A Blockchain-Enabled Model to Enhance Disaster Aids Network Resilience

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Abstract: The disaster area is a true dynamic environment. Lack of accurate information from the affected area create several challenges in distributing the supplies. The success of a disaster response network is based on collaboration, coordination, sovereignty, and equality in relief distribution. Therefore, a trust-based 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 in a distributed technological ecosystem.

This study aims to analyze the application of blockchain technology on disaster management resilience. Blockchain technology, the Internet of Things (IoT), and Dynamic Voltage Frequency Scaling (DVFS) algorithm are integrated in a network-based simulation. The results indicate an advancement in disaster-aids network strategies using smart contracts for collaborations. From the investigations, insights have been derived for researchers in the field and the managers interested in practical implementation.

Keywords: Blockchain T echnology, Internet of Things, Dynamic Voltage Frequency Scaling, Disaster Supply Chain Model, Agent Based Modeling

INTRODUCTION

Disaster relief supply chain management is defined as a 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 and 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 and 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 dynamics of the environment.

Equity and fairness among aid two recipients are also other essential aspects that require more consideration (Cavdur et al., 2016 and 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 a 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 an affected area in the least possible time.

To overcome some of the current challenges, 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 systems.

Disaster management is a vast arena and this study focuses only on the information and communication influences on disaster governance, and the structure of this study focuses 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 the blockchain technologies, IoT, and modeling and simulation are an opportunity to redefine the new architecture of emergency awareness governance;
- New techniques such as the blockchain technology, IoT, and modeling and simulation, etc. are proved to be of great support for dealing with biological, technological, and natural disasters;
- Decentralized and distributed systems (Cloud Computing, IoT, etc.) are hoping to be integrated tools for addressing the ecosystem of disaster governance.

THE SYSTEMATIC APPROACH

This segment briefly explains a systematic literature review on the disaster supply network. The diagram of the literature review is exemplified in three different aspects disaster management, humanitarian logistics and blockchain supply chain, as represented in Figure 1.

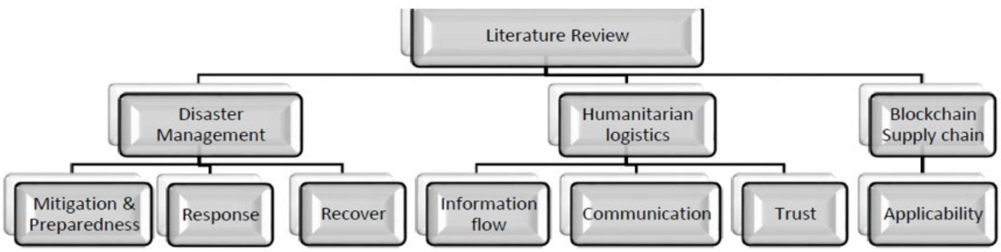

Fig. 1: *Literature review Scheme (retrieved from Pour, 2021)*

The scope of the literature review is shown in Table 1. 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 was emphasized.

Table 1: *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

CiteNetExplorer, a new java-based software tool developed for analyzing and visualizing direct citation networks was introduced by in late 2014. The software offers sophisticated functionality for drilling down into citation networks dealing with a specific topic of interest. The details of the scope of the literature review in regards of the principal component's bodies of disaster supply chain literature are represented in Table 2.

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 3.

The Web of Science database was used as the search query and the keywords combinations are shown in 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 and b) only the English language within Journal publications was considered for this review.

Table 2: *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

Table 3: *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 documents to find the roots and paths of methods related to the disaster supply network.

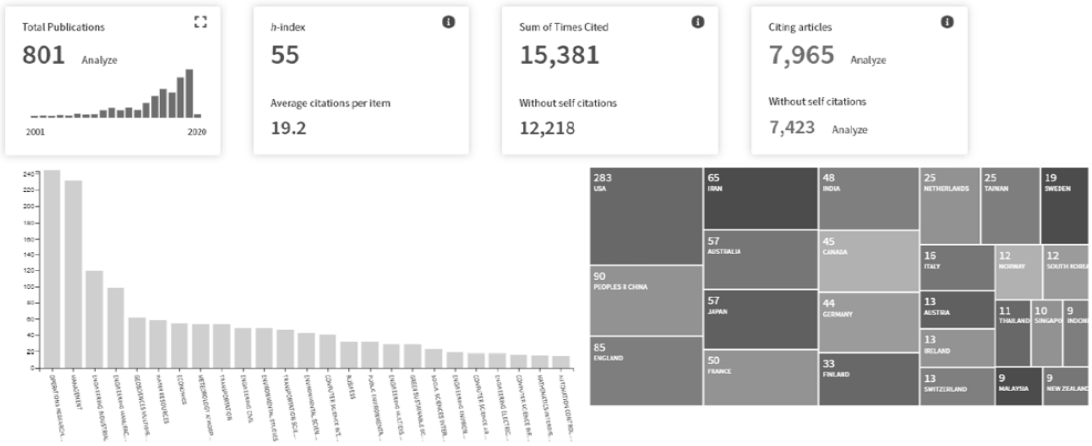

Fig. 2: Disaster Supply Chain Publications Tree Map (retrieved from Pour, 2021)

