can get various numbers. It starts to build the data center. The data center includes a virtual-based network and some parameters which can conduct the blockchain structure. To evaluate the results the following tools are used:

- CloudSim Simulator Version 3.3: a java-based simulation toolkit that supports the functionalities of queueing and processing of events. The toolkit enables modeling, simulation, and experimentation in cloud computing and application services. It is used in this model to import algorithms that are required for the design of cloud datacenters. The policy of using CloudSim is to manage the workflow and is entity-based. Since the scale of real testbeds, utilization is limited to experiment, simulation tools are a suitable alternative that enables the possibility to evaluate the hypothesis in an environment that can reproduce tests of cloud computing free of cost and tune the performance bottlenecks before deploying on real clouds. MultiCloudSim library is imported for task scheduling and queuing

- NetBeans (Version 8) Environment: an open-sourced Integrated Development Environment (IDE) supports the development of a set of modules of Java application types which is used as a browser for input data, compute the cloud networks, and IoT. NetBeans is run in the Ubuntu terminal.
- Bigdata Processing: an open-source tool for java, which enables the system to be capable of processing all data without sacrificing throughput as data grows in size. Using big data processing provides scalability of allocating more tasks at a given point in time. It is used to define the entities in the network.
- SimJava: a discrete event, process-oriented simulation package which builds blocks to define and run the simulation in Java (Institute for Computing Systems Architecture)
- Epigenomics workflow: used to automate the process of genome sequencing which is associated with resource-intensive tasks. It is a data processing pipeline to automate the execution of various sequence operations plus filtering out the noisy and contaminating sequences, map sequences into correct locations (Bharathi et al., 2008).

The input datasets are through Docker by CloudLets and brokers that are applied as limited workflow in the network in the format of MIPS. For each of these CloudLets, data centers are generated with different CPU cores. To consider random input data of the virtual machines which are in control of physical machines, the normal distribution is used for the simulation. The simulation specifications are shown in Table 27.

Table 27

Simulation Specifications

No.	Type	MIPS	RAM	Bandwidth	Virtual Machine Monitor	Virtual Machine Capacity	Processing Elements
1	A	300	512-2 GMB	10 – 100 Mb/s	Xen-IntT	2000-2200 MB	1-3
2	B	500	256-512 GMB	10 – 100 Mb/s	Xen-IntT	2000-2200 MB	1-3
3	A	300	512-2 GMB	10 – 100 Mb/s	Xen-IntT	2000-2200 MB	1-3
4	B	500	256-512 GMB	10 – 100 Mb/s	Xen-IntT	2000-2200 MB	1-3
5	A	300	512-2 GMB	10 – 100 Mb/s	Xen-IntT	2000-2200 MB	1-3
6	B	500	256-512 GMB	10 – 100 Mb/s	Xen-IntT	2000-2200 MB	1-3

For this model, several various servers with different core, aggregation, and accessibility are considered. To run the model, a CPU 7 is required to develop the configurations. The minimum virtual number request (VNR) is considered. At first, VNR = 0.0001 for the simulation run is applied and the topology is conducted.

In the next step, the data for scheduling, DVFS-based algorithms, and probability models are executed in the NetBeans environment. The total computing capacity is based on the MIPS value which builds the blockchain structure and simulates the model. This step takes several hours. When the simulation is completed, the results are demonstrated automatically. The simulation results ".tr" can be indexed and represented with Chrome. To analyze the results, the datasets of Bigdata, CloudSim, Bchaincloudsim are added to the platform. The logs are registered on the server. In every virtual machine different information is required to be stored based on the userId and the IdShift which consider the blockchain data on the servers.

