An Agent-Based Modeling Approach To Assess Coordination Among Humanitarian Relief Providers

by

Megan Menth

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Major Professor
Dr. Jessica L. Heier Stamm

Abstract

Coordination between humanitarian organizations is critical during the response effort to a disaster, as coordinating aid improves efficiency, reduces duplication of efforts, and ultimately leads to better outcomes for beneficiaries. One particular challenge arises when temporary facilities must be established post-disaster due to the destruction of buildings. For example, the 2015 Nepal earthquakes created a need for the placement of over 4,000 temporary learning facilities after several school buildings were damaged or destroyed. It is important that humanitarians coordinate well to fill these needs efficiently and effectively, while maintaining equity among beneficiaries in the affected areas. This means ensuring that enough facilities are provided in a timely manner, and are distributed fairly to all in need.

The goals of this thesis are to study coordination strategies focusing primarily on the placement of temporary educational facilities for children following a disaster. This research also aims to gather useful data by surveying active humanitarians in order to better understand their decisions made in the field. This work uses the results of this survey, along with publicly available data published after the 2015 Nepal earthquakes to create an agent-based simulation model, and uses the Nepal case study to demonstrate the efficacy of the model framework.

This research finds that organizations' initial location of operation can greatly impact the number of facilities they are collectively able to establish, the geographic disparity across the region, and the organizations' utilization. Specifically, while focusing efforts on the districts with the most need is most efficient and effective, a more uniform approach yields a more equitable response. This work also finds that there can be a trade-off between overall effectiveness and the number of partnerships established in the field.

These findings show a need for further study into the intricacies of coordination between humanitarian workers. This author advocates for the use of information sharing mechanisms among practitioners, as well as further utilization of agent-based modeling as a means of studying the complex nature of disaster response. Specifically there is a need to further study educational needs as a logistical problem, and strategies for solving the post-disaster facility location problem.

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Abbreviations

ABM Agent-Based Modeling

ANOVA Analysis of Variance

CFS Child Friendly Space

DES Discrete Event Simulation

EMS Emergency Medical Services

GBV Gender Based Violence

GIS Geographic Information System

IASC Inter-Agency Standing Committee

IDP Internally Displaced Person

LP Linear Programming

NFI Non-Food Item

NGO Non-Governmental Organization

POLR Provider of Last Resort

SNA Social Network Analysis

TLC Temporary Learning Center

UNICEF United Nations Children's Fund

UNOCHA United Nations Office for the Coordination of Humanitarian Affairs

USAR Urban Search and Rescue

WASH Water, Sanitation, and Hygiene Cluster

WHO World Health Organization

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Dedication

This work is dedicated to the children of Nepal.

1 Introduction

Responding to natural disasters, epidemics, or other major catastrophic events is a complex area of study in humanitarian research, given that response needs may be as massive as the disaster is destructive. Several different types of actors are involved, including military or government organizations, private organizations or businesses, non-governmental organizations (NGOs), local community leaders, and other individual actors, all of which share a similar goal of trying to provide some unique type of aid or service to those who are directly affected by the event–the beneficiaries. Responding to a disaster is complex when considering the sheer number of people involved, and the chaotic environment is made even more complex by the high degree of uncertainty about supply and demand. To mitigate this high level of complexity, coordination among aid-providers is critical in delivering fast and effective relief to those in need.

Coordination is defined as the alignment of humanitarian providers' aid efforts in the most effective and efficient way possible [3]. In humanitarian work, equity or fairness in how aid is distributed or how services are provided is considered just as important as maintaining efficiency, or the. This thesis specifically studies how the broad concepts of equity and efficiency relate to each other through a case study where agent-based modeling is applied to examine coordination among multiple organizations that open temporary educational facilities following an earthquake.

The first chapter of this thesis discusses background information about the humanitarian field, a summary of the disaster that motivated this work, research goals, and contributions of the thesis. Chapter 2 gives a thorough review of the literature in regard to factors that influence humanitarian decision making, the facility location problem, coordination strategies and challenges, and agent-based modeling. Chapters 3 and 4 discuss the two methodologies used in this thesis: data collection through surveying humanitarian leaders and agent-based simulation modeling. The results produced by these methods are examined in Chapter 5, followed by concluding remarks and future research opportunities in Chapter 6.

1.1 Background

This thesis is centrally motivated by a particular disaster, the Nepal earthquakes that occurred in the Spring of 2015. Specifically, this research addresses the need to analyze coordination between and within different groups of humanitarian actors by simulating part of the Nepal earthquake response. Also, since there is a need to quantitatively study programs that are targeted for children, this research emphasizes the response to children's rights and needs following a disaster through the placement of educational and child protection facilities.

