Understanding Decision Support in Large-Scale Disasters: Challenges in Humanitarian Logistics Distribution

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Abstract. Disasters are characterized by conflicting, uncertain, or lacking data. Nevertheless, humanitarian responders need to make rapid decisions. This is particularly true for the immediate response to a sudden onset disaster. Since most humanitarian decision support systems (DSS) make important assumptions on data availability and quality that are often not fulfilled in practice, decision-makers are largely left to their experience. In this paper, we identify three major challenges for an operational DSS to support distribution planning: (i) deep uncertainty; (ii) reflecting field conditions and constraints; and (iii) rapid humanitarian logistics modeling. We review the relevant theories and provide an outline of the system requirements to develop a system for operational responders to achieve targeted service level on distribution of disaster relief through proper utilization of resources, time and scheduling.

Keywords: Decision support systems · Deep uncertainty · Disaster response · Rapid decision-making · Humanitarian logistics distribution

1 Introduction

For decades, responders have been searching for information and data to provide better aid. Today, there is no information shortage in disasters any more: increasing public participation, volunteers, responders and affected communities alike produce large amount of data [11,13]. However, such datasets are often incomplete because of infrastructure disruptions and access difficulties [14]. Even if data is available, it needs to be formatted and shared to support coordination [16] so that response can be organized in an efficient and effective way [49].

Humanitarian logistics becomes vital when natural disasters strike. Responders need to deal with uncertainties in the shortest possible time to make decisions that save human lives and alleviate suffering. However, humanitarian needs (demands) and available resources and goods (supplies) are dynamically evolving [57]. Particularly in the early phases of the response, little is known about what is needed at which place, and responders are left to make decisions without appropriate data or computational support [13].

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This paper discusses challenges and approaches for developing a dynamic information system (IS) to support decision-making on distribution disaster aid goods. We base our work on the Dynamic Emergence Response Management Information Systems (DERMIS) principles, developed by Turoff et al. [51] to assist efficient and effective decision-making.

The remainder of this paper is divided into three parts. Firstly, we discuss different research challenges to identify gaps that require further research. Secondly, we present our research approach. Finally, we draw conclusions.

2 Research Challenges

Due to many socio-technical interdependencies, the onset of a disaster causes complex chains of interactions [10] that are unique [62] and cannot be predicted. These characteristics of a disaster make it difficult for responders to identify relevant information [10] to allocate adequate humanitarian logistics for rapid action.

According to Van Wassenhove [58], proper allocation of resources is one of the reasons for avoiding the creation of bottlenecks in relief operation and it requires management procedures to maintain information and resources for rapid and timely response [44]. Many authors conduct systematic reviews and survey on the aspect of relief goods distribution networks in response to disasters and summarizes some promising challenges in this area [2,18,25,27–29,36–38,52,59]. After having an in-depth study of these articles, we realize that distribution planning for disaster relief goods is not a standalone area of research. It is connected with few other areas and thus complex in nature. For example, responders need to know the demand, products' sourcing and procurement and transport arrangements before making plans on relief distribution.

Anaya-Arenas et al. [2], Holguín-Veras et al. [25], Kovács and Spens [27], and Van Wassenhove and Pedraza Martínez [59] focus on demand uncertainty. According to them, demand is always unpredictable at the time of disaster and it changes frequently. To make proper distribution of relief goods, responders need to assess fields' demand and make arrangement to collect those demandable products. They perform several complex activities to arrange those scarce resources. Most of the authors of the articles listed above emphasize proper humanitarian supply chain modeling because it covers a wide area of distribution planning starting from fund collection to effective and efficient distribution. Anaya-Arenas et al. [2] identify challenges in stock management and relocation, transportation, and coordination, collaboration, and communication among humanitarian supply chains. These challenges are also supported by Cozzolino [18], Kovács and Spens [28], Nolz et al. [36], and Van Wassenhove and Pedraza Martínez [59]. Additionally, type of the disaster as well as the geolocation of disastrous area and its political and social structures play important roles in relief distribution planning to that specific area [25,27,38].