In the next step, the network is developed including all the servers. With a search based on the hostList, it returns the score of servers that DVFS is added on. On the cloudLet, a list of information is returned. The "broker" provides the output in the timeslots and time intervals on the virtual machine. The other parameter is the blist which is based on the fit function for the proposed method. It is an approximate probability of the total datacenters that are intended to run the blockchain. In the next part, the load process is reviewed, and determine when the migration algorithm is needed to be applied. The next part is another cloudLet that is sent to the hostList and the information that is asked to be returned is energy consumption for each of the virtual machine scheduling tasks. In the next part, the changes in CPU utilization, memory, and the network structure are analyzed when migration is applied to the virtual machine. The next part includes the MIPS results based on DVFS, quality of the network services, and the simulation runs on both algorithm of the reference model and the proposed model. When this part is completed, it reads the outputs from the brokers, builds the chains, tries to connect to each of the virtual machines (1 to 4), and extracts the data related to the cloudLets. The outputs are returned for broker 0 and broker n-1 and print the ones that receive the tasks. The simulation parameters are shown in Table 28.

Table 28

Simulation Parameters

Virtual Machine Parameters	Description
Image Size (MB)	10000
Ram VM Memory	512
MIPS	250
Bandwidth	1000
Number of CPUs	2
Virtual Machine Manager	Virtualize multiple operating systems to run concurrently on a host computer

SIMULATIVE ANALYSIS

The analysis presents the impact of blockchain technology on disaster supply management resilience using simulation. To have a multi-facet investigation, various cases are considered. The degree of efficiency of the proposed model is analyzed by varying the input parameters. Hence, the simulation experiments can state the impacts of the proposed model on disaster supply management resilience. The components that are evaluated for the study in order to support the research questions and the hypothesis are shown in Table 29 and the simulation conditions in Table 30.

Table 29

Output Metrics

Outputs	Description	Research Question	Hypothesis
Throughputs	Amount of data that can be transferred from one location to another within a specific time (MIPS)	Performance	1A, 1B
Successful Migration	Transfer tasks from the overloaded node to the next block in the virtual machine with the capacity to handle the request	Performance Resilience	1B 2A, 2B
Delays	Required time for the tasks to be handled by the blockchain method (Min)	Performance Resilience	1A 2A
Errors	Unsuccessful migration of tasks handled by virtual machines	Resilience	2A
Number of Actions	Number of actions that can be supported in every time step of the model (Min)	Performance Resilience	1B 2B
Energy Consumption	Required energy amount to receive the needs requests and process them in the network (kWh)	Resilience	

Table 30

Conditions of Simulation

Number	Condition
1	SCESHL model
2	DVFS algorithm applied to the SCESHL model
3	The proposed blockchain-enabled DVFS-based model
4	The proposed blockchain-enabled DVFS-based model integrated with MAS

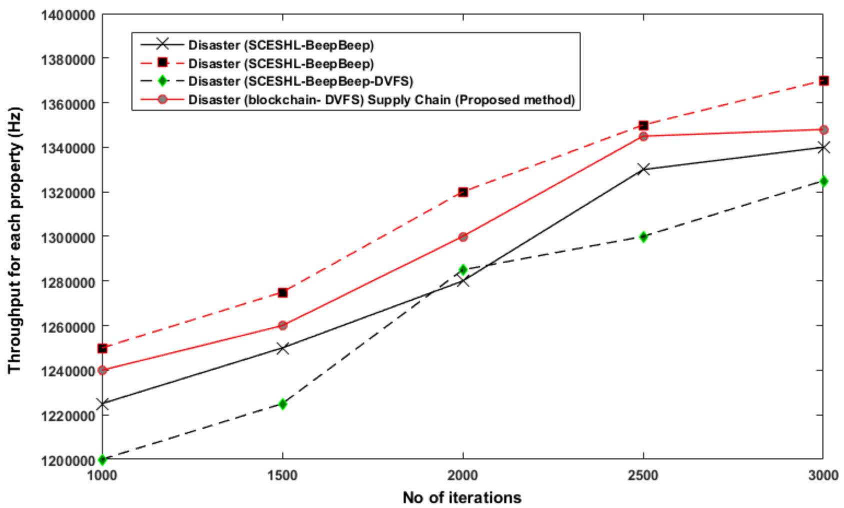
The results of this study are compared to the results of a published article by Betti et al. (2020) entitled Smart Contract Enabled Simulation for Hyperconnected Logistics (SCESHL). The aim is to verify the model and check how much improvement can this model contribute to the body of knowledge. The reference model is considered with two conditions. First is the format proposed by the authors using a complex event processing library to implement properties of hyper-connected logistics called BeepBeep. For the second condition, the DVFS algorithm is just added to their model to analyze the changes. The simulation of the proposed model also includes two conditions. First is the model using the DVFS algorithm, and second is when the trigger is applied, and the DVFS-based algorithm runs the blockchain-enabled model in a binary ABM (Table 28) and the results of the simulation runs are depicted in the following figures.

