Impact of coordination on post-earthquake Last Mile Relief Distribution operations in India

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Abstract: The operations to deliver relief to disaster affected populations are complex requiring careful planning, execution, and coordination especially during the Last Mile Relief Distribution (LMRD) phase. This paper investigates the impact of coordination on LMRD performance in the context of India, one of the most affected countries in the world by natural disasters. The research was carried out in two phases. First, qualitative interviews were conducted with Indian government, national, and international non-governmental organizations involved in disaster relief operations in the country. Second, an Agent-Based Simulation model representing Indian LMRD operations was developed and used to evaluate the impact of three coordination scenarios on the total level of inventory in distribution centers (TLIDC) and the logistics chain responsiveness during the 45 days period following an earthquake. Findings indicate that better coordination can reduce TLIDC by up to 16% and improves responsiveness by up to 13%. The practical implications of these findings are discussed.

1. Introduction

Natural disasters are occurring with a higher frequency all over the world. A recent United Nations (UN) report indicates that, in the last two decades, there have been more than 600,000 people killed and trillions of dollars of damages caused by natural disasters (UN, 2015). In 2015, 198 natural disasters were registered causing a total economic loss of 37 Billion US Dollars, the highest amount recorded in a single year. As most natural disasters are uncertain and unpredictable (e.g., Earthquakes), it is difficult and costly to prepare adequately for their consequences. The World Health Organization (WHO) defines natural disasters as “events that occur when significant numbers of people are exposed to extreme events to which they are vulnerable, with resulting injury and loss of life, often combined with damage to property and livelihoods” (Wisner and Adams, 2002). Therefore, in a disaster situation, the primary objective is to provide quick relief to the affected populations in the form of food, water, medicine, and shelter, a process that involves various stakeholders including governments, international organizations (UN, WHO), and non-governmental organizations (NGOs).

Following a disaster, there is an urgent need to provide relief items (food, water, medicine, shelter) to large populations scattered over wide geographical areas where transportation and communication infrastructure (roads, bridges, railways, phone lines) can be seriously damaged (Oloruntoba and Gray, 2006). The backbone of these disaster relief operations is an effective and efficient logistics system, which enable relief items to reach the affected populations in a timely manner and in sufficient quantities. This type of logistics is known as “emergency logistics” and account for about 80% of total expenditure in disaster relief operations (Jiang and Yuan, 2019; Van Wassenhove, 2006).

Although emergency logistics operations deal primarily with the post-disaster response phase, their success is influenced by the pre-disaster preparedness phase and risk reduction plans. For instance, a clear identification of the central, regional, and local entities in charge of disaster management, their duties and responsibilities, and the chain of command linking them is important for a quick and efficient response (Kaynak and Tuger, 2014). Similarly, design and delivery of training programs for staff involved in post-disaster response is key for smooth relief activities (Holguín-Veras et al, 2014). Education of local communities on aspects of rescue and first aid, assessment of damage to buildings and infrastructure, location of affected populations, evaluation of relief needs, and the use of technologies such as microblogs is very helpful for the organizations involved in post-disaster relief operations (Dutt et al, 2019; Opdyke et al, 2018). From an operational perspective, determining the optimal locations for establishing logistics infrastructure (warehouses, distribution centers, local relief supply facilities), planning for joint emergency logistics operations between civilian and the military, given the unique assets and capabilities possessed by the latter, and putting in place clear coordination processes and mechanisms between local and international relief providing organizations, are all pre-requisites for effective and efficient relief operations when a disaster strikes (Boonmee et al, 2017; Tatham and Rietjens, 2016; Nabi, 2014).

Emergency logistics is different from and more complex than commercial logistics (Jiang and Yuan, 2019; Balcik and Beamon, 2008). Demand in commercial logistics is known in terms of type of items, quantities required, and when and where items need to be delivered. In emergency logistics, demand is random and unpredictable because of the inherent uncertainty in disaster situations and the difficulty to determine the size of the populations affected, where they are located, and what type of relief is required (Balcik and Beamon, 2008). In commercial logistics, the level of infrastructure’s (roads, railways, airports) storage and transportation capacity is known, whereas in emergency logistics, this is difficult to determine because of the destruction taking place in and the hostility of the disaster areas (Ertem et al, 2010). Commercial logistics generally benefits from well operating information systems, but in a disaster situation, lack of information is a key challenge to emergency logistics managers (Sheu, 2007). Performance in commercial logistics is measured mainly by financial indicators (cost, profit), but in emergency logistics, it is measured by the ability to fulfil the needs of the disaster affected populations within the minimum possible time (Ertem et al, 2010, Sheu, 2007).

Emergency logistics operations are organized as follows: in the aftermath of a disaster, relief items are received in a primary hub or hubs (these are national level warehouses to store relief items) either in or close to the affected area and then transferred to central warehouses (these are regional level warehouses to store relief items). Next, they are moved to local distribution centers from where they are distributed to the affected regions (Feng et al, 2020; Balcik et al, 2008). Last Mile Relief Distribution (LMRD) is the ultimate stage of these operations where relief providing organizations connect directly with the disaster affected populations (Huang and Rafiei, 2019; Decker, 2013). As such, LMRD operations scope includes the storage of relief items in local distribution centres and the processes of their distribution to the disaster affected populations (Balcik et al, 2008). Previous research on LMRD focused mainly on the transportation aspects of the operations such as vehicle routing decisions, fleet capacity, availability, and management (Rabta et al, 2018; Noyan and Kahvecioğlu, 2018; Balcik et al, 2008; Martinez et al, 2011; Battini et al, 2014; Decker, 2013). Other studies identified some of the performance indicators related to LMRD such as total cost of relief operations, time to deliver relief items to the affected populations, and level of fairness in providing relief items to the locations affected by the disaster (Huang and Rafiei, 2019; Vitoriano et al, 2011; Sheu, 2007; Tzeng et al, 2007).

However, research related to LMRD is still new and many of its aspects are still under investigated. For instance, there is a limited number of LMRD operational models to optimize allocation of relief operations’ resources and items. The scope of past LMRD research has focused mainly on the “Last Mile Vehicle” problem (transportation modes to distribute relief items) without taking in account the wider LMRD operations scope and complexity. In addition, most of LMRD operational models are generic for all disasters and do not take in account the differences between types of disasters and the unique difficulties they create for relief operations (Battini et al, 2014; Balcik et al, 2008). Challenges such as limited availability of qualified staff in disaster relief, inadequate use of technology to support logistics operations and field operational planning, poor identification of operational constraints during relief distribution, lack of institutional learning, and limited collaboration and coordination between organizations involved in relief operations have attracted little attention in past LMRD research (Decker, 2013).

Following a disaster, a significant number of organizations (government departments of the affected country, NGOs, international agencies) get involved in relief operations. For this process to be successful, there is a need for coordination between these organizations. Coordination in the context of relief operations is defined as “the relationships and interactions among different actors operating within the relief environment” (Balcik et al, 2010). Effective coordinaton facilitates sharing of resources, exchange of information, job dispatching, and joint decision-making among the organizations (Jiang and Yuan, 2019). This enables better identification of needs, more efficient relief operations, improved access to resources, and rapid fulfillment of demand, leading to an improved and more equitable distribution of relief items among the affected regions and populations (Gutjahr and Nolz, 2016). However, coordination is difficult due to the fact that organizations can be responsible for different aspects of relief operations, operate in different geographical areas, and come with different organizational cultures and management processes (Rodríguez-Espíndola et al, 2017).

Coordination is more important and difficult during the LMRD phase due to the high uncertainty regarding the types and quantities of relief items needed by the affected populations, lack of information about the resources and capacity available to organizations providing relief, and the constraints (e.g., destruction of roads and bridges) caused by the disaster in the affected areas (Balcik et al., 2010, home-affairs, 2011). Furthermore, coordination can also be affected by organizational and behavioral factors such as competition between NGOs as these try to attract more funding from donors, willingness of organizations to share information with others, level of knowledge and competency of staff, awareness of the cultural characteristics of the affected regions populations, trust between organizations providing relief, language barriers, and communication with communities in the affected areas (Roy and Lebcir, 2021). From an operational perspective, coordination impacts aspects such as identification of the most affected areas, determination of the needs of populations in these areas, relief items distribution planning and management, and oversupply and waste of non-required relief items (home-affairs, 2011).