At the first point, the search key was the disaster supply chain. The visual tree map of the search results is shown in Figure 2 and Figure 3. The citation visualization of supply chain management in disaster response is depicted Table 3 using CitNetExplorer. The results represented that the United States of America was the first leader of research followed by China and England as represented in Figure 4.

However, the topic is to 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 5.

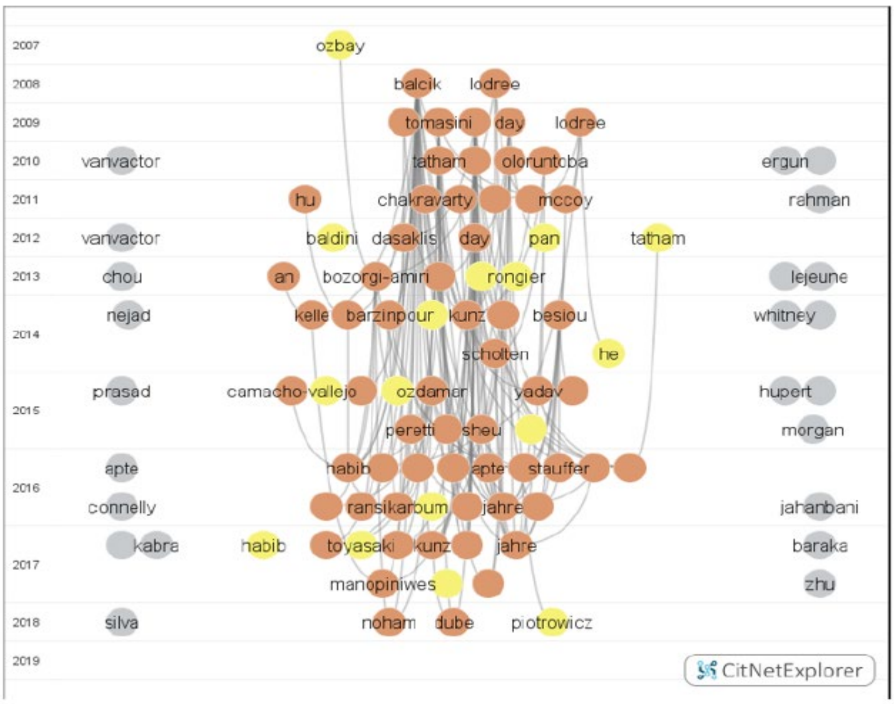

Fig. 3: Keyword „Supply Chain Management in Disaster Response" – Citation Visualization

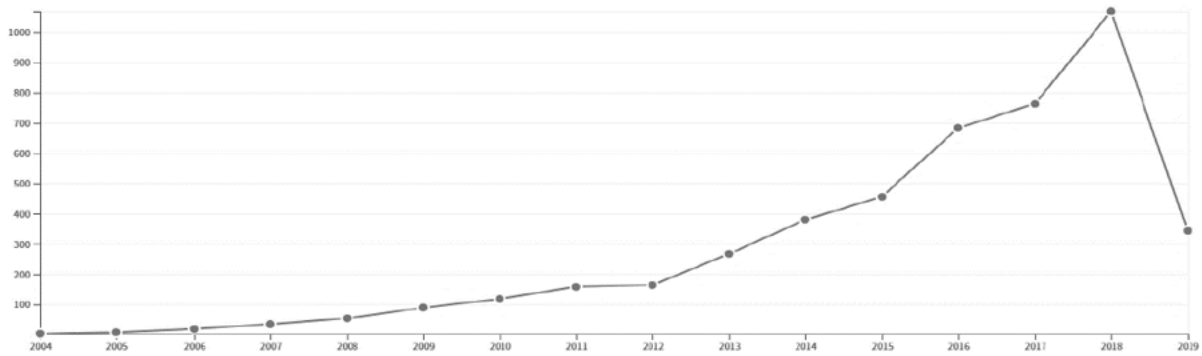

Fig. 4: *Sum of Times Cited per Year*

The main topic for this study 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 as represented in Figure 5. The next search topic is blockchain technology in the supply chain and the results are 58 publications in the period 2017-2019.