1. Throughput

The Y-axis is the throughput for each property, and X-axis is the number of input tasks consumed per second. The results for four conditions are shown in four diagrams in figure 28. The figure shows that the results of conditions 3 and 4 are most likely the same as conditions 1 and 2. When the DVFS is applied, no changes happen to the system. Even though the number

Figure 28

Throughput Diagram



of iterations is getting slightly better. The reason is due to the spatial complexity. In condition 4, when the agents are considered within the DVFS-based model, throughputs are higher than condition 1. This depicts that the proposed model is efficient and can be applied as a decision support system for disaster supply chain management.

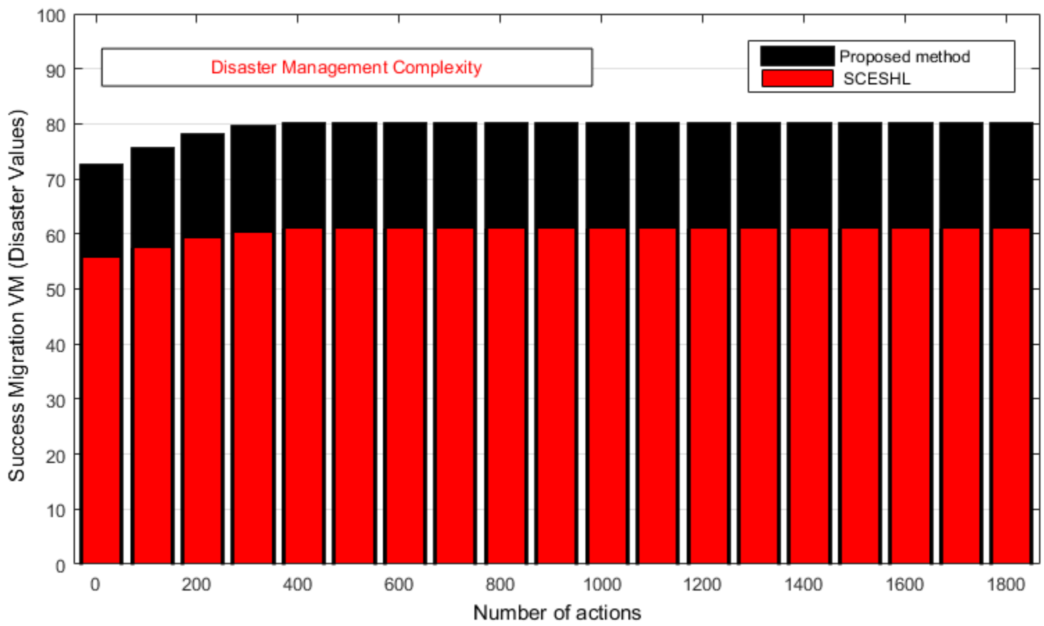
One of the aspects that are focused on in this study is the time complexity of the disaster aids network. The results (figure 28) display the proposed model provides a step of improvement. This can also verify the proposed model throughput management. In total, the model could achieve the optimal solution that was looking for using the DVFS-based model considering blockchain agent-based conditions.

2. The number of successful immigrations

The X-axis is representing the number of events that are increasing within time. Migrations are the indicators of data management within all virtual machines. Migrations are very beneficial in case of having many loads of data to the system such as disaster cases. Figure 29 depicts that the proposed model could have a significant level of a successful migration of virtual machines. There are 20-25% more migrations due to the implementation of the DVFS

Figure 29

The Successful Migration Diagram



algorithm in the proposed model. As the rate of successful migrations increases, there would be less damage to the resources and the outputs have higher performance.