Coordination, in supply chain managememnt and logistics, is defined as an “act of properly combining a number of objects (i.e. actions, objectives, decisions, information, knowledge, and funds) for the achievement of the chain goal” (Simatupang et al., 2002). Effective coordination is challenging in emergency logistics, especially LMRD, as the process of “combining the objects” is affected by the uncertainty and the complexity of the disaster context and “achievement of the chain goal” is challenging given the imperceptibility of the services, immeasurability of the missions, and the multiplicity of stakeholders (Beamon and Balcik, 2008). Consequently, the role, mechanisms, and effect of coordination on emergency logistics and LMRD warrant more attention from researchers and practitioners if performance is to be improved.

Therefore, the aim of this paper is to investigate how coordination could be effectively organized in the challenging and constrained LMRD context and what would be its impact on logistics performance. The research takes place in India, one of the world’s most disaster-prone countries, where relief operations face considerable challenges due to the size of country, the different types of disasters affecting it (earthquakes, floods, landslides), and widespread poverty in many of its regions. The context of India is very relevant as past research already identified “coordination” as a major factor and challenge affecting disaster relief operations in the country (home-affairs, 2011).The paper is organized as follows: a literature review is presented in section 2 followed by the methodology and model development in section 3. Section 4 focuses on the scenarios, results, and findings. The paper concludes with section 5 covering discussion of the findings and conclusions of the study.

2. Literature Review

2.1 Natural Disasters in India

India is geographically vast, populous, and prone to a variety of natural disasters. The country is very near to the equator, which makes it vulnerable to tropical storms originating from the Indian Ocean and affecting the vast coastal areas on the eastern and western parts. It is also located on the top of the border between the Indian and Eurasian tectonic plates increasing the likelihood of earthquakes (59% of the country has witnessed moderate to severe earthquakes in the past (Home Affairs, 2011)). The central areas of the country are home to the Thar desert, which is characterized by frequent droughts (SAARC, 2015). A recent study indicated that 27 out of the 35 states in the country are at risk of natural disasters (India.Gov.In, 2015).

The country witnessed a total of 431 natural disasters during the period 1980-2010 causing more than 140,000 deaths (Purohit and Suthar, 2012). Between 1997 and 2018, the cumulative financial loss due to natural disasters was estimated at 79.5 Billion US Dollars, the fourth in the world (UNISDR, 2018). Furthermore, natural disasters tend to have significant consequences and are difficult to deal with their aftermath, given the widespread poverty, poor state of infrastructure in many regions, and the huge scale of destruction seen in the past when disasters occurred.

2.2. Emergency Logistics

The Fritz Institute defines emergency logistics as “the process of planning, implementing and controlling the efficient, cost-effective flow and storage of goods and materials as well as related information, from point of origin to point of consumption for the purpose of meeting the end beneficiary’s requirements” (Thomas and Kopczak, 2005). It encompasses a range of activities, including preparedness, planning, procurement, transport, warehousing, tracking and tracing, and customs clearance (Thomas and Kopczak, 2005).

Although research in the field of logistics is well established, the focus on emergency logistics is relatively new and attracted attention only recently (Nurmala et al, 2017). Examples of this research include aspects such as evacuation operations (Scheer et al, 2012), relief items stock pre-positioning (Rawls and Turnquist, 2011, Döyen et al, 2012), facility location (Mete and Zabinsky, 2010; Mentzer and Konrad, 1991) and casualty transportation and relief distribution (Mete and Zabinsky, 2010).

Evaluation of performance in emergency logistics is measured through two main dimensions, namely effectiveness and efficiency. In general, effectiveness focuses on the logistical goal, for example fulfilment on time or in-stock availability. Efficiency represents the ratio of resources utilized against the results achieved (Mentzer and Konrad, 1991). In emergency logistics, availability and supply of relief items on time to affected populations measure effectiveness. Efficiency is captured through the response time during the disaster situation, replenishment rate of relief items, percentage of demand supplied fully to the affected population, and meeting donors’ expectations (Ertem et al, 2010; Kovács and Spens, 2007).

2.3. Importance of LMRD

LMRD is the ultimate stage of relief operations and the final connector of humanitarian organizations with the affected populations. In a disaster situation, the primarily objective is the distribution of the accurate amount of required relief items (demand) at the exact time to the correct place to fulfil the needs of the affected populations (Decker, 2013). However, achieving this objective in the context of LMRD is substantially difficult and costly because of the uncertainty and complexity of the disaster context (unpredictable demand and location of the affected populations, damaged transportation infrastructure, reduced or non- availability of communication networks). Organizations delivering relief need to develop rapidly a clear “picture” about the situation in the disaster area so that LMRD operations can be organized in an efficient way (Decker, 2013).

Transportation of relief items has been a recurrent theme in LMRD research, and a number of quantitative models have been developed for this purpose. Examples include a stochastic programming optimization model of LMRD transportation network under conditions of uncertainty regarding transportation capacity, state of transportation network, and demand for relief items (Han et al, 2011) . Balcik et al. (2008) presented an optimization model to minimize the total transportation cost for unsatisfied and late satisfied demand for different types of relief items. Other research investigated resource allocation and vehicle routing in earthquake disasters (Battini et al, 2014) and LMRD fleet allocation in large scale disasters using simulation modelling (Das and Hanaoka, 2014).

Despite the importance of the work cited above, its scope is very narrow and covers mainly the transportation elements of LMRD operations. There are several other challenges to relief supply chains in general and LMRD operations in particular, which have been barely touched. This include lack of qualified staff in disaster relief, inadequate use of technology to support logistics operations, lack of institutional learning, and limited collaboration between the organizations involved in relief operations (Decker, 2013).

2.4. Coordination in Emergency Logistics and LMRD

The term “coordination” is used to describe the relationships and interactions among different actors providing disaster relief (Balcik et al, 2010). Coordination is critical to the success and orderly execution of emergency logistics and LMRD operations as it was reported that many organizations delivering relief had to interrupt their operations because of lack of coordination. This has been a regular point of criticism to the organizations involved in relief operations (Perry, 2006).

However, implementing an effective coordination mechanism between relief organizations faces many challenges. These include language barriers, different organizational policies, cultures, and processes management (Decker, 2013). To overcome these, organizations tried to implement some practices to improve coordination, especially during the LMRD phase, on aspects such as resources sharing, information exchange, and joint decision-making (Chen et al, 2008). For example, the UN, in association with other agencies, established entities such as OCHA (Office for the Coordination of Humanitarian Affairs), UNJLC (United Nation Joint Logistics Centre) and IASC (Inter-Agency Standing Committee), and joint decision-making programs like CERF (Central Emergency Response Fund) to improve coordination during disaster relief operations (Tatham et al, 2010; Kehler, 2004; Reindorp, 2002). Other organizations used collaborative information technology tools and standardization of operations to improve coordination during relief operations (Maghsoudi et al, 2018; Ergun et al, 2014).

3. Methodology

The methodology selected in this research is a simulation modelling technique known as Agent Based Simulation (ABS) (North and Macal, 2007). Simulation modelling, which cover a multitude of techniques including Discrete Event Simulation, System Dynamics, and ABS, involves the building of a computer-based model, which mimic (simulate) the working of a real world context (Robinson, 2014; Owen et al, 2010). Simulation modelling techniques are very popular and have been extensively applied in practice due to their advantages. These include the ability to solve models portraying complex systems where an analytical solution is impossible, significant reduction in time, cost, and risks compared to direct experimentation in the real world, representation of uncertainty and interactions between the elements of a system, and above all, the ability to simulate the impact of alternative policies and interventions to provide evidence for decision making (Robinson, 2014). Simulation modelling techniques have been applied in a wide range of areas including health, defense, aviation, project management, manufacturing, supply chain management, logistics, and transportation (Negahban and Smith, 2014, Siebers et al, 2010).

3.1. Rationale for Selecting ABS

ABS is a simulation modelling approach, which focuses on the “individual agent” as the key unit for understanding the behavior of complex systems (North and Macal, 2007). In ABS, it is assumed that the modelled context (system) includes a number of interacting agents, whose behavior and actions are known and defined by clear rules. The responses and interactions between the different agents present in in the context (in line with the rules guiding their behavior) affect and determine the state of the whole context at any given time. It is important to emphasize that the concept of “agent” in ABS is wide and is not restricted to human beings. Agents represent any entity in the system, which can be involved in decision making such as firms, households, government departments, and countries.