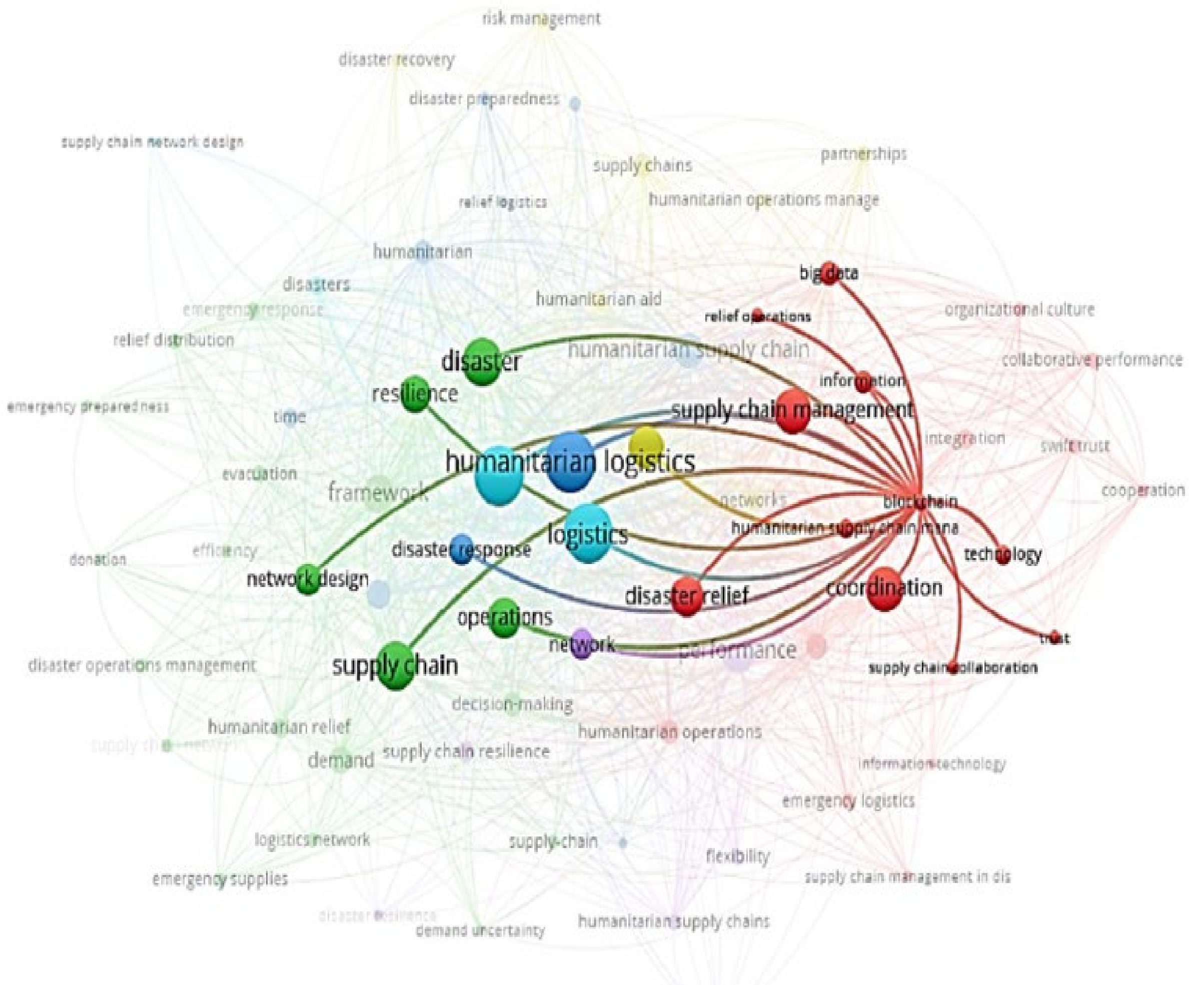

Fig. 5: *Disaster Supply Chain Citation Network – Blockchain Links (retrieved from Pour, 2021)*

METHODOLOGY

This chapter addresses 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 AND MODEL DESIGN

This study follows the approach to provide a framework related to key objectives of disaster supply chain management. 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 (Dynamic Voltage Frequency Scaling) algorithm is used.

The research design for this study is shown in Figure 6. 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. A systematic approach is needed, 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 level of vulnerability and risks. A deep understanding of supply chain risks and managing methods keeps the system dynamic, efficient, and resilient. Collaboration is the key that holds organizations together in case of a disaster (Pour, 2021). 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 model is developed based on the literature review, Blockchain technology for decentralized network brainstorming (mind mapping), and simulated stream of data.