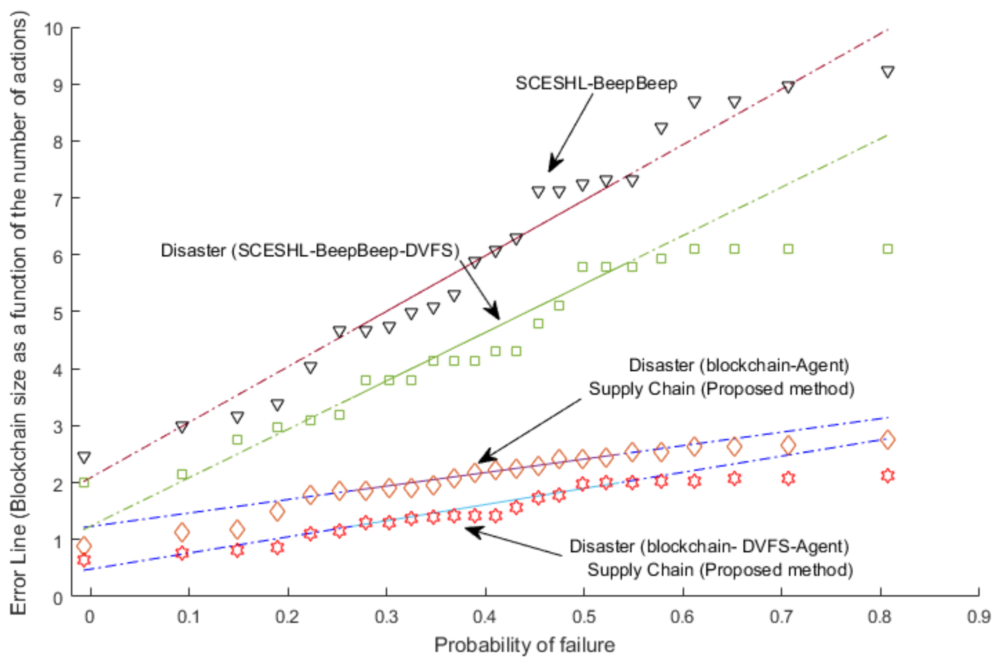
Figure 29 also reflects the disaster management complexity. When the number of events increases, the complexity of disaster management also magnifies. The system requires performing more successful migration of tasks to manage all the input data effectively. The tasks are the inputs of the sensor data that is considered as the stream of input data in the model.

3. The Errors Diagram

The Y-axis is the error line based on the number of actions and the function that is producing those actions. The X-axis is the probability of failures. Figure 30 represents the results for all four conditions of models. As can be seen, the errors are higher in conditions 1 and 2. The blockchain-based processing line includes a high level of actions and complex timing. When the DVFS is applied, the error is improved by almost 8% compared in condition 2, 15% improvement in errors in condition 3, and 17% improvement in condition 4. Figure 31 shows that when the option of migration is available, the tasks (the demands requests from the affected population) can be handled more effectively and the disaster managed more efficiently. As the errors in the system decrease, the delay time would reduce as well. There are more failures in conditions 1 and 2 as shown in Figure 30. Therefore, the proposed model is an efficient model regarding reducing the response time in disaster response.