ABS assumes that the context to be modelled includes a number of agents and that the context is at an “initial” condition at the start of the simulation. As time progresses, agents take actions, which alter their own states and, consequently, the overall situation (state) of the context. In response, agents take further actions to close the gap between their objectives and the state of the context. Therefore, the context is dynamic and its state, at any given time, is the result of the combined actions taken by all the agents. The actions taken by the agents can be unilateral or directed towards other agents (interactions). In ABS, it is assumed that the actions are not taken randomly, but they are informed by a set of decision rules adopted by the agents (Daya Kaul and Ayaz, 2009).

Following a disaster situation, a number of organizations (government departments, armed forces, local, national, and international NGOs) arrive at the disaster area (context) to provide relief to the affected population. Each individual organization tends to have its own logistics “elements” including facilities (warehouses, distribution centers) and the staff distributing relief items. As relief operations take place, they cause a change to the elements’ state (e.g., quantity of medical supplies left in an NGO warehouse) and the state of the whole disaster area context (e.g., percentage of the affected population receiving medical treatment). Depending on the magnitude of the difference between the state of the disaster area (context) and the objectives of the relief distribution organizations (which own and manage their logistics elements), further actions are taken and these are informed by the mandate, codes and procedures, and decision-making rules of the organizations. Actions can be unilateral (e.g., transporting medical supplies from an organization own warehouse to its distribution centers) or interactive (e.g., an organization requesting transfer of medical supplies from the warehouse of another organization to its distribution centers). This conceptualization of logistics operations in disaster contexts fits well with the ABS assumptions cited above making it a suitable methodology for this research.

3.2. Development of the Model

3.2.1. Model Development Process

The model development process included two main phases. A first qualitative phase focusing on understanding the organization of disaster relief operations in India and the challenges affecting these during the LMRD stage. This was followed by a quantitative phase to build an ABS computer model representing LMRD operations.

To understand the organization and challenges of LMRD operations in India, data was collected through 25 semi-structured interviews involving 9 (36%) Indian government employees, and 16 (64%) national and international NGOs disaster management practitioners with experience in post-earthquake relief operations. The number of interviews is in line with recommended practice in qualitative research, which indicate that a number of interviews between 15 and 30 is sufficient to get meaningful findings from the data (Marshall et al, 2013).

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The participants were selected because of their extensive experience in post-earthquake relief operations in India and in other countries, and held positions covering several aspects of post-disaster management including executive director, disaster response officer, response manager, coordination manager, capacity development officer, shelter development officer, and logistics coordinator. The interviews were semi-structured and included a pre-determined list of questions covering the objectives of the research and informed by the literature review carried out for this study. During the interviews, the participants were given the opportunity to expand on the questions to cover the issues they felt to be important and the interviews proceeded in a conversational manner with participants providing rich information around the themes covered by the questions. This qualitative data collection method is in line with simulation modelling recommended practice that experts’ knowledge is key for successful building of models (Hawe et al, 2012).

In addition, 19 reports from government and NGOs (UN, SEEDS (an Indian NGO), CASA (Church’s Authority for Social Action), Red Cross) describing response operations in previous earthquake disasters, problems faced by the responders, mandates of the organizations involved in providing relief, and lessons learnt from the operations, were analyzed. These reports were specifically selected because of their focus on emergency operations following earthquakes in India, covered different organizations (local, international, governmental, non-governmental), and included detailed accounts of the management of post-disaster operations, areas of difficulty, and recommendations on how to overcome these in future disasters.

The interviews and reports indicated that disaster response in India is organized centrally under the responsibility of the National Disaster Management Agency (NDMA), which reports to the Ministry of Home Affairs. NDMA is supported in this endeavor by the Prime Minister, who allocates the financial, physical, logistical, and human resources to the affected areas based on local government information regarding the severity of the disaster, the scale of the affected areas, and the level of central government and international relief and assistance required.

Regarding post-earthquake LMRD operations, these are organized as follows: Organizations including government departments, local, national and international NGOs arrive at the affected area. These organizations work distinctly, each having its own district warehouse, local distribution centers, responders, and relief items (See Figure 1). Once the affected populations and the types and amounts of relief items required are determined, organizations start distributing these to the populations.

*Insert Figure 1 Here*

The interviews highlighted a number of challenges, which faced post-disaster in general and post-earthquake in particular LMRD operations in the past. The main challenges identified are:

* Inadequate sharing of information between the organizations (prioritization of the tasks, goal selection, risk sharing, mutual adjustment, proper communication between organizations);
* Lack of collaboration and sharing of resources between the organizations (multi-source information, mutual aid); and
* Absence of joint decision making between the organizations (knowledge sharing, protocol sharing, joint decision structuring and analyzing).

These findings from the interviews were not different from those on the reports. For example, one report highlighted a “lack of communication and coordination resulting in a wastage of relief items by supplying the same relief items to the same community by different organizations”. A respondent cited in another report, affirmed that “demand for many relief items was not met on a timely manner due to long replenishment time for some organizations, which makes it hard to fulfil the demand of some affected communities”. This is in line with past research, which highlighted “coordination” as the most critical factor affecting earthquake LMRD operations (Decker, 2013).

3.2.2. Description of the ABS Model

The information generated through the analysis of the interviews and reports regarding the structure, management, and challenges of post-earthquake LMRD operations in India informed the building of the ABS model. The model, built using the NetLogo software (Altay and Pal, 2014), includes three categories of relief organizations: (i) governmental, (ii) national (local NGOs), and (iii) international (international NGOs). Each category is represented through three agents, namely “district warehouse”, “distribution centers”, and “responders”.

For every category of organizations, orders originate from the responders and these are sent to the distribution centers. The latter receive these orders and send them upstream to the district warehouse. The orders are then fulfilled by the district warehouse and the required quantities of relief items are supplied to the distribution centers and from there downstream to the responders. Therefore, there is an information flow moving upstream and a material flow moving downstream on the relief chain for every single category of organizations (See Figure 2).

Each responder generates an order for relief items every day and the combined daily orders from all responders are sent to the distribution centers within the same category of organizations. The district warehouse receives then the cumulative orders from all distribution centers. The lead-time (time from initiation of the demand and its fulfilment) between responders and distribution centers is 2 days and between distribution centers and district warehouse is 3 days. All relief items are received first in the district warehouse before they are shipped to the distribution centers and from there to the responders.

*Insert Figure 2 here*

These processes were represented in the ABS model taking account of the following assumptions:

* The distribution centers and responders follow the base-stock policy rule defined as follows: once the inventory position (stocked quantity) of a relief item drops below a predetermined base-stock level (the inventory position is checked on a daily basis), agents (responders, distribution centers) immediately order the difference between the base-stock level and current inventory position (otherwise, the agent does not place any order).
* The whole quantity of relief items received by the responders is distributed to the affected populations (there are no losses or waste of relief items).
* Affected individuals are formally identified to avoid duplication of relief distribution (individuals need to sign when receiving relief items to avoid duplication of supply).
* The capacity of district warehouses is sufficient to meet the demand of the affected populations in line with previous research on un-capacitated facility.
* Daily demand for relief items is represented by a random variable given the chaotic and uncertain situation following an earthquake. In general, there is a sudden increase in demand for relief items in the immediate aftermath of an earthquake followed by a period where the demand decreases gradually to become more “stable” as rescue operations take place and the situation start to get back to some kind of normality. Therefore, the daily demand random variable is assumed to follow a Poisson distribution.

3.3. Validation and Testing of the Model

Validation of simulation models is required so that they can be used to evaluate policy scenarios. In ABS, this is divided into (i) structural validation (checking that the model reflects the structure of the real world system it represents) and (ii) behavioral validation (testing if the model can reproduce observed past behavior of the system) (North and Macal, 2007). For this model, the list of agents and their behaviors, relationships, and interactions processes were derived from interviews with participants from Indian government and non-governmental organizations, and from analysis of government earthquake response reports. The ABS model structure was checked with the interview participants, who suggested changes until they were satisfied that the model structure is a good reflection of the processes taking place in the real world.

To assess the model ability to replicate past real-world behavior, it was tested against information from the 2001 Gujarat earthquake, which was a major one with a magnitude of 7.7 on the Richter scale. The variable used to compare the simulation model to the reality is the average number of blankets supplied. The model generated a value of 27127 comparative to a real-world one of 30584 confirming the validation of the model.