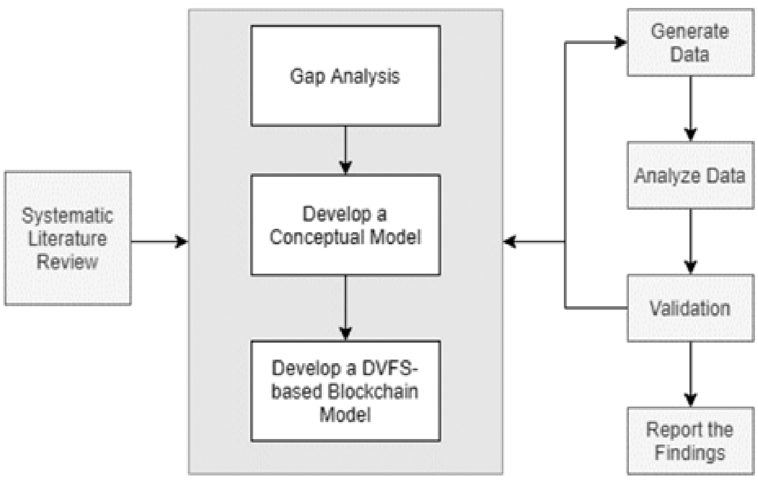

Fig. 6: Research Design (retrieved from Pour, 2021)

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 – Distributed Ledger Technology - has been applied in the field of disaster management 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 improve 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, 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 DYNAMIC VOLTAGE FREQUENCY SCALING (DVFS) -BASED MODEL

Several recent critical reviews of disasters conclude 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 of 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).

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 (Pour, 2021).

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 (Pour, 2021). The conceptual model includes three phases as represented in Figure 7.

Numerous components are considered as valuable inputs to the network and at the same time, the updating and tracking of the network should be applied. The data is 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.

The application of Multi Agent Systems (MAS) enables modeling the behavior of the agents and provide a learning path to enhance the decision-making process.

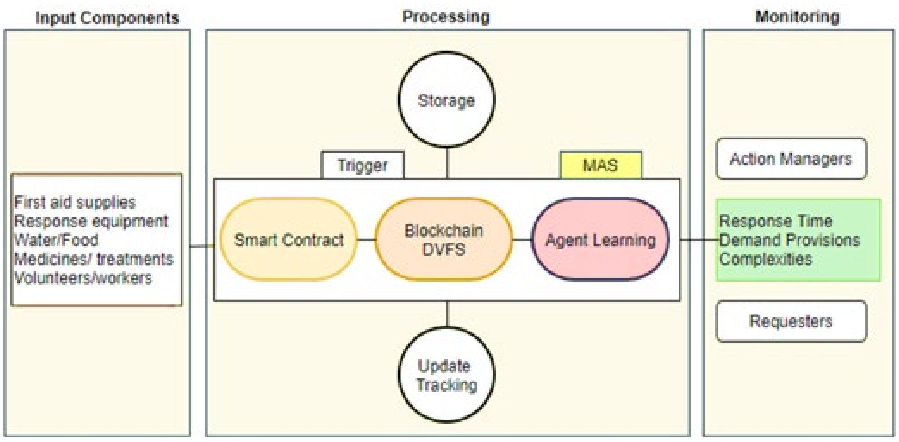

Fig. 7: Conceptual Model (retrieved from Pour, 2021)

The process of generating encrypted information through cryptography is of high importance. The science of using mathematical rules for the cryptography of the known data is based on encryption.

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.

AGENT-BASED MODELING (ABM)

ABM – Agent Based Modeling is a modeling paradigm that defines the behavior of the system by the entities and their interactions. Modeling with ABM includes