According to Tzeng et al. [52], after a disaster occurrence, decisions on humanitarian support requires a rapid analysis of the situation even on the basis of limited and often incomplete information and Nolz et al. [37] suggests

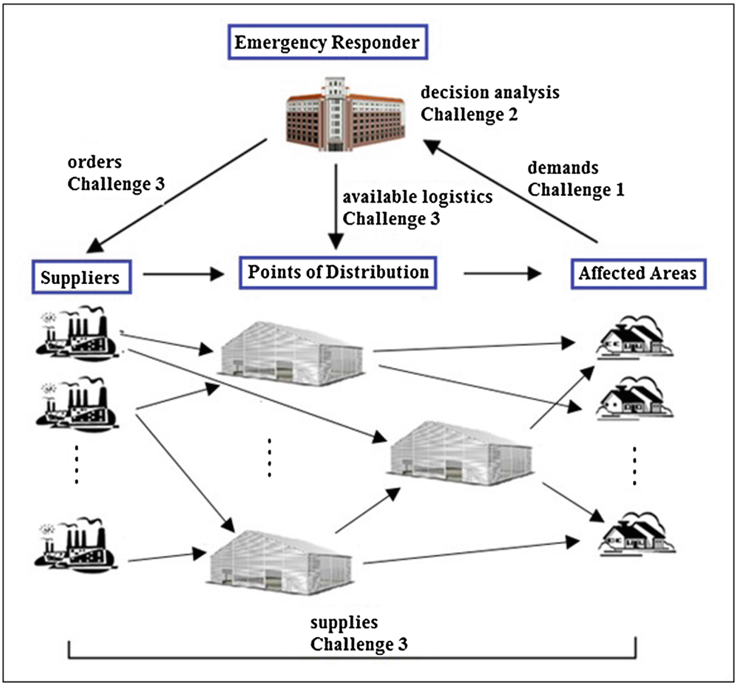

Fig. 1. Challenges in distribution of disaster aid goods

developing a decision support system to perform this complex analysis task and assist practitioners with alternative solutions. So, a computer based [45], well-structured [15], flexible [62], effective and efficient decision support system (DSS) is needed to acquire and analyze data from various sources and assist humanitarian logisticians to take decision on distribution of goods.

From the above discussion on challenges of disaster relief distribution, we conclude that for developing such DSS, researchers need to deal with the three most salient research challenges that are portrayed in Fig. 1. Challenge 1 deals with uncertain information on demand for humanitarian logistics; Challenge 2 analyzes that information to meet requested demand by taking field conditions and constraints into consideration; Challenge 3 discusses the humanitarian supply chain to make logistics available to the survivors.

2.1 Deep Uncertainty

The term *uncertainty* is present in (almost) every research field but differs in meaning and implication [53]. Walker et al. [53] and Pruyt and Kwakkel [42] define uncertainty as knowledge inadequacy or limitation on past, current and future events. Benini [7] discusses Smithson's (1989) typology of ignorance, where uncertainty is placed within a wider taxonomy of information ignorance under incomplete statements subclass (see Fig. 2) and it has its own subordinate types:

vague, ambiguous and probabilistic statements. Similarly, Walker et al. [53] identify that lack of knowledge or information is not the only reason for uncertainty; knowledge inexactness, unreliability and ignorance also brings uncertainty in the scene. Additionally, they claim that excessive information and latest or updated version of it can reveal the existence of uncertainty in certain situations. For example, inexact and unreliable information creates knowledge gap, whereas excess and new information makes current knowledge inconsistence and fragile. All of these information categories are widely available in disastrous events and thus, make situations uncertain. According to Luis et al. [33], uncertainty is prevalent in the distribution of humanitarian logistics and it exists throughout all phases of decision-making [14]. Pruyt and Kwakkel [42] divide uncertainty into seven levels: marginal uncertainty, shallow uncertainty, medium uncertainty, deep uncertainty, and recognized ignorance. The authors characterize deep uncertainty as the ability to generate or consider multiple possibilities with no tracing of internal relationship among themselves. Klibi et al. [26] and Comes et al. [14] define deep uncertainty as the absence of apposite information to asses and identify upcoming unusual events that need to be taken care of. Decision-making becomes more challenging when uncertainty is deep [14]. For example, when a disaster strikes, it creates a chaotic environment; the behavior of the complex socio-technical systems affect is unpredictable and the disruption of infrastructures causes breakdown in information flows [32]. Thus, it creates uncertainty in demand and supply of each relief item and in distribution networks due to possible damages to storage facilities and transportation links [50]. Pruyt and Kwakkel [42] identify three uncertainty prone situations:

1. if it is difficult to find appropriate mechanisms from many existing ones for real-world solution,
2. if the probabilities for acceptable real-world outcomes are uncertain and
3. if acceptance fluctuates.