4. Results and Findings

Following the development of the ABS model portraying the structure of the post-disaster LMRD operations and its validation with past observed data on an earthquake in India, the next step was to use the model to explore the possible impact of alternative coordination policies on the performance of the relief chain, in line with the aim of this study. The model was fit for scenario analysis as its structure was checked and confirmed by experts in disaster management in India and its output was very close to real world observations, indicating a sound structure of the model.

In this context, several scenarios portraying possible policies to improve coordination between organizations involved in LMRD operations were identified. These scenarios reflect feasible coordination policies, which take account of the damage, difficulties, and constraints caused by earthquakes to the disaster areas and the organization of relief operations.

4.1. The Concept of the “Coordination Hub”

An extensive literature review was conducted to identify changes, which could improve coordination in post-earthquake LMRD operations and can be implemented in the Indian context. The review led to the selection of the UN’s cluster approach for management of emergency operations (UN, 2015) as a promising policy. Under this approach, a cluster (a group of organizations working together in post disaster relief operations) share a unified “information hub” allowing faster information exchange and spread, improved resources utilization, and swift humanitarian response operations (Jahre et al, 2007).

The current research adopted this idea by selecting the introduction of a “coordination hub” as a possible new policy to improve Indian LMRD operations. The proposed coordination hub will have access to all relief organizations’ district warehouses and distribution centers and will have information about the exact quantities of relief items available in these warehouses and centers. All distribution centers will send their relief items requests to the proposed coordination hub and the latter will supply the exact quantity requested by each distribution center. As such, the coordination hub enables an integrated approach to manage the diverse and huge quantities of relief items during the LMRD phase. It is important to note that the suggested coordination hub is not a physical building, but a virtual cloud platform, which incorporate information about the types and available quantities of relief items, and operational processes in all warehouses and centers.

4.2. Coordination Scenarios

To evaluate the possible effect of the new policy of introducing a coordination hub in Indian LMRD operations, three possible scenarios were identified during the interviews conducted with the participants in this study. These are (See Figure 3):

* *Scenario 1: No coordination:* This represents the current situation. The three categories of organizations (governmental, national agencies, international agencies) supply relief individually. As a result, there are three relief chains working separately.
* *Scenario 2: Partial coordination:* The coordination hub links together the district warehouses of the three categories of organizations (governmental, national agencies, international agencies). Distribution centers send requests for relief items to the coordination hub. The latter sends instructions to fulfil these requests from any of the district warehouses where the items are available. However, responders are restricted to send their requests for relief items to the distribution centers of the same organizational category only.
* *Scenario 3: Full Coordination:* The coordination hub links together the district warehouses and the distribution centers of the three categories of organizations (governmental, national agencies, international agencies). District warehouses and distribution centers operate in the same way as under the partial coordination scenario. However, responders are allowed to send requests for relief items to any of the distribution centers and these are fulfilled from the center where the items are available.

*Insert Figure 3 here*

The ABS model was run for 45 days in line with short-term relief operations in India as this research focuses on the immediate post-disaster relief phase (Özdamar et al, 2004). The model was altered to represent the three scenarios and results were collected on a number of performance indicators to evaluate to the impact of coordination on LMRD operations performance (see Table 1 for the model parameters).

The affected population size is assumed to be 675 as most villages and local districts in India have populations between 400 to 1000 people with an average of 700 and, in the majority of cases, around 95% of the population is affected and need relief following an earthquake.

*Insert Table 1 here*

4.3. Results

Results regarding LMRD performance were collected following the running of the ABS model under the three coordination scenarios mentioned above. Given that the main aim of LMRD operations following a disaster is to provide relief to the affected population in a timely and efficient manner, the performance indicators included in the model reflect these two objectives. The results are as follows:

4.3.1. Total level of Inventory in Distribution Centers

The total level of inventory in distribution centers (TLIDC) represents the total number of relief items (e.g., Blankets, bottles of water), which need to be available in the distribution centers to satisfy the demand of the affected population during the 45 days period following the earthquake. The focus is on the distribution centers because, as it is assumed in the model, there is sufficient quantities of relief items in the district warehouses (upstream part of the logistics chain) to fulfil the needs of the affected population. Shortages tend to occur at the level of responders (downstream part of the logistics chain) because of poor planning and delays in processing information and moving items along the logistics chain leading to either under-supply or over-supply in distribution centers as these lies in the middle between district warehouses and responders (Merminod et al, 2014; Maliszewski et al, 2012; Han et al, 2011; Mete and Zabinsky, 2010; Sheu, 2007; Tzeng et al., 2007). The problem is exacerbated where there is a lack or no coordination between the different groups of organizations involved in relief operations.

The results regarding the TLIDC under the three coordination scenarios are presented in Table 2 for the three categories of organizations (government agencies, national NGOs, international NGOs). The results indicate that coordination will improve the TLIDC and reduce over-supply in distribution centers for all categories of organizations.

For example, TLIDC for category 3 can be reduced from 1815 under no-coordination to 1751 under partial coordination and to a further reduced level of 1516 under full coordination. The trend is similar for the average TLIDC for the distribution centers of all categories of organizations. It is reduced by around 5% (from 1838 to 1747) under partial coordination and 16% (from 1838 to 1534) under full coordination.

*Insert Table 2 here*

These results demonstrate that if the organizations involved in disaster relief operations coordinate activities in terms of sharing information and resources, then they can achieve a better operational performance and satisfaction of the populations in need of assistance. This can be explained by the fact that, following an earthquake, one of the major obstacles to relief operations are damaged transportation infrastructures such as roads and bridges, which hinders relief delivery operations. A more proactive policy of sharing resources and information between different organizations can play a significant role in overcoming these difficulties.

4.3.2. Responsiveness of the LMRD logistics chain

Given the need to respond rapidly to the needs of populations following a disaster, it is important that supply chains are organized and designed to be responsive to variations in demand for relief items (Merminod et al, 2014). The ability of the LMRD logistics chain to fulfil the needs of the population in a timely manner is critical. People affected by a disaster need to be provided with relief items when and where these are required as any delays can cause significant suffering to a population already in a vulnerable situation. To assess how coordination policies could affect the LMRD logistics chain responsiveness and ability to respond to relief items demand, a “Total Penalty Score (TPS)” is calculated under each of the three coordination scenarios. This score is an accumulation of the daily individual penalties incurred by responders in the LMRD logistics chain (for the three categories of relief organizations).

The individual penalties reflect the three possible situations a responder can face on any given day and these are for a single day:

* Responder able to fulfil all the demand for relief items. Individual penalty is 0;
* Responder able to fulfil part of the demand for relief items. Individual penalty is 1;
* Responder not able to fulfil any demand for relief items. Individual penalty is 2.

Individual penalties of 1 and 2 (partially met and unmet demand respectively) reflect an undesirable outcome for the LMRD logistics chain as affected populations are not provided with all the relief items they need. In addition, it creates further complexities with regard to the management of the chain. If demand is not fully met on a given day, new requests are generated by responders and these are added to the backlog of relief items previously requested adding more pressure on the LMRD logistics chain.

The simulation results (see Table 3) provide evidence that better coordination reduces the TPS for every category of organizations and for the whole LMRD logistics chain.

*Insert Table 3 here*

As an example, for category 2, the TPS goes down from 21356 in case of no-coordination to 20448 in case of partial coordination and then to 17400 under full coordination. The trend of the average TPS is similar starting from a value of 21778 if there is no coordination, it goes down to 21129 and 19132 if coordination is partial and full respectively. This represents a 3% and 13% reduction in the TPS compared to non-coordination situation, indicating that increased coordination improves the responsiveness of the logistics chain and its ability to respond better to the needs of the disaster affected population.

5. Discussion

Providing relief to post disaster-affected populations is critical for saving lives and alleviating the distress and pain caused by natural disasters. However, this noble endeavor is complex and fraught with difficulties as both infrastructure and normal patterns of life are severely affected when a disaster strike. This research aims at exploring ways to improve the management and performance of relief operations by improving coordination between the different groups of organizations involved in these operations. The research focuses on LMRD and this is driven by the fact that LMRD represents the final phase of the disaster logistics chain where needs are acute and urgent, and challenges are the most complex.