Figure 30

The Error Line Diagram

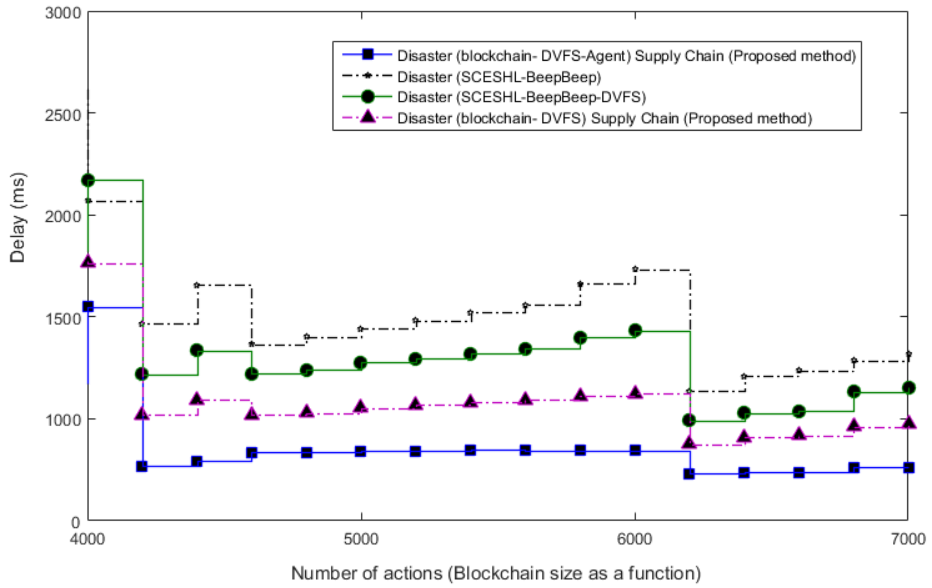


4. Delay diagram

The X-axis shows the number of actions (events) in terms of the functions that blockchain is handling the tasks within and the Y-axis is showing the delay time in Minutes. As can be seen in Figure 31, the proposed model has less delay which is rooted in having fewer errors. The tasks that are entering the machines within this model are handled at a faster pace. Condition 4 where the relationship between the blockchains and the DVFS is managed using ABM has fewer errors and delays. Hence, the proposed model could manage delays more efficiently. There is a 5% improvement from condition 1 to 2 to 3 and to 4.

Figure 31

The Delay Diagram

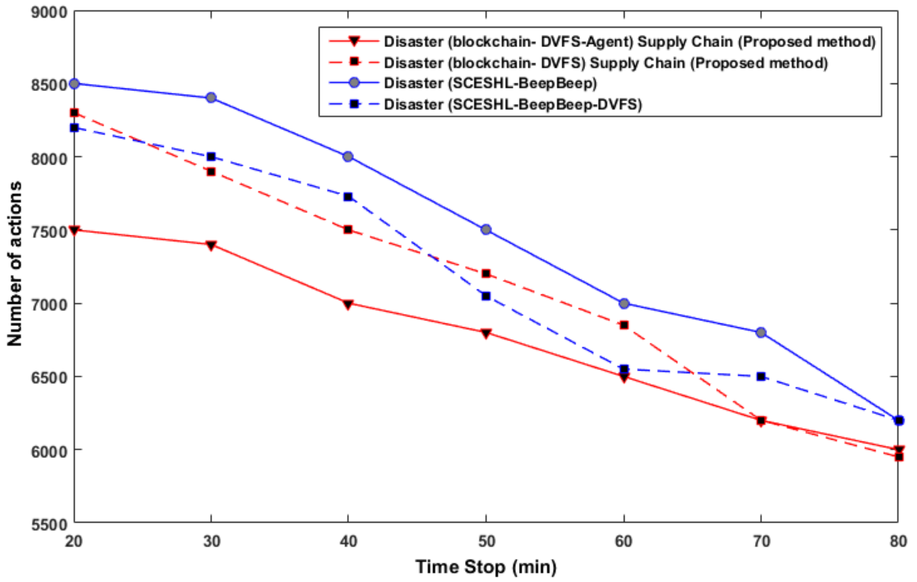


5. Number of Actions Diagram

Figure 32 represents the number of actions that can be supported in every time step of the model measured in Minutes. As the model gets more complex, it can receive more requests and handle more tasks. As time passes, the number of actions that can be handled is reducing. If 90000 requests are received to the platform in case of a disaster and the aim is to manage the requests, different models have different capacities to receive them in the first place. As can be seen in figure 32, conditions 3 and 4 have less capacity comparing to conditions 1 and 2. The reason is that in the proposed model when an action is received, a specific duration is required for the DVFS to allocate the task to the middle nodes. Hence, fewer actions in a one-time step can be received.