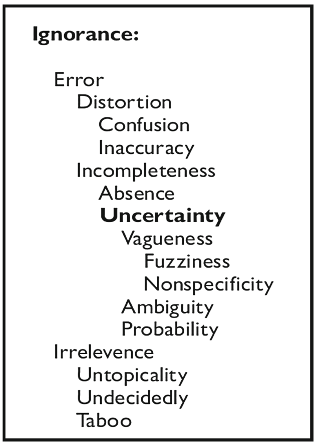

Fig. 2. Smithson's typology of ignorance, retrieved from [7]

According to Liberatore et al. [32], survivors and disastrous situations are not the only reasons for uncertainty. They claim that reporters, NGOs, and other emergency agencies are also responsible for making situations unstable. The information they provide is sometimes unstructured and cannot be utilized directly for identifying hidden relationships among datasets to assist decision-making in highly uncertain environment [31,32,54]. So, for making better decisions, uncertainty analysis becomes prominent, especially in disaster management [1].

Many researchers have been working on tackling uncertainties through scenario and model development. However, according to Hamarat et al. [21], no model or scenario should be considered as the *best* because the characteristics of uncertainties vary depending on the situations. Thus, decision makers always need some adjustments in decision-making variables in any system. Luis et al. [33] identify a trend on modelling uncertainty based on physical damages caused by a disaster and the immediate post-disaster functionalities. They point out uncertainty in demand and supply of relief goods. If the disaster is transboundary (e.g. across countries), it becomes more challenging to regain control [3].

Hamarat et al. [21] propose an iterative computational model-based approach for taking decision under deep uncertainty and demonstrate it with policy-making for energy transition. Their approach iteratively explores thousands of plausible scenarios to get a satisfying dynamic adaptive policy, where the concentration on time (rapidness) is missing. Comes et al. [14] emphasize time and availability of experts in their integrated framework to produce plausible scenarios. Thus, the authors advice future researchers to focus on the relevance of information to the decision type in the time available. This is relevant to the disastrous events, where getting correct information in time is crucial. Thus, Pruyt and Kwakkel [42] generalize the approach to deal with deep uncertainty. According to them, alternative outcomes should be generated by using multiple possible features or alternative model structures. Figure 3 portraits different parameters that Liberatore et al. [32] suggest to consider while dealing with uncertainty in humanitarian logistics. As soon as data acquisition on demand (in deep uncertain situations) is completed (up to the considerable level), responders conduct decision analysis (Challenge 2) to identify the actual need.

2.2 Decision Analysis for Operational Response

Decision support technology is a generalized term that requires different systems, hardware and communication tools to work together with a purpose of solving real-time complex problems [49]. It requires integrated efforts from both humans and technical tools for proper decision-making in humanitarian support [4,45,47]. More specifically, decision support system is an integration of hardware and software, developed to assist humans on decision making [54]. [54] have identified four basic components of a decision sup-port system: (1) data repository, (2) data analysis capability, (3) models for solution, evaluation (alternative solutions) and recommending actions to take, and (4) technology for interactive usage of the data and model and to display them when necessary.