The selected context for the research is India, one of the most disaster-prone countries in the world and where economic and social conditions constitute serious constraints for effective relief operations. The research aims were investigated in two steps. First, analysis of past relief operations reports and extensive interviews with key stakeholders were conducted to understand the structure and management of relief operations especially during the critical LMRD phase. The findings from this step highlighted clearly that poor coordination is the most important barrier to better LMRD operations in India. Second, an ABS model representing current LMRD operations was developed and used to predict whether and to what extent better coordination would improve the performance of LMRD logistics operations. The results demonstrate that performance will be improved if the relief logistics chains of different categories of organizations are better coordinated and more integrated.

The adoption of a holistic coordinated approach to relief operations whereby different groups of organizations works together in a coherent way to distribute relief to the affected population can mitigate against the risks, which could be faced by a single group of organizations (e.g., shortage of relief items). This should address an essential weakness in disaster relief operations as poor coordination has been consistently highlighted as a significant problem in emergency logistics (Decker, 2013).

Achieving better coordination is contingent upon several factors. These include the creation and adoption of a plan of mutual aid between relief organizations, development of a centralized information system accessed by all organizations, joint decision making, clearer resource sharing policies among relief provision staff, integration of activities between the local area of the disaster and the wider external context where the area is located, and including coordination processes at the strategic and tactical planning for relief distribution (Merminod et al, 2014) . These factors are, to a great extent, in line with the findings from the interviews in India where participants highlighted the importance of joint planning among agencies (e.g., goal selection, risk sharing), sharing resources among organizations in the field (e.g., mutual aid), and joint decision making (e.g., knowledge sharing, joint decision structures and mechanisms).

The suggested “Coordination Hub” in this research is a promising way to enable better inter-organizational integration and coordination in LMRD operations. The creation of a computer based virtual hub in the cloud should facilitate information exchange, enable sharing of resources, increase communication, and enhance joint decision-making processes among relief provision organizations. To make this a reality, organizations need to review their mandates and work practices to avoid conflicting objectives and make relief distribution operations seamless (Merminod et al, 2014).

From an operational perspective, the creation and running of the coordination hub require efficient planning and management. It is necessary to have reliable high-speed internet connection in the disaster region. Information about government disaster management regulations, and roles and responsibilities of different organizations involved in relief operations need to be gathered and inputted in the hub. Organizations’ staff need proper training on how to use the computer-based coordination hub platform, the processes to upload and use the information on it, and the protocols to keep this information safe and secure throughout the whole relief operations duration. The technology underpinning the hub should allow timely update of information regarding, for example, the number of organizations actively involved in relief operations, type and inventory level of relief items per organization, and the demand for these items. In addition, virtual connectivity between organizations needs to be enabled so that relief provision activities can be coordinated.

Individual organizations are also required to make changes to achieve the expected benefits of coordination and realize the full potential from the coordination hub. They need to create an effective information management system to have an accurate knowledge about the location of the affected population, their needs in terms of relief items, and the state of the infrastructure and landscape in the disaster-affected area as these are important for an efficient inter-organizational information and resources sharing. As such, organizations will be able to feed accurate information into the coordination hub and improve the overall performance of relief operations.

Although post-disaster relief operations are complex, the LMRD phase is associated with additional layers of difficulty and complications. For instance, destruction of transportation infrastructure may render access to disaster areas difficult. Getting accurate information about the state of the disaster affected areas to assess the needs of the populations and determine demand for relief items is challenging (Roy and Lebcir, 2021). Some organizations, especially international ones, do not have storage and transportation facilities in the affected regions and will need to rely on local organizations to distribute relief items. Communication infrastructure such as phone lines is likely to be affected making exchange of information between the affected region and other areas difficult. The ABS model reflects these challenges through assuming that governmental, local NGOs, and international NGOs can share storage and transportation resources (e.g., military helicopters and heavy lorries) to distribute relief items. Responders have the freedom to communicate with staff outside of their organizations to facilitate exchange of information regarding the state of the disaster area and populations’ needs to everyone involved in relief operations. The rationale for including the coordination hub in the model is to overcome communications constraints as the hub relies on the internet cloud and is not affected by the possible damage to phone lines in the disaster affected region.

The ABS model structure and its coordination mechanisms overlap with many studies focusing on the organization of post-disaster response activities. For example, Kaynak and Tuger (2014) suggested a new emergency logistics system to deal with earthquakes in Turkey composed of three levels: national, regional, and local to facilitate information exchange, resources sharing, and distribution of relief items. An analysis of emergency relief operations following the 2014 Uttarakhand (India) disaster highlighted the importance of coordination in emergency logistics operations and the need to develop IT technical infrastructure and staff skills to enable better collaboration between the organizations involved in relief operations (Kabra et al, 2015). Similarly, it was found that hardware and software capacity, IT training and experience played a key role in facilitating coordination of post-disaster operations following hurricanes Katrina and Rita in 2005 (Kapucu and Garayev, 2011). IT training and equipment are important for an effective use of the coordination hub included in the model. Trust between organizations and their preparedness to share information and resources, a key aspect of the coordination scenarios tested in this study, was found to be critical for successful coordination and joint decision making in emergency operations (Kabra et al, 2015; Kapucu and Garayev, 2011). Furthermore, and in line with our ABS model, coordination through sharing of resources between different groups of organizations was found to improve the performance of post-disaster relief operations in the South East Asian region (Pazirandeh and Maghsoudi, 2018).

From a methodological perspective, this research combined successfully qualitative methods such as interviews with rigorous quantitative methods, namely ABS, to understand the importance of coordination in the Indian LMRD system. The adoption of this combined methods approach is in line with findings from previous research recommending the use of more than one method to analyze the challenges of disaster operations management. The interviews conducted with practitioners with considerable experience in disaster management in India led to the identification of coordination as the most important challenge to LMRD operations. This paved the way to the idea of creating a coordination hub as a possible operational solution to address this challenge taking in account the local characteristics and constraints of the Indian context. The ABS model results provided evidence that creating a coordination hub would improve coordination processes and performance of LMRD operations in the country.

As it is the case with all simulation methodologies, the ABS model developed in this research has some limitations related to the simplifying assumptions, which may not fully capture real-world complexities. For instance, relief organizations are divided into 3 categories: governmental, national NGOs, and international NGOs. However, it is possible that more categories exist as, for example, government agencies can be further broken down into military and civilian organizations, and international NGOs can be broken down into regional and global NGOs. Similarly, the assumption that there is no wastage or loss of relief items can be unrealistic as disaster regions are challenging and difficult to operate in leading to losses of some relief items. In addition, assuming that that all individuals will have identification documents so that there is no duplication of relief supply to the same individuals is difficult to achieve. Following a disaster, many people would have lost their identification documents or cannot access their damaged homes to collect them. It is also likely that some shortages of relief items will occur during the emergency response operations especially for high demand items such as drinking water and medical supplies. However, other research covering some of these limitations agree with the main finding from our ABS model that coordination improves emergency logistics operations. For example, Ozdamar et al (2004) found that coordination reduces the level of unfulfilled demand for relief items when the total supply is insufficient to cover total demand. Coordination between the civilian and military branches of government was found to improve satisfaction of relief items’ demand and distribution operations efficiency even if demand is uncertain (Wang et al, 2015). More recently, Diehlmann et al (2021) explored collaboration between government, NGOs, and the private sector in disaster emergency operations and found that involving the latter group would reduce undersupply and lead to better satisfaction of the disaster affected populations’ needs.

The success of post-disaster relief operations and effective emergency logistics is contingent upon a multitude of drivers and factors from strategic planning and disaster preparedness at the state level to the availability of transportation resources at the local level (Bastos et al, 2014). Although coordination, on its own, does not solve all emergency logistics challenges, it has been highlighted as a critical factor for successful post-disaster relief operations given the significant number of organizations involved, the spread of the disaster affected populations over large areas, the different mandates and remits of organizations, the interdependence between different relief activities, the need to collect and communicate information about the state of the disaster area to all organizations, the importance of sharing resources, and the requirements for joint decision-making (Roy and Lebcir, 2021; Kabra et al, 2015; Kapucu and Garayev, 2011).