Figure 32

The Number of Actions Diagram



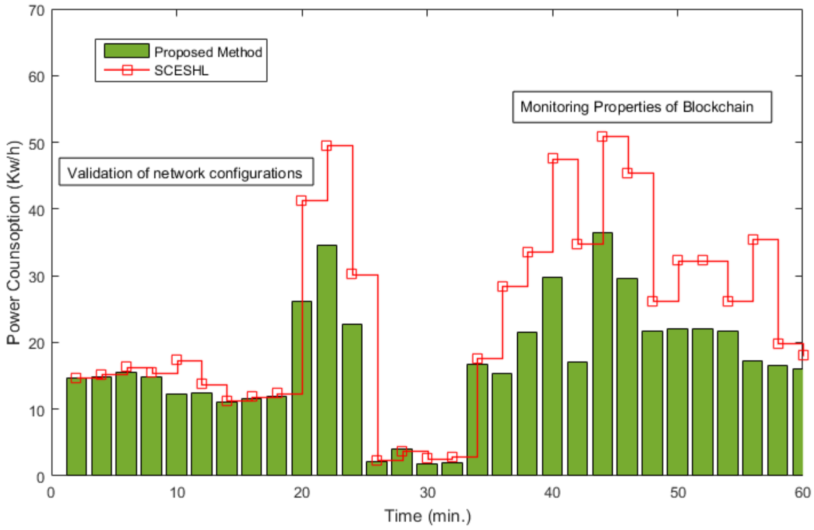
Even though conditions 1 and 2 can receive more actions, it includes more errors while the proposed model can receive less action with having fewer failures and delays. Although receiving more actions is a benefit for a disaster management system, handling those tasks is more important for disaster resilience. Therefore, the proposed model proved the efficiency and optimizing the research variables by having a smaller number of failures and delays in the entire network while consuming minimum energy power.

6. The Power Consumption Diagram

Figure 33 depicts the amount of energy that is required for first receiving the needs requests (actions), and second process them in the network to manage the tasks until the disaster response actions are completed. The Y-axis represents the power consumption in terms of kWh and shows that the proposed model is observing the green computing policies. The X-axis is the time in terms of minutes and shows within time, as the algorithm is executed in the minute of 30, the model is optimized around 9.12% comparing to the referenced model.

Figure 33

The Power Consumption Diagram



As can be seen in Figure 33, all four conditions are having somehow the same results at the initial stage which is validating the network configurations. As the algorithms are implemented, the proposed model is consuming less power comparing to the referenced model. Figure 35 proves that time complexity, space complexity, and the computations regarding the datacenters that are running to support the network for disaster response, are consuming less power to provide better results. This demonstrates that the complexity of computation of the proposed model is less compared to the referenced model.

CHAPTER 5

DISCUSSION

There is a new trend in the literature with a focus on the key role of emerging technologies such as industry 4.0, IoT, and blockchain technology in disaster supply management to examine the application of such advanced technologies in managing disasters and enhance resilience. The findings explore the support of advanced technology applications such as big data and IoT to provide real-time information and enhance the collaboration through swift trust among the participants in disaster relief aids.

This study obtained a holistic view of the state of the art of research approaches in blockchain application in the field of disaster management based on various analyses of main path extraction, citation network clusters, and co-occurrence of keyword analysis. The results of the quantitative literature analysis indicate a huge trend of research on blockchain adoption in the field of supply chain management and disaster supply chain network in the past three years. This study contributes to the body of knowledge in evaluating the development of research areas within the disaster management field. Using software tools, the flow of information and different paths of research approach is detected. A landscape of research developed by authors-keyword analysis provides a better understanding of blockchain capabilities in disaster management resiliency.