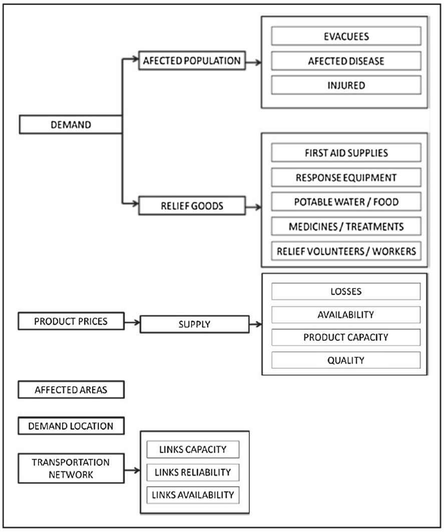

Fig. 3. Uncertainty parameters in humanitarian logistics [32]

Thompson et al. [49] note three sources of data inflow during a disaster: public, news media, and reports. According to the authors, public data is unreliable (to some degree), news media only covers a specific location and initial reports from public safety organizations alter by current situations, available resources and freelance responses. So, an appropriate decision support system should be able to integrate data (structured and unstructured) from multiple sources, analyze them and make them ready to use by the normative models for producing solutions and thus, can help practitioners to mitigate problems in relief distribution.

Shim et al. [45] propose a simplified decision-making process model that includes seven phases (see Fig. 4): problem recognition, problem definition, alternative generation, model development, alternative analysis, choice and implementation. So, decision analysis is necessary to decompose complicated problems into smaller and manageable components for decision aid with potential choices [46] that reflect the desire of the decision-maker [41]. However, decision analysis is all about explaining the decision situation and suggesting decision-making process [40], where computer system is integrated to facilitate these activities [46]. Balcik et al. [5] argue that it is necessary to consider the type of disaster, its impact on the affected society and location while designing decision support systems because it may cause relief activities to vary. Additionally, humanitarian operations are being affected by the realistic field conditions and constraints: lack of time, pressure to make decisions, lack of resources and often computational power, long working hours for volunteers, tensed atmosphere etc.

Developing an efficient and effective DSS for an operational responder is not an easy task. While working on a disastrous event, responders face many critical challenges. According to Thompson et al. [49], these challenges for humanitarian

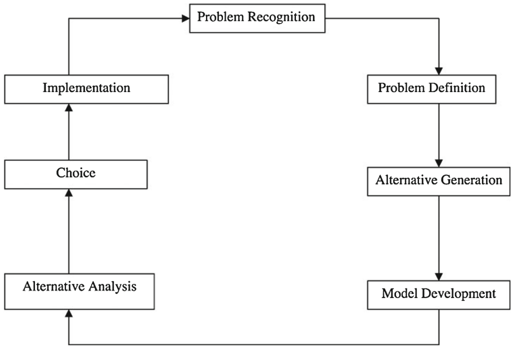

Fig. 4. Decision-making process of decision support systems [45]

response come from lack of coordination among responding actors, poor information flows between headquarter and field, and processing and validating relevant information for rapid decision-making. Thus, information becomes a vital resource for responders because it helps them to communicate with suppliers, coordinate with other agencies and allocate resources. Operational responders always suffer from information inaccessibly, lacking and overhead. According to Zang et al. [63], diversity of information and its distributed ownership are the major challenges in disaster relief operations. For example, when a disaster strikes, information can come from various sources: survivors, media and reports, and NGOs and other emergency agencies [32]. Thus, operational responders need to closely observe the situation, accumulate adequate and relevant information, properly analyze them and make an effective and efficient distribution plan [63].

According to Ter Mors et al. [48], operational responders should be able to prioritize tasks and identify relationships among them. This identification of relationship or dependency among tasks will help responders to determine who to communicate and coordinate to complete the tasks. Furthermore, operational responders should know when a task should be performed and under which circumstances [48]. While dealing with such complex tasks of resource allocation and scheduling, operational responders also need to concentrate on disrupted infrastructures, so that alternate distribution network can be planned. For achieving better control over the emergency response operations, Van de Walle and Turoff [61] emphasize the sensible development of flexible and dynamic operational decision support system. This system would facilitate operational responders to easily extract valid, relevant, meaningful and timely information. Nevertheless, this efficient extraction largely depends on quality and availability of inflow data and the effectiveness of data collection and analysis techniques [49]. After finalizing relief materials, their destination and time, emergency responders take initiative to find out how to meet the demand (Challenge 3).