The difficulty to achieve effective coordination in disasters’ relief operations should not be viewed as an unsurmountable challenge. Past studies already reported some coordination successes in different regions (Handayani and Mustikasari, 2018; Tatham and Spens, 2016; Kabra et al, 2015; Nabi, 2014; Kapucu and Garayev, 2011) and recent developments such as the use of microblogs (Dutt et al, 2019), social media and big data analytics (Joseph et al, 2018), Geographic Information Systems (Jiang and Yuan, 2019), and Artificial Intelligence (Fan et al, 2021) to facilitate coordination in disaster management are all reasons for optimism in the future.

6. Conclusion

This research addresses an important and current problem in disaster operations management. The use of the ABS methodology in this research to analyze coordination problems is innovative in the Indian context especially that the model was informed by a variety of sources and data collection methods. This study adds knowledge to a theme expected to gain more importance in the future given the increase in the frequency and severity of natural disasters.

The findings indicate that better coordination between the organizations involved in post-disaster LMRD operations has the potential to improve the performance of the logistics chain, its ability to quickly respond to the uncertainty caused by the disaster, and to fulfill, in a timely manner, the needs of the affected populations. This is important as coordination has been highlighted as a key enabler of better emergency logistics management in the Indian context.

This research can be further expanded to explore other issues, which were not covered in the current study. The model was validated using data from a single earthquake disaster and it would be important to use data from other disasters to make the findings more general. It focuses on earthquakes in India and there is a need to investigate other types of disasters (e.g., floods) and in different countries (e.g., developed countries). Its scope is limited to LMRD operations only and it is important to extend it to the whole relief supply chain. It is also necessary to carry out further analysis on the best way to set up the coordination hub and identify the best working procedures, technological platforms, and operational processes to achieve this. Finally, the ABS model could be extended to a district (several cities and villages) or a state (several districts) to understand the influence of coordination at these levels.

To conclude, this research highlighted the importance of addressing coordination challenges in emergency logistics and LMRD operations as this can have a positive impact on the performance of the operations. However, it is important to state that successful post-disaster relief operations depend on the whole cycle of emergency management from the pre-disaster preparedness phase to the post-disaster recovery phase. A multitude of factors and drivers interact in complex ways to determine the extent to which relief operations are able to provide support and assistance to disaster affected populations in a timely and efficient manner. Coordination has been highlighted as an important enabling factor in these complex operations and further research is required in this critical area as the frequency and severity of natural disasters is expected to continue on the increased trend in the future.

References

Altay, N. & Pal, R. 2014. Information Diffusion among Agents: Implications for Humanitarian Operations.

Production and Operations Management, 23**,** 1015-1027.

Balcik, B. & Beamon, B. M. 2008. Facility location in humanitarian relief. International Journal of Logistics, 11**,** 101-121.

Balcik, B., Beamon, B. M., Krejci, C. C., Muramatsu, K. M. & Ramirez, M. 2010. Coordination in humanitarian relief chains: Practices, challenges and opportunities. International Journal of Production Economics, 126**,** 22-34.

Balcik, B., Beamon, B. M. & Smilowitz, K. 2008. Last mile distribution in humanitarian relief. Journal of Intelligent Transportation Systems, 12**,** 51-63.

Bastos, M.A.G., Campos, V.B.G. and de Mello Bandeira, R.A., 2014. Logistic processes in a post-disaster relief operation. Procedia-Social and Behavioral Sciences, 111, 1175-1184.

Battini, D., Peretti, U., Persona, A. & Sgarbossa, F. 2014. Application of humanitarian last mile distribution model. Journal of Humanitarian Logistics and Supply Chain Management, 4**,** 131-148.

Beamon, B. M. & Balcik, B. 2008. Performance measurement in humanitarian relief chains. International Journal of Public Sector Management, 21**,** 4-25.

Boonmee, C., Arimura, M. and Asada, T., 2017. Facility location optimization model for emergency humanitarian logistics. International Journal of Disaster Risk Reduction, 24,485-498.

Chen, R., Sharman, R., Rao, H. R. & Upadhyaya, S. J. 2008. Coordination in emergency response management. Communications of the ACM, 51**,** 66-73.

Das, R. & Hanaoka, S. 2014. An agent-based model for resource allocation during relief distribution. Journal of Humanitarian Logistics and Supply Chain Management, 4**,** 265-285.

Decker, M. 2013. Last Mile Logistics for Disaster Relief Supply Chain Management: Challenges and Opportunities for Humanitarian Aid and Emergency Relief, Anchor Academic Publishing (aap\_verlag).

Diehlmann, F., Lüttenberg, M., Verdonck, L., Wiens, M., Zienau, A. and Schultmann, F., 2021. Public-private collaborations in emergency logistics: A framework based on logistical and game-theoretical concepts. Safety Science, 141, p.105301.

Döyen, A., Aras, N. & Barbarosoğlu, G. 2012. A two-echelon stochastic facility location model for humanitarian relief logistics. Optimization Letters, 6**,** 1123-1145.

Dutt, R., Basu, M., Ghosh, K. and Ghosh, S., 2019. Utilizing microblogs for assisting post-disaster relief operations via matching resource needs and availabilities. Information Processing & Management, 56,1680-1697.

Ergun, Ö., Gui, L., Heier Stamm, J. L., Keskinocak, P. & Swann, J. 2014. Improving humanitarian operations through technology‐enabled collaboration. Production and Operations Management, 23**,** 1002-1014.

Ertem, M. A., Buyurgan, N. & Rossetti, M. D. 2010. Multiple-buyer procurement auctions framework for humanitarian supply chain management. International Journal of Physical Distribution & Logistics Management, 40**,** 202-227.

Fan, C., Zhang, C., Yahja, A. and Mostafavi, A., 2021. Disaster City Digital Twin: A vision for integrating artificial and human intelligence for disaster management. International Journal of Information Management, 56,102049.

Feng, J.-R., Gai, W.-M., Li, J.-Y. & Xu, M. 2020. Location selection of emergency supplies repositories for emergency logistics management: A variable weighted algorithm. Journal of Loss Prevention in the Process Industries*,* 63**,** 104032.

Gutjahr, W.J. & Nolz, P.C. 2016. Multicriteria optimisation in humanitirian aid. European Journal of Operational Research, 252,351-366.

Han, Y., Guan, X. & Shi, L. 2011. Optimization based method for supply location selection and routing in large-scale emergency material delivery. Automation Science and Engineering, IEEE Transactions on, 8**,** 683-693.

Handayani, N.U. and Mustikasari, A., 2018. Coordination and Collaboration Functions of Disaster Management Centers for Humanitarian Logistics: a Case Study at Merapi Eruption. In MATEC Web of Conferences (Vol. 159, p. 01046). EDP Sciences.

Hawe, G.I., Coates, G., Wilson, D.T. and Crouch, R.S., 2012. Agent-based simulation for large-scale emergency response: A survey of usage and implementation. ACM Computing Surveys (CSUR), 45, 1-51.

Holguín-Veras, J., Taniguchi, E., Jaller, M., Aros-Vera, F., Ferreira, F. and Thompson, R.G., 2014. The Tohoku disasters: Chief lessons concerning the post disaster humanitarian logistics response and policy implications. Transportation research part A: policy and practice, 6,86-104.

Home-Affairs, M. O. 2011. Disaster management in India. In: INDIA, G. O. (ed.).

Huang, K. & Rafiei R. 2019. Equitable last mile distribution in emergency response. Computers &

Industrial Engineering*,* 127**,** 887-900.

INDIA.GOV.IN. 2015. National Portal of India. India at a Glance. Available at: http://india.gov.in/india-

glance/profile [Accessed 10/04/2018].

Jiang, Y. & Yuan Y. 2019. Emergency logostics in a large-scale disaster context: Achievements and challenges. International Journal of Environmental Research and Public Health, 16,779.

Joseph, J.K., Dev, K.A., Pradeepkumar, A.P. and Mohan, M., 2018. Big data analytics and social media in disaster management. In *Integrating disaster science and management* (pp. 287-294). Elsevier.

Kabra, G., Ramesh, A. and Arshinder, K., 2015. Identification and prioritization of coordination barriers in humanitarian supply chain management. International Journal of Disaster Risk Reduction, 13, 128-138.

Kapucu, N. and Garayev, V., 2011. Collaborative decision-making in emergency and disaster management. International Journal of Public Administration, 3,366-375.

Kaynak, R. and Tuğer, A.T., 2014. Coordination and collaboration functions of disaster coordination centers for humanitarian logistics. Procedia-Social and Behavioral Sciences, 109,432-437.