1.1.1 Nepal Earthquakes

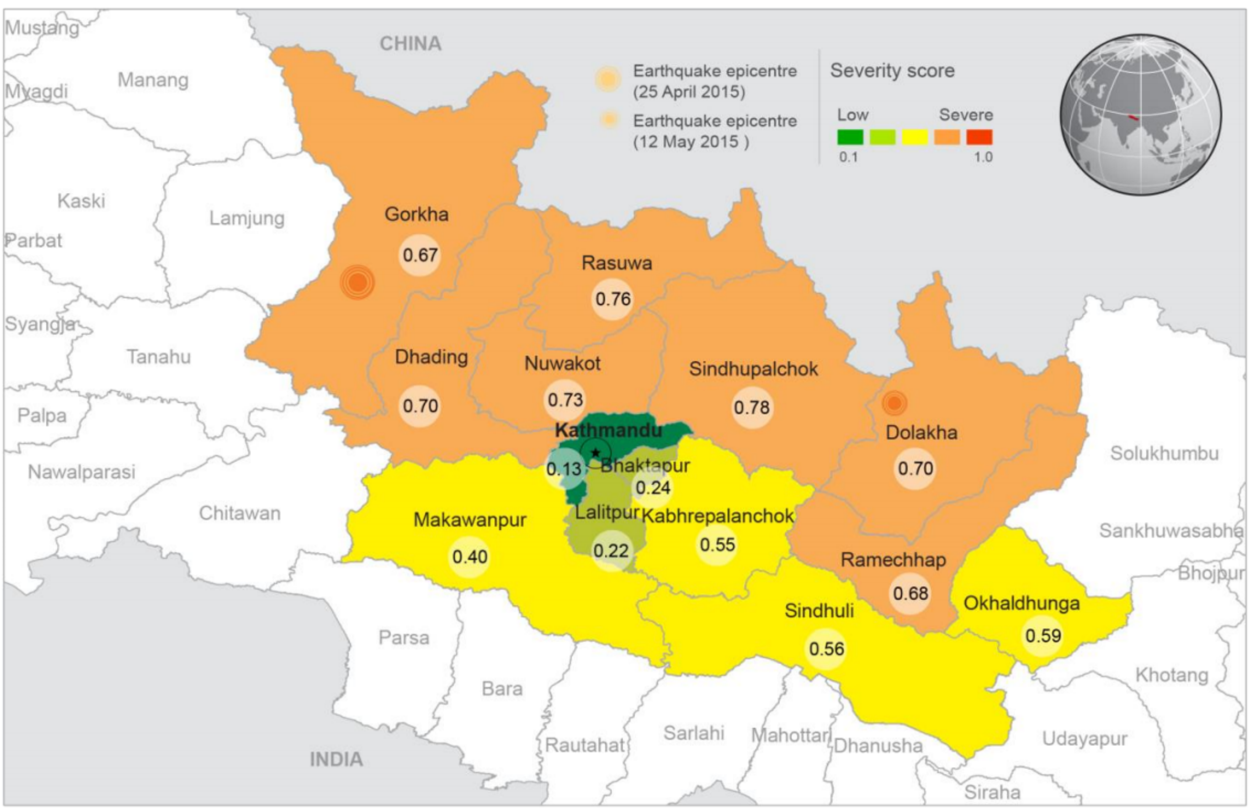

Figure 1: Map of Nepal earthquake impact severity according to UNOCHA as of 02 June 2015 [1]

The country of Nepal saw a massive earthquake, known as the Gorkha earthquake, on 25 April 2015 of magnitude 7.8 on the Richter scale. This was followed by a multitude of aftershocks, and another major earthquake of magnitude 7.3 on 12 May 2015, just over 130 km east of the original epicenter in the district of Dolakha. These natural disasters affected 39 out of Nepal's 75 districts, 14 of which were left in severe condition, including the highly populated capital of Kathmandu. The devastating earthquakes killed over 8,600 people, injured over 100,000, and destroyed over 500,000 homes [1]. The infrastructure of Nepal was also severely damaged as well through both the earthquakes themselves and subsequent landslides.