2.3 Rapid Humanitarian Logistics Modeling

The concept of humanitarian supply chain (HSC) is different from the concept of commercial supply chain (CSC) and they differ from many aspects, such as assessing demand, sourcing and procurement, and delivery or supply infrastructure [30]. CSC has some structured ways to deal with demand and supply but HSC must deal with uncertainty in every phase of its functionality. For example, information inaccessibility, incompleteness, lacking and overload, unpredictable demand, disrupted infrastructure, damaged roads, delivery in short time and many other unknowns and uncertainties [30]. The general objective of humanitarian aids supply chain is to provide food, water, medicine, shelter and supplies immediately to people in need [6]. In humanitarian relief operations, needs and supplies are badly unstable because it is hard to predict demandable products and find potential suppliers [57]. Such operations require sufficient skills and knowledge on mobilizing disaster affected people and resources [58]. Thus, these operations demand proper communication and coordination among involved organizations and all the people within these organizations [3] to lessen the uncertainty in disaster relief distribution. Holguín-Veras et al. [25] claim that humanitarian logistics covers a broader working area in operational environment, where it always deals with urgent needs, life-or-death decisions and scarce of resources. This chaotic setting of operational environment becomes acute when transportation and communication networks collapse and these situations are quite normal when a disaster strikes. Thus, humanitarian supply chain should be managed effectively and efficiently to perform a successful relief operation [29]. Effectiveness ensures the targeted service level has been met and efficiency ensures that the response has been made by using minimum resources, cost and time. For achieving such efficient and effective humanitarian supply chain, Holguín-Veras et al. [25] suggest focusing on seven major components: (1) the objectives being pursued, (2) the origin of the commodity flows to be transported, (3) knowledge of demand, (4) the decision-making structure, (5) periodicity and volume of supply, and (6) the state of the social networks and (7) supporting systems.

Nevertheless, rapid response to the need of urgent relief goods is vital for saving victims' lives and humanitarian logistics plays an important role in such situations. According to Holguín-Veras et al. [24], it is common for humanitarian logistics to perform its activities when needs are at peak level, resources are insufficient and supporting systems are impacted. While responding to disastrous events, humanitarian logistics takes initiatives to search and rescue victims, and transport and distribute resources (equipment, personnel and goods) to assess the situation and meet the demand [25]. In this research, we are concentrating on rapid distribution of humanitarian relief goods that mostly includes faster demand assessment, quick allocation of resources and distribute them at an efficient and effective way. Thus, we need to model a humanitarian supply chain that would rapidly perform this activities for getting better control over emergency situations. In addition to placing demand and receiving supplies, the model should provide appropriate and updated stock information to operational responders. For better performance in distribution activities, the model should also be able to suggest alternative transportation networks (e.g. from supplier to warehouse, warehouse to warehouse, warehouse to the affected area). We consider that further studies are necessary to develop the concept of alternative distribution network along with the plan for time efficient and cost effective distribution of humanitarian logistics. For developing such a distribution model, we need to consider the following requirements [12,20,23]:

1. additional uncertainty (infrastructure disruption, security issues, political environment, facility location identification, unpredictable demands),
2. complex communication and coordination (information inaccessibility, shortage of logistics experts, multiple and unknown suppliers, local influential persons, government and civilians),
3. harder-to-achieve efficient and timely delivery (improper planning, lack of technology, manual processing, prioritization of goods, costly and lengthy distribution network selection), and
4. limited resources (funds, volunteers, vehicles, availability of relief items).

In addition to make decisions on products and suppliers, managers of humanitarian organization need to focus on procurement planning to obtain resources (donations, volunteers etc.), transport (from donor to beneficiary), warehousing (central and local), tracking and tracing for delivery confirmation [34].

Our research agenda is to develop an IS artifact (DSS) for supporting rapid humanitarian logistics decision-making on the basis of excessive, incomplete, conflicting and uncertain information (*constraints*). The aim of our DSS is to provide effective (reaching target service level), efficient (minimizing use of resources, cost and time) and equitable plans (facility location, flow mapping, routing and scheduling) for humanitarian logistics distribution. To support decision-making under uncertainties, the system will map current information flows against a series of bench-marks and thus determine the level of uncertainty along with various scenarios and adaptive paths. Thus, we will also focus on possible supply planning (especially the downstream part) for the prioritized distribution of disaster relief items as decision-makers not only have to decide which aids to deliver but also where and at what point in time. For developing such computerized IS artifact (DSS), we follow the related information categorization technique of Comes and Van de Walle [13]: (1) information on disaster that focuses on what (needs)-, where (infrastructures and accessibility)- and how (resources)- to support and (2) humanitarian logistics supply chain that deals with the distribution of relief materials and with all actors who are involved in this process.