Kehler, N., 2004. Coordinating humanitarian assistance: a comparative analysis of three cases. Master

Thesis, Virginia State University /http://scholar.lib.vt.edu/ theses/available/etd-05202004-170632/unrestricted/KehlerMajorPaper.pdfS (10.21.2016).

Kovács, G. & Spens, K. M. 2007. Humanitarian logistics in disaster relief operations. International Journal of Physical Distribution & Logistics Management, 37**,** 99-114.

Maghsoudi, A., Zailani, S., Ramayah, T. & Pazirandeh, A. 2018. Coordination of efforts in disaster relief supply chains: the moderating role of resource scarcity and redundancy. International Journal of Logistics Research and Applications, 21**,** 407-430.

Maliszewski, P. J., Kuby, M. J. & Horner, M. W. 2012. A comparison of multi-objective spatial dispersion models for managing critical assets in urban areas. Computers, Environment and Urban Systems, 36**,** 331-341.

Marshall, B., Cardon, P., Poddar, A. and Fontenot, R., 2013. Does sample size matter in qualitative research?: A review of qualitative interviews in IS research. Journal of computer information systems, 54,11-22.

Martinez, A. P., Stapleton, O. & Van Wassenhove, L. N. 2011. Last Mile Vehicle Fleet Management in Humanitarian Operations: A Case-Based Approach. working paper, INSEAD publication.

Mentzer, J. T. & Konrad, B. P. 1991. An efficiency/effectiveness approach to logistics performance analysis. Journal of business logistics, 12**,** 33.

Merminod, N., Nollet, J. & Pache, G. 2014. Streamlining humanitarian and peacekeeping supply chains. Society and Business Review, 9, 4-22.

Mete, H. O. & Zabinsky, Z. B. 2010. Stochastic optimization of medical supply location and distribution in disaster management. International Journal of Production Economics, 126**,** 76-84.

Nabi, P.G., 2014. Coordinating post-disaster humanitarian response: lessons from the 2005 Kashmir earthquake, India. Development in Practice, 24,975-988.

Negahban, A. & Smith, J. S. 2014. Simulation for manufacturing system design and operation: Literature review and analysis. Journal of Manufacturing Systems, 33**,** 241-261.

Netlogo. 2014. <https://ccl.northwestern.edu/netlogo/> [Online].

North, M. J. & Macal, C. M. 2007. Managing business complexity: discovering strategic solutions with agent-based modeling and simulation, Oxford University Press.

Noyan, N. & Kahvecioğlu, G. 2018. Stochastic last mile relief network design with resource reallocation. OR Spectrum, 40**,** 187-231.

Nurmala, N., De Leeuw, S. & Dullaert, W. 2017. Humanitarian–business partnerships in managing humanitarian logistics. Supply Chain Management: An International Journal, 22**,** 82-94.

Oloruntoba, R. & Gray, R. 2006. Humanitarian aid: an agile supply chain? Supply Chain Management: an international journal, 11**,** 115-120.

Opdyke, A., Javernick-Will, A. and Koschmann, M., 2018. A comparative analysis of coordination, participation, and training in post-disaster shelter projects. Sustainability, p.4241.

Owen, C., Albores, P., Greasley, A. & Love, D. 2010. Simulation in the supply chain context: matching the simulation tool to the problem.

Özdamar, L., Ekinci, E. & Küçükyazici, B. 2004. Emergency logistics planning in natural disasters. Annals of operations research, 129**,** 217-245.

Pazirandeh, A. and Maghsoudi, A., 2018. Improved coordination during disaster relief operations through sharing of resources. Journal of the Operational Research Society, 69,1227-1241.

Perry, M. R. 2006. Humanitarian relief challenges in the wake of the South East Asian tsunami disaster, Dept. of Management, Monash University. https://doi.org/10.4225/03/5938f77d52948.

Purohit J, & Suthar C. 2012. Disasters statistics in Indian scenario in the last two decades. International Journal of Scientific and Research Publications, 2,1-5.

Rabta, B., Wankmüller, C. & Reiner, G. 2018. A drone fleet model for last-mile distribution in disaster relief operations. International Journal of Disaster Risk Reduction*,* 28**,** 107-112.

Rawls, C. G. & Turnquist, M. A. 2011. Pre-positioning planning for emergency response with service quality constraints. OR spectrum, 33**,** 481-498.

Reindorp, N. 2002. Trends and challenges in the UN humanitarian system. The new Humanitarianisms: a review of Trends in Global Humanitarian Action. HPG Report, 11.

Robinson, S. 2014. Simulation: the practice of model development and use, Palgrave Macmillan.

Rodríguez-Espíndola, O., Albores, P. & Brewster, C. 2017. Disaster preparedness in humanitarian logistics: A collaborative approach for resource management in floods. European Journal of Operational Research, 264, 978-993

Roy, P. & Lebcir, R.M. 2021. The objectives and factors affecting performance of last mile relief distribution in post-disaster operations: The case of India. Asian Journal of Management, 12, 55-66.

SAARC. 2015. India disaster knowledge network. Available at: http://www.saarc-sadkn.org/countries/india/disaster\_profile.aspx [Accessed 10.04.2020 ].

Scheer, S. J., Varela, V. & Eftychidis, G. 2012. A generic framework for tsunami evacuation planning. Physics and Chemistry of the Earth, Parts A/B/C, 49**,** 79-91.

Sheu, J.-B. 2007. An emergency logistics distribution approach for quick response to urgent relief demand in disasters. Transportation Research Part E: Logistics and Transportation Review, 43**,** 687-709.

Siebers, P.-O., Macal, C. M., Garnett, J., Buxton, D. & Pidd, M. 2010. Discrete-event simulation is dead, long live agent-based simulation! Journal of Simulation, 4**,** 204-210.

Simatupang, T. M., Wright, A. C. & Sridharan, R. 2002. The knowledge of coordination for supply chain integration. Business process management journal, 8**,** 289-308.

Tatham, P. and Rietjens, S., 2016. Integrated disaster relief logistics: a stepping stone towards viable civil–military networks?. Disasters, 7-25.

Tatham, P. and Spens, K., 2016. Cracking the humanitarian logistic coordination challenge: Lessons from the urban search and rescue community. Disasters, 40,246-261.

Tatham, P., Pettit, S., Schulz, S. F. & Blecken, A. 2010. Horizontal cooperation in disaster relief logistics: benefits and impediments. International Journal of Physical Distribution & Logistics Management, 40**,** 636-656.

Thomas, A. S. & Kopczak, L. R. 2005. From logistics to supply chain management: the path forward in the humanitarian sector. Fritz Institute, 15**,** 1-15.

Tzeng, G.-H., Cheng, H.-J. & Huang, T. D. 2007. Multi-objective optimal planning for designing relief delivery systems. Transportation Research Part E: Logistics and Transportation Review, 43**,** 673-686.

UN 2015. U.N study: Natural disasters caused 600,000 deaths over 20 years. In: CHAN, M. (ed.). Time.

UNISDR. 2018. Review of Disaster Events. Centre for Research on the Epidemiology of Disasters.

Van Wassenhove, L. N. 2006. Humanitarian aid logistics: supply chain management in high gear. Journal of the Operational research Society, 57**,** 475-489.

Vitoriano, B., Ortuño, M. T., Tirado, G. & Montero, J. 2011. A multi-criteria optimization model for humanitarian aid distribution. Journal of Global Optimization, 51**,** 189-208.

Wang, L., Song, J. & Shi, L. 2015. Dynamic emergency logistics planning: models and heuristic algorithm. Optimization Letters, **9,**1533–1552.

Wisner, B. & Adams, J. 2002. Environmental health in emergencies and disasters: a practical guide, World health organization.

