Role and Importance of Coordination in Last Mile Relief Distribution: The Case of Earthquakes in India

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Abstract: The world has witnessed an increasing number of natural disasters in recent years affecting large populations. The logistical operations to deliver relief to these populations are complex requiring careful planning and execution especially during Last Mile Relief Distribution (LMRD), the ultimate phase in these operations. LMRD is the phase where the disaster logistics chain directly connects with the affected communities and whose performance is affected by many factors. Among these is the level of coordination between the organizations involved in relief operations. The aim of this paper is to evaluate the impact of coordination on LMRD performance in the context of India, the most affected country in the world by natural disasters. The research was conducted into two phases. First, qualitative interviews were conducted with Indian government, national, and international NGOs involved in disaster relief operations in the country to determine the factors affecting LMRD operations. Second, an Agent-Based Simulation (ABS) model was developed to represent the Indian LMRD system in order to evaluate the impact of coordination on its operational performance and ability to satisfy the needs of the affected people. Several scenarios reflecting different coordination policies were evaluated on the ABS model. The qualitative phase findings identified coordination as the most significant factor affecting LMRD operations performance in India. The ABS model results provided empirical evidence that better coordination during LMRD can reduce the level of inventory, hence costs, to satisfy disaster relief demand by approximately 16% and improve responsiveness by 13%. This research identifies coordination as a major driver of LMRD operations performance in India and provides empirical evidence of the magnitude of LMRD performance improvement by adopting new coordination policies. Practical implications of the research findings and suggestions on how to implement these policies are presented.

Keywords: Emergency Logistics, Last Mile Relief Distribution, Agent Based Simulation, Coordination, India

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 [1]. In 2015, 198 natural disasters were registered causing a total economic loss of 37 Billion United States Dollar (USD), 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" [2]. 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 [3]. 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 [4].

Emergency logistics is different from and more complex than commercial logistics [5]. 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 [5]. 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 [6]. 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 [7]. 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 [6].

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 [8]. Last Mile Relief Distribution (LMRD) is the ultimate stage of these operations where relief providing organizations connect directly with the disaster affected populations [9]. 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 [8]. Previous research on LMRD focused mainly on the transportation aspects of the operations such as vehicle routing decisions, fleet capacity, availability, and management [8, 10, 11]. 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 [12-14].

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 [8, 11]. 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 [9].

Effective collaboration and coordination of activities between entities engaged in the relief efforts is a challenging task. 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 collaboration and communication between these organizations. However, this 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 [15].

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 [16]. 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 [17].

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" [18]. 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 [19]. 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 [17].

2. Literature Review

2.1. 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" [20]. It encompasses a range of activities, including preparedness, planning, procurement, transport, warehousing, tracking and tracing, and customs clearance [20].

Although research in the field of logistics is well established, the focus on emergency logistics is relatively new and attracted attention only recently [21]. Examples of this research include aspects such as evacuation operations [22], relief items stock pre-positioning [23, 24], facility location [24, 25] and casualty transportation and relief distribution [26].

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 [27]. 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 [6, 28].

2.2. 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 [9]. 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 [9].

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 [29]. Balcik, Beamon [8] 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 [11] and LMRD fleet allocation in large scale disasters using simulation modelling [30].

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 [9].

2.3. Coordination in Emergency Logistics and LMRD

The term "coordination" is used to describe the relationships and interactions among different actors providing disaster relief [16]. 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 [31].

However, implementing an effective coordination mechanism between relief organizations faces many challenges. These include language barriers, different organizational policies, cultures, and processes management [9]. 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 [32]. 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 [33-35]. Other organizations used collaborative information technology tools and standardization of operations to improve coordination during relief operations [36, 37].

3. Methodology

The methodology selected in this research is a simulation modelling technique known as Agent Based Simulation (ABS) [38]. Simulation modelling, which cover a multitude of techniques including Discrete Event Simulation, System Dynamics, and ABS, involve the building of a computer-based model, which mimic (simulate) the working of a real world context [39, 40]. 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 [40]. 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 [41, 42].

3.1. Rationale for Selecting ABS

ABS is a simulation approach which focuses on the "individual agent" as the key unit for understanding the behavior of complex systems [38]. In ABS, individual agents' behavior is defined and the overall system behavior is an emergent property of the interactions between the individual agents. 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 is involved in decision making such as firms, households, government departments, and countries.

ABS assume 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 [43].