VERIFICATION AND VALIDATION

There is more interest in using simulation models in research studies nowadays. Developers and users apply the models to aid decision-making and solve problems by using the information obtained from the results (Sargent, 2010). Model verification is checking the correctness of the computer program and computerized model implementation (Sargent, 2010). Model validation is the process of sustaining the computerized model that is applicable in the targeted domain and has a satisfactory range of accuracy (Sargent, 2010). Usually, the validation process of a model is quite costly. The validation of the conceptual model is to determine whether the theories and assumptions are consistent with the system theories and the model is a reasonable representation of the system. Specification verification is to ensure the software design and implementation of the conceptual model on the specified computer system is satisfactory. Implementation verification is to ensure that the simulation model is implemented according to the model specification. Operational validation is to determine the output behavior of the model has sufficient accuracy for the model over the domain of intended applicability (Sargent, 2010).

One of the techniques to verify and validate a model is to compare it to other models. Various results of the simulation can be validated by comparing them to other valid models (Sargent, 2010). For this study, the proposed model is compared to a valid model by Betti et al. (2020).

The results of the study prove that the integrated blockchain DVFS-based model can enhance the performance of a disaster supply network. Based on the proposed research questions and hypothesis, the results of the simulation prove that there is a positive relationship between response time and demand provision with information sharing. The results also justified the second research question that the blockchain DVFS-based model can enhance the disaster supply network resilience because the results of the simulation prove a positive relationship between the model with the disaster supply network monitoring and disaster complexity management.

RELATIONS TO THE IDENTIFIED CHALLENGES THROUGH LITERATURE REVIEW

The results of the study are consistent with the results of the previous articles in the literature. As was pointed out in several articles, real-time information can enhance disaster supply management. The results of the simulation display that the application of blockchain technology along with IoT can improve the response process and enhance disaster management resilience. Plus, this study focused on disaster management complexity as one of the critical challenges identified through the literature and proved that the application of the proposed model can improve complexity management.

In addition, one of the limitations of blockchain technology application was identified to be the high energy consumption. This study used a DVFS-based algorithm that can tackle this challenge where the simulation results proved that less energy was consumed in the proposed model.

This study considered Betti et al. (2020) article as the fundament for the study, the simulation results of the proposed model were consistent with the referenced model and a step of improvement to that model was achieved which makes the model more applicable to tackle the disaster supply chain challenges. The findings of the study in comparison to the literature is explained in Table 31.

The results of the study follow two of the future work ideas provided in the literature which first is developing models to tackle the blockchain limitations. The second is managing blockchain-based disaster complexities. Applying the DVFS algorithm is the approach that could support confronting both challenges.

Table 31

Finding of the Study in Comparison to the Literature

Finding	Comparison with theory
A positive influence on response time is evident in the proposed model application	This finding is consistent with previous findings that decentralized reliable collaboration and information sharing can enhance disaster supply resilience. blockchain technology can contribute significantly to improving disaster management (Aranda et al., 2019; Balcik et al., 2010; Dubey et al., 2020; Tatham et al., 2010; Van Wassenhove, 2006)
The model enables collaboration through smart contracts and distributed network which enhances disaster management performance	Application of blockchain technology has a positive impact on real-time event identification (Aranda et al., 2019; L'Hermitte & Nair, 2020; Papadopoulos et al., 2017). The results of the study depict that the response is strongly dependent on the underlying processes established for collaboration (Tatham et al., 2010; Van Wassenhove, 2006)
The response time and demand provision improve by using the blockchain technology DVFS-based model	The simulation validates that more actions can be supported within each timestep, there would be fewer delays in response with fewer errors (Betti et al., 2020; Lohmer et al., 2020)

Table 31 (continued)

The advantage in response time is significant at high process efficiency and less failure. The information-sharing through the network is significantly shortened using blockchain technology & DVFS algorithm	Blockchain-based models can enhance collaboration among relief actors, improve humanitarian logistic performance, share real-time information, and enhance trust (Dubey et al., 2020; Khan et al., 2021; L'Hermitte & Nair, 2020)

THE IMPLICATION OF THE MODEL

This study develops a potential application of blockchain technology in disaster supply management and an in-depth analysis of the influence of blockchain technology on disaster management resilience. The study includes a quantitative simulation experiment to support the research questions as well as investigate indications of the functioning mechanisms of the disaster management complexities in responding to the huge number of demands in the disaster response critical time. For this purpose, the response time, delay, and disaster complexity were considered as influencing factors. The results indicate a significant improvement in disaster supply management in an efficient combination of DVFS algorithm and blockchain technology.