Table 1. ABS Model Parameters.

|  |  |
| --- | --- |
| Parameter | Value |
| Size of the affected population | 675 |
| Duration of LMRD operations | 45 days |
| The lead time between the coordination hub and the distribution centre | 3 days |
| The lead time between the distribution centre and the responders | 2 days |
| The initial stock of the distribution centre | 0 |
| The initial stock of the responders | 0 |
| Penalty for total fulfilment of demand in a given day | 0 |
| Penalty for partial fulfilment of demand in a given day | 1 |
| Penalty for no fulfilment of demand in a given day | 2 |

Table 2: Total Level of Inventory in Distribution Centers.

|  |  |  |  |
| --- | --- | --- | --- |
| Category of Organizations | Scenario 1 (No Coordination) | Scenario 2 (Partial coordination) | Scenario 3 (Full coordination |
| Category 1: Government agencies | 1846 | 1743 | 1732 |
| Category 2: National NGOs | 1854 | 1747 | 1355 |
| Category 3: International NGOs | 1815 | 1751 | 1516 |
| Average | 1838 | 1747 | 1534 |
| Average Improvement (%) compared to Scenario 1 | n/a | 5% | 16% |

Table 3: Total Penalty Score (responsiveness).

|  |  |  |  |
| --- | --- | --- | --- |
| Category of Organizations | Scenario 1 (No Coordination) | Scenario 2 (Partial coordination) | Scenario 3 (Full coordination |
| Category 1: Government agencies | 22212 | 22121 | 22144 |
| Category 2: National NGOs | 21356 | 20448 | 17400 |
| Category 3: International NGOs | 21768 | 20818 | 17853 |
| Average | 21778 | 21129 | 19132 |
| Average Improvement (%) compared to Scenario 1 | n/a | 3% | 13% |

Figure Captions

Figure 1. Organization of LMRD operations in India.

Figure 2. The flows of supply and demand in the LMRD model.

Figure 3: ABS snapshots of coordination policies in LMRD

Figure 1

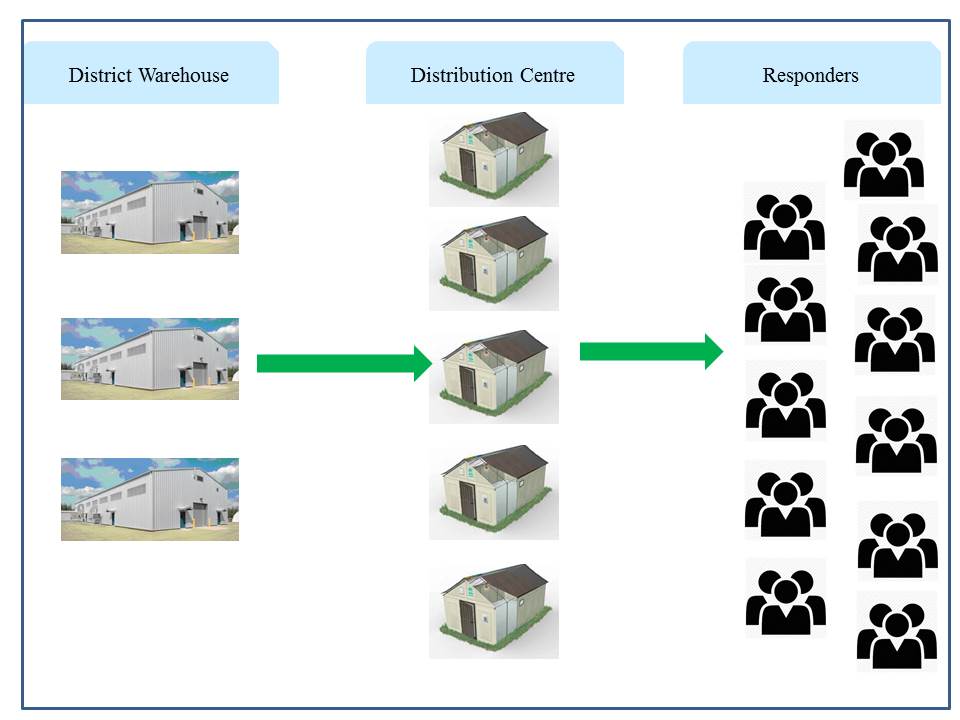
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Figure 2

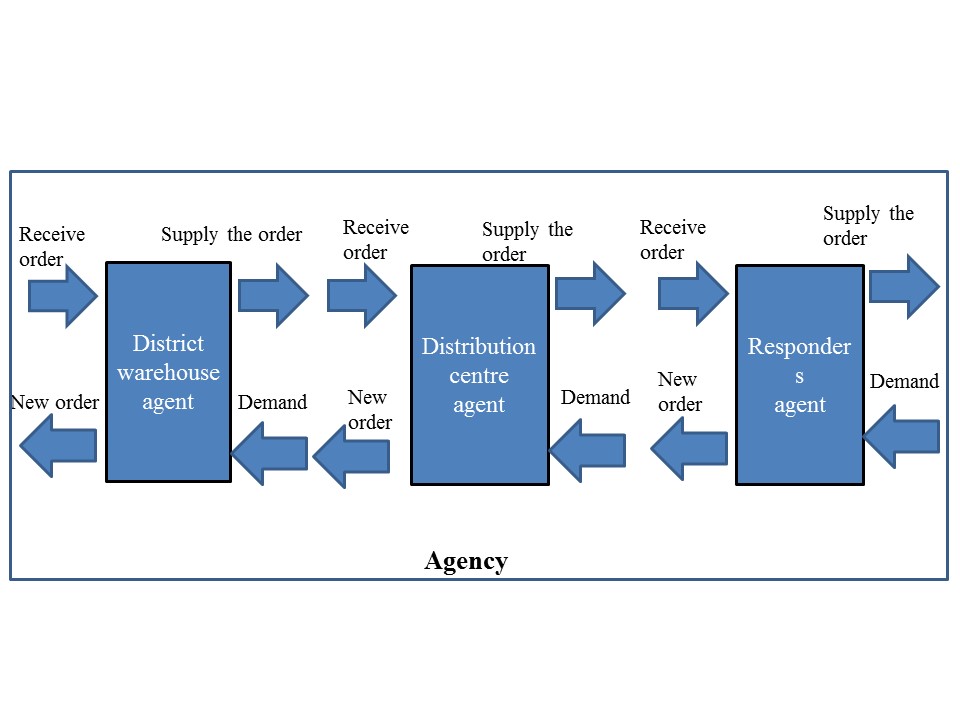
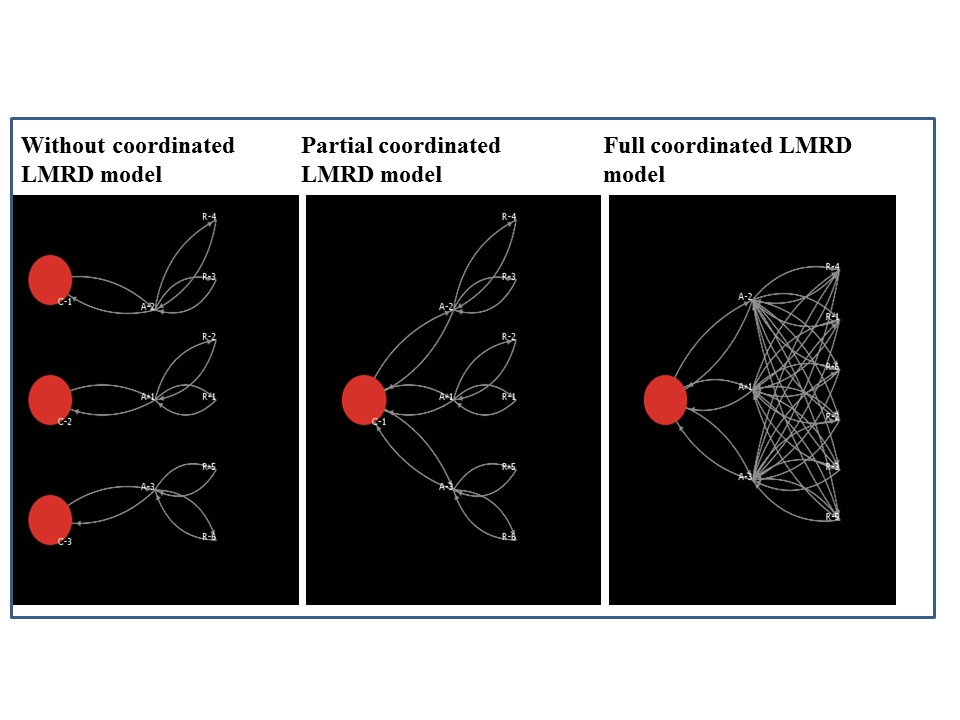


Figure 3



Keywords: Emergency Logistics, Last Mile Relief Distribution, Agent Based Simulation, Coordination, India, Earthquake, Qualitative method, Natural Disaster, Relief chain, Simulation.