The map in Figure 1 shows the severity score of the affected districts, a metric that was developed by the United Nations Office for the Coordination of Humanitarian Affairs (UNOCHA) [1] that accounts for both damage from the earthquakes and original vulnerabilities that the regions faced prior to the disaster. While the map shows that impacts in some areas are considered more severe than others, the less severely affected areas are actually the most populated ones, and therefore need is relatively equal across all affected districts. This means that for this particular disaster there is no need to prioritize some districts over the others when supplying humanitarian aid [1].

As of this writing, recovery efforts are ongoing. Several factors have complicated aid efforts, including limited access to remote areas, heavy congestion in and around the capital of Kathmandu, and displacement and migration of certain populations. Protection of women and children has proven to be another main challenge in the overall response. Women and children in particular were already vulnerable to trafficking, early marriage, or children-raising-children scenarios prior to the disaster, and were therefore expected to be at even higher risk during the hectic response phase [1]. These protection challenges are all the more difficult to monitor considering limited access and mass migration. Finally, due to the second major earthquake and continual risk of aftershocks and landslides, assessing needs is a challenging and slow-moving process, requiring considerable coordination between all actors providing relief.

1.1.2 Cluster Coordination

The UN Cluster system was implemented as part of a larger humanitarian reform in 2005 to provide appropriate contacts to assist in coordinating efforts within certain sectors of the relief chain [4]. Clusters represent major areas of need that are common across most disasters, such as health, logistics, and shelter. Any entity working on a particular need can participate in cluster meetings. Figure 2 shows the 11 clusters, along with the organizations that are responsible for leading each cluster. The cluster leads provide six core functions. These include supporting, informing, monitoring, and advocating for other organizations within the cluster and country leaders; contingency and preparedness planning; and implementing cluster strategies and programs. They also are known as the Provider of Last Resort (POLR), or the organization responsible for addressing any remaining gaps that cannot be filled by other organizations or governing bodies [4].

Not all clusters are necessarily present to all disaster responses, rather clusters are *activated* if the local government does not have the capacity or the resources to provide sufficient relief. In other words, organizations within the clusters do not respond to an event unless they are formally invited [4]. In terms of this case study, the Nepal disaster was so damaging that all clusters were activated immediately following the first earthquake.

Cluster coordination can refer to the coordination that occurs either within a single cluster or among two or more clusters, that is, either *intra*- or *inter*-cluster coordination. For instance, the Education Cluster has many roles during a disaster response that range from assessing school damages, to acquiring emergency school kits through a supply chain, to reestablishing schools or setting up temporary learning centers. Intra-cluster coordination often involves the sharing of information, resources, or finances between agencies that have a direct role in providing these educational services. On the other side of the spectrum, coordination can also occur between clusters in several different ways. The Education Cluster may work with agencies from the Early Recovery Cluster while assessing school damage and planning for future stability. Similarly, it may be necessary to consult the Logistics Cluster when acquiring resources or tools through a supply chain to maintain efficiency. Thirdly, it is common practice that all schools, even temporary ones, have running water and working toilets; this would require collaboration with the Water, Sanitation, and Hygiene (WASH) Cluster. There are also opportunities for cross-cutting programming such as promoting proper hand-washing (Health Cluster), supplying information about HIV/AIDS (a health working group), and securing rights for beneficiaries such as implementing Gender Based Violence prevention programming (GBV, Protection subcluster). Information flow is critical for all