3 Towards Rapid Humanitarian Distribution Planning – Our Approach

Designing an IS artifact will be designing IT product (DSS in our case) using information from appropriate sources and technologies by following explicit working procedures [55]. Depending on user requirements, system specifications and effective development, various design theories are available for different information systems types, such as management information systems (MIS), decision support systems (DSS), executive information systems (EIS), transaction processing systems (TPS), etc. [56]. According to Markus et al. [35], these different system types are considered as contributions to the IS field because their design theories and principles are developed basing on individual contexts.

In disaster management, it is necessary to perform complex tasks to deal with high uncertainty and multiple stakeholders and suppliers for providing rapid response to affected areas [39]. Human decision makers face difficulties to conduct these complex tasks for producing precise, efficient and unbiased outcomes [17]. They require computer aided DSS to process (such as order, store, retrieve, analyze) available information and share it among participating responders. According to Van de Walle and Turoff [61], this collaborative and integrative organizational work plays a key role to make a DSS successful. In addition to this sharing attitude, each DSS must follow a set of principles to assist decision-making on humanitarian logistics in feasible and effective ways [35,39,56].

Our research on rapid humanitarian distribution planning is in an emerging stage. Although we need more study to finalize our approach, here we present our generalized research steps to address the challenges depicted in the previous section. The development of our decision support system requires both empirical and design-oriented research. Thus, our work will follow a twofold approach:

1. Analyze how IS support decision-making on relief distribution planning in sudden onset disasters, and
2. Design, develop, implement, test and evaluate the decision support system.

The process model portrayed in Fig. 5 visualizes our research approaches. Initially, we develop our knowledge by reviewing existing DSS. We shall scrutinize those to understand how fast they support decision-making in specific problem domains (prioritizing logistic) by utilizing what type of information (structured, unstructured and/or sparse), technology and mechanism. This knowledge will help us identify the behavior of our targeted DSS. Then, we shall proceed to the design and development phase of our system. Finally, our system will be validated and empirically tested by some measurement instruments.

To develop the system, our research will deal with structured *and* unstructured data. The former includes data from topography, population registers, infrastructure, and pre-disaster functionality. The latter comes from sources ranging from sensor data to social media. There will be two data collection phases:

1. Design phase (or *first* evaluation cycle): data related to the targeted disasters from multi-disciplinary contexts will be acquired from social media, preparation packages, interview transcripts, observational notes-pictures-videos, surveys and online/offline documents.

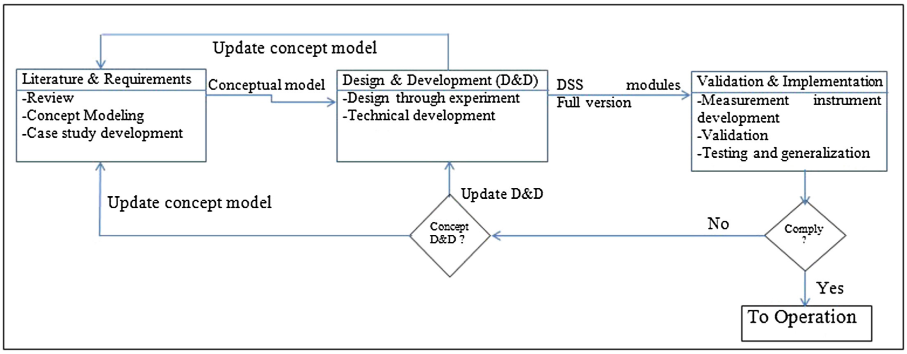

Fig. 5. Process model for our research approach

2. Evaluation phase (or *second* evaluation cycle): data will be collected during externally aligned project exercises and potentially complementary humanitarian training, also offering an opportunity to collect quantitative data from tables, decision points and duration, preferences, logistics flows etc.