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 a warehouses) 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 warehouses to its distribution centers) or interactive (e.g. an organization requesting transfer of medical supplies from the warehouses 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. Context and Development Process of the Model

3.2.1. Context of the Study

The building of the model took place in India, a suitable country for this research for a number of reasons. It 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. India 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 [44]). Furthermore, widespread poverty, poor state of infrastructure in many regions, and the huge scale of destruction seen in the past following natural disasters, make the country an adequate context for this study.

3.2.2. 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 Indian government employees, and national and international NGOs disaster management practitioners with experience in post-earthquake relief operations. 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.

The interviews and reports indicated that national authority in terms of relief operations lies with the Prime Minister (PM), who approves the policies, plans, and guidelines to tackle the consequences of disasters. The PM is also responsible for allocating 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.

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 the task, goal selection, risk sharing, mutual adjustment, proper communication between agencies);

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 agencies". 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 [9].

3.2.3. Description of the ABS Model

The information generated through the analysis of the interviews and reports regarding the structure, management, and challenges of earthquake LMRD operations in India informed the building of the ABS model. The model, built using the NetLogo software [45], 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 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 the organization. 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.

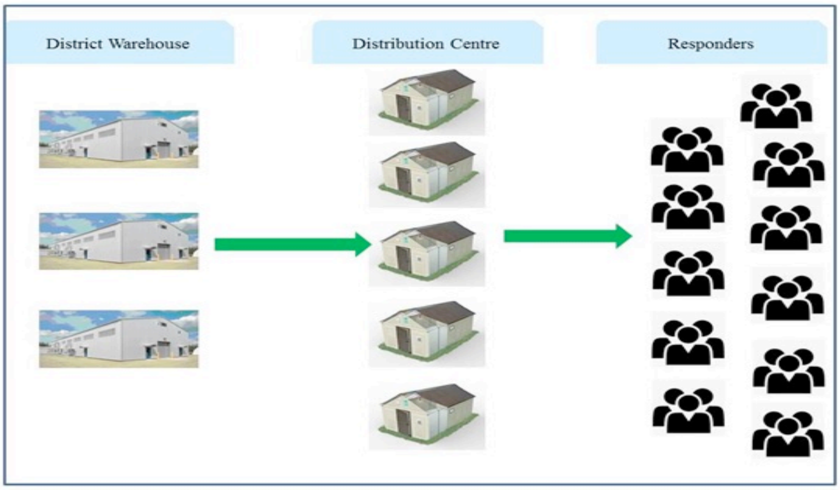

Figure 1. *Organization of LMRD operations in India.*

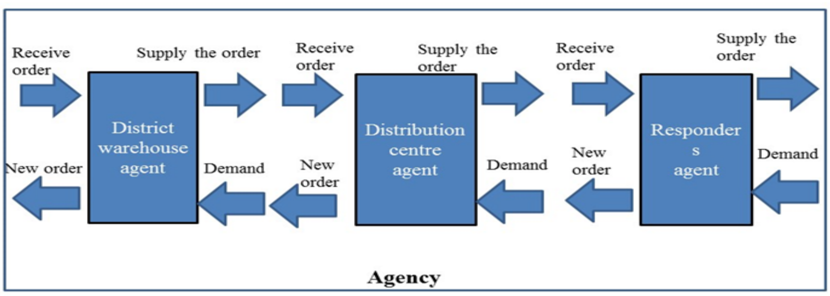

Figure 2. *The flows of supply and demand in the LMRD model.*

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 at 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 known past behavior of the system) [38]. 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 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

The aim of this research is to determine the impact of coordination policies between organizations providing relief to populations affected by natural disasters (in this case earthquakes) with a special focus on the LMRD phase of relief operations. Therefore, several scenarios portraying policies to improve coordination between organizations involved in LMRD operations were identified. The scenarios reflect feasible solutions, 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 possible 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 [46] 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 [46].

The current research adopts 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:

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.

The ABS model was run for 45 days in line with short-term relief operations in India [17] as this research focuses on the immediate post-disaster relief phase [47]. 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).

Table 1. *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

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.

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 a disaster. 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 [7, 12, 26, 48-50]. 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.

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%

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.

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 [51]. 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 time 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 respondent 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, 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.

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%

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 focus 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, the most disaster-prone country 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 work 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 [9].

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 [25]. 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 [51].

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 need 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.

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.

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.

This research has some limitations, which could be addressed through future research. 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). It focused on LMRD operations only and it is important to extend the scope 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, the 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. 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.

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