The model can be an effective tool to handle large-scale disasters aids network challenges. Plus, such blockchain-enabled models can improve crisis management in a broader context. In addition, the finding of this study provides some insights for other researchers interested in the field as well as disaster management teams.

LIMITATIONS & FUTURE RESEARCH

This study aims to present the research path of blockchain application into the field of disaster aids supply management. Some of the research gaps and future directions of blockchain technology that are proposed by several researchers in managing disasters based on the systematic review of the literature are presented in addition to articles that have studied blockchain application in disaster management. However, there is still a need for clarity about how to manage disasters, reduce the lead time, and lead to more resilient aid supply networks.

More research is required on the meaningful indicators for resilience quantification, empirical investigations on real networks to uncover the potentials and barriers. This study has limited the data collection of the systematic literature review to one single source which does not cover all the scientific contributions in the field. Future studies can include more publications and compare results on the evolving research trends.

This study proposes various future research paths. One is to develop mechanisms and methods to respond efficiently to different types of disasters. Smart platforms and architectures can be designed to classify potential hazards and reassess the governance strategies. The other is to clarify the efficiency of the current studies with real cases such as the integration of such technologies into current disaster management systems to trace the shortage of supplies in the pandemic crisis. There is a need for real case applications of proposed models and frameworks in industries to address the technical and behavioral challenges in the adoption of blockchain technology. The technical challenges of blockchain technology including scalability, network participants' integrity, computational power distribution, preserving the confidentiality of users, and safety of the applied encryption algorithms can be focused on future studies.

There are some limitations to blockchain technology as well. First, the operations and maintenance for running the full nodes compensation would be costly. Second, latency for the transaction confirmation process. Third, the transaction processing could be slower compared to the traditional payment transaction system. Fourth, the consensus mechanism requires the entire network to perform complex algorithms for mining (Rajan, 2018). Some of the blockchain technology application issues in the humanitarian sector recognized by Coppi and Fast (2019) are the absence of robust regulatory frameworks, lack of clarification of application, lack of connection between hype and evidence, and the knowledge gap of governance and ethics related to blockchain technology. The model has a limitation in collecting real data due to the confidentiality of the information regarding the communication and collaboration of agencies during a disaster. The other limitation of the model is the focus on a general concept of a disaster and not different scenarios where the dynamics of the disaster could be depicted. The other limitation of such type of research is that there is no possibility to have onsite validation of the results of model implementation unless a disaster occurs.

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APPENDICES

APPENDIX A – MODEL RUN

Figure 34

Model Run Snapshot

```
                 -
*****Datacenter: ClusterChainDatacenter_0*****
User id          Debt
5                5384
6                5384
**********************************
*****Datacenter: ClusterChainDatacenter_1*****
User id          Debt
**********************************
//////////////////// Map_Reduce Tasks LoadedHost //////////////////////////////////////////
UnderLoadedHost Name is :  Host_0
//////////////////// MigrationVm //////////////////////////////////////////
MigrationVm Name is :  VM_1
Simulation completed.

========== Networks QoS |UBest|XBest|X|FU| ==========
DataC_ID    FUN    ClusterID    Migration    Time    Responce    SimTime
    4        SUCCESS        3            4            258.06        0.1            258.16
    9        SUCCESS        3            4            258.06        0.1            258.16
    3        SUCCESS        3            3            271.18        0.1            271.28
    8        SUCCESS        3            3            271.18        0.1            271.28
    2        SUCCESS        3            2            285.71        0.1            285.81
    7        SUCCESS        3            2            285.71        0.1            285.81
    1        SUCCESS        3            1            301.88        0.1            301.98
    6        SUCCESS        3            1            301.88        0.1            301.98
    0        SUCCESS        3            0            320        0.1            320.1
    5        SUCCESS        3            0            320        0.1            320.1
-----------------------------------------------------------------------------------------------
Fast Data Processing finished!
BUILD SUCCESSFUL (total time: 0 seconds)
```

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