For data analysis, we combine an quantitative and an qualitative approach. This mixed-method procedure will facilitate a complete and synergistic utilization of data to create rich insights on the targeted phenomenon [19]. For example, qualitative interview transcripts can be exploited to identify numeric data for statistical analysis, whereas quantitative survey data can be converted to descriptive notes for thematic or pattern analysis [9]. This indicates that numeric trends of qualitative data can be merged with the specific details received from quantitative data to identify new behavior for the system [22]. Venkatesh et al. [60] identify dominant and priority trends in this mixed-method of data analysis: quantitative dominated qualitative analysis or vice versa, where researchers collect data rigorously and analysis for domination. However, researchers are encouraged to put equal weight and emphasis on both data types.

According to Bhimani and Song [8] and Salvadó et al. [43], there is always a gap between practice on humanitarian operations and academic research because academic research does not have complete understanding on the needs in practice [8]. By considering the findings by [8,43], we plan to work collaboratively with the practitioners (through the aligned project) and involve them into the research from the very beginning. This will help us to understand their needs in detail and work accordingly. In this way, the evaluation process of our research can be started at early stage by the practitioners, which will facilitate them to check whether it is working effectively (reaching the targeted service level), efficiently (minimizing use of resources, cost and time) and equitably (dealing with facility location, prioritizing, flow mapping, alternate supply network, routing and scheduling) for the expected humanitarian logistics distribution operations.

4 Discussion and Conclusion

After pinning down the areas of concern for our research, we are focusing on developing a DSS that will rapidly analyze situations and assist stakeholders or practitioners on decision-making despite of lacking, conflicting and uncertain information. Moreover, we shall propose possible downward supply planning for effective, efficient and equitable distribution of humanitarian logistics to the affected areas. Since network decisions are strategic and often irreversible, temporal factors will also play an important role in our system: decision makers are required to choose not only *how* to set up a network, but also *when* there is sufficient information to make such a decision. Similarly, they do not only have to decide *which* aids to deliver but also *where* and at *what* point in time.

The success of our DSS depends on how it tackles the identified challenges: deep uncertainty, decision analysis for operational response and rapid humanitarian supply chain modeling. The demand for humanitarian logistics always fluctuates, which makes the entire system unstable. Humanitarian supply chains mostly deal with real-life constraints, such as suppliers, goods, delivery vehicles, roadways, warehouses, security, and volunteers. These physical constraints are crucial for distribution planning and impossible to upgrade at the time of disaster. However, we can switch from one provider to another for achieving targeted service levels on distribution of disaster relief through proper utilization of resources, time and scheduling. Emergency responders can switch after analyzing available information. So, we mainly target to upgrade the decision analysis phase in our research. Developing a system with the capability of rapid analysis of the demand and suggestion of alternatives (arrangements) for its delivery will accelerate distribution and, thus, respond to the emergency call quickly.

This decision support artifact will have specific user requirements, system specifications, and effective development procedures suitable for the contexts or scenarios that we will be concentrating on. In such way, it leads us to generate scenario-specific principles and build theories for designing and developing a DSS for humanitarian logistics distribution. Thus, it will create knowledge on certain problem settings and add values to IS research on decision support in humanitarian logistics. Nevertheless, this system will require adequate and quality information to produce proper decision. Additionally, the literature we studied for this research is mainly based on the Norwegian repository of Google Scholar (scholar.google.no), which limits our knowledge development on the context.

Our aimed decision-making support system will integrate and analyze information (structured and unstructured) from different heterogeneous sources to assist stakeholders for responding rapidly to disastrous situations with necessary humanitarian logistics, despite of time lacking for collecting additional information. Consequently, it is our research quest to find the best quality of information for generating this rapid decision support on humanitarian logistics distribution. Thus, the quality of the data stored in databases of various humanitarian organizations could be a challenge to deal with. Interviewing humanitarian assistance practitioners will be another challenging task to conduct. The research challenges and approaches we have discussed are a preliminary observation to design and develop our intended DSS. In near future, we will continue our literature work in other repositories and analyze the system requirements in detail to design the prototype, develop the system and test it in practice and thus, minimize the gap between academic research and practitioners' work.

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