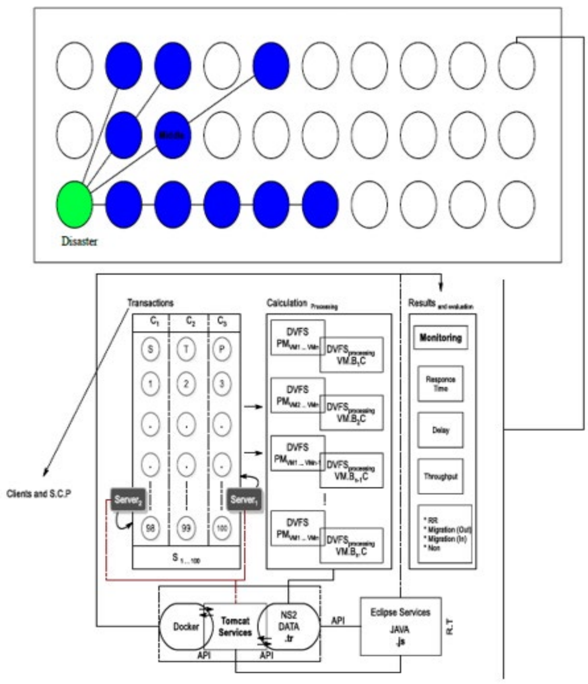

Fig. 8: Model Execution – Blockchain enabled DVFS-based Disaster Management (retrieved from Pour, 2021)

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 9 depicts the stages of ABM. "Running an ABM is a computer provides a formal proof that a particular micro-specification is appropriate to generate the global behavior observed during the simulation".

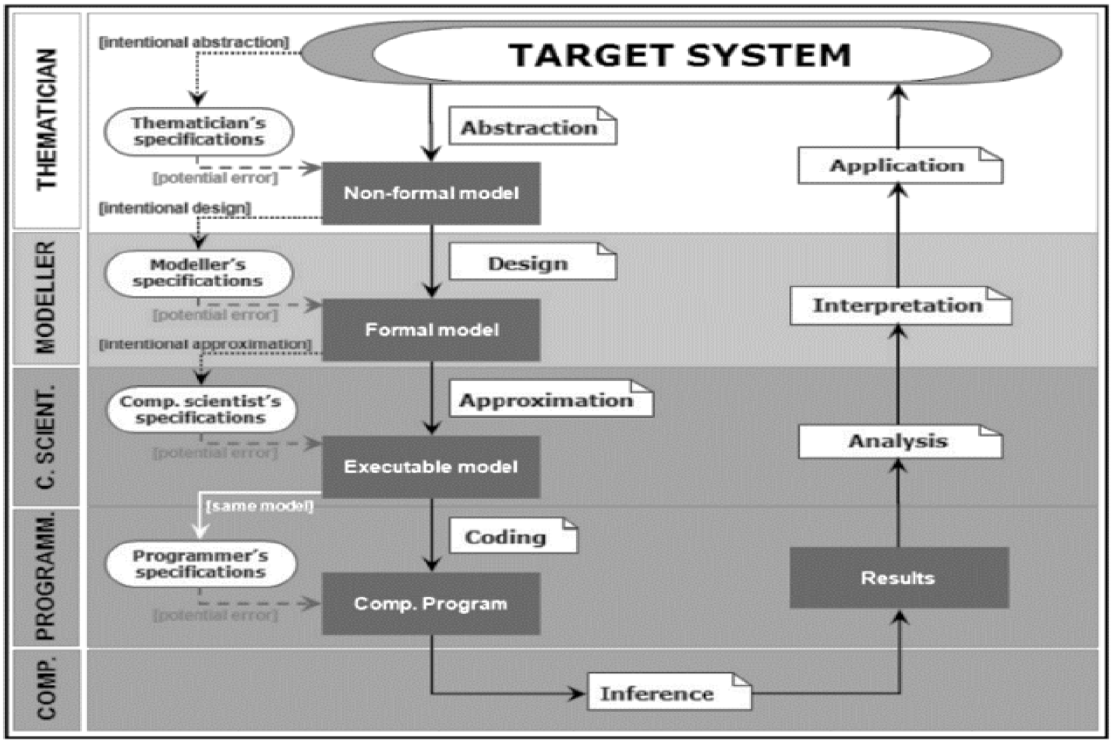

Fig. 9: *Different stages of ABS - Agent Based Modeling*

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 agrees 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).

OVERCOMING LIMITATIONS AND RESEARCH FOR THE FUTURE

This paper aims to present the research path of blockchain technology application into the field of disaster aids management. Some of the research gaps and future directions of blockchain technology that are proposed by numerous 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 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 used one source to collect data, future studies can include more publications and compare results on the evolving research trends.

The study proposes various future research paths, i.e. the development of 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. Other mechanisms will be developed to clarify the efficiency of the current studies with real cases such as the mixing of such technologies into current disaster management systems to trace the shortage of supplies in the pandemic crisis. There is a necessity for real case applications of proposed models and frameworks in industries to address the technical and behavioral challenges in the embracing of blockchain technology.

Scalability, integrity, safety, and user's confidentiality are some of the technical challenges of blockchain application that can be studied in future research.

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.

Some of the limitations of this study that can be addressed in future works include the data collection, single case analysis, and onsite validation of the simulation results.

The studied 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. Another 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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