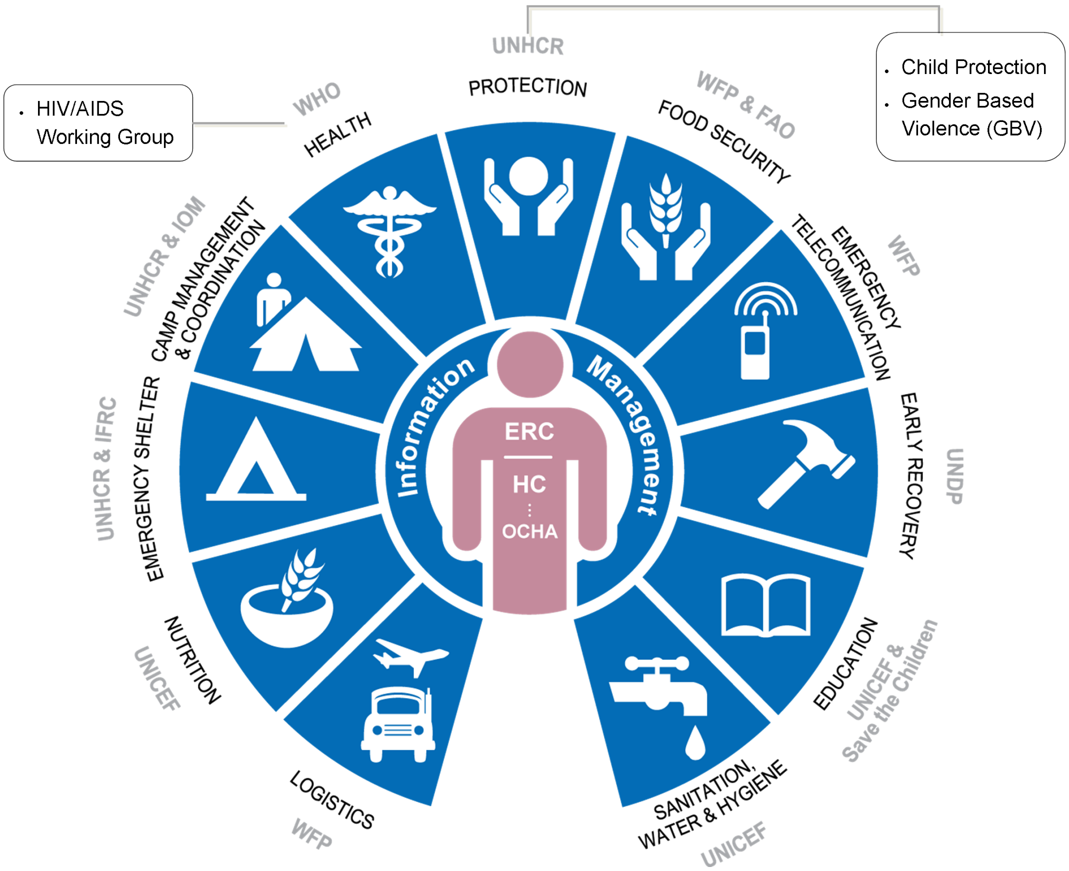

Figure 2: Diagram of cluster divisions with cluster leads [2]

of the above examples, and UNOCHA bears the primary responsibility to gather, synthesize, and disseminate this information among the clusters.

This research focuses primarily on the flow of information as the key coordination mechanism between the Education Cluster and the Child Protection subcluster. Specifically, this thesis examines the flow of needs assessment information to the different actors that can fill these demands, along with the forwarding of information between organizations. The reason for emphasizing this particular type of coordination is mainly due to the fact that reliable data is crucial in all aspects of a response effort. For example, a smooth-running resource supply chain would be much less effective if the data about the population to be served were inaccurate or not received in a timely way. Without proper information flowing to the right clusters, organizations would need to take more time to assess for themselves where they are most needed, or would simply guess in haste, leaving the strong potential for under-served populations or duplication of efforts.

1.1.3 Targeted Services for Children After a Disaster

There are two primary methods used for supplying education to children following a disaster; temporary learning centers (TLCs) provide formal education in a temporary facility or outdoor space, while child friendly spaces (CFSs) provide a similar space for more informal education. This research emphasizes disaster relief services for children for three main reasons. First, the children of Nepal, particularly females, have been identified as marginalized or at higher risk of being trafficked out of the country [1]. Second, there is a need to address education as a long-term life-saving mechanism and essential for children to sustain normal cognitive development [5]. Education may often be overlooked in the first stages of response efforts as there is not a sense of immediacy such as with the need of food or water, for example. The argument makes sense, as children can live without school, but cannot live without food or water, and therefore the latter is prioritized. Despite this differential between the two types of needs, education is still classified as a *need* and a fundamental right given that education is essential for a child's long-term health and wellbeing. According to the United Nations Children's Fund (UNICEF), children should return to formal and/or informal schooling *as soon as possible* following a disaster. Doing so allows children to return to a sense of normalcy, and gives them the structure and support to overcome the psychological harm associated with natural disasters or crises [5].

Thirdly, education is emphasized in this research since it is not traditionally thought of as a logistics problem. This type of aid is unique in that one cannot prioritize educational needs the way other needs may be prioritized. For instance, supplying health services may be easier to prioritize based on the severity of those affected, while the severity of educational needs for children is arguably uniform across any affected area. Rather than being able to classify need on a continuous scale based on severity, educational needs are more binary; a population of children either has access to schooling or they do not. Quality of that education is another issue, however this research is more concerned with analyzing the equitability of access to education rather than the quality of the education provided in emergencies.

Formal Education

The Education Cluster established four main initiatives in order to meet the educational needs of children ages 3–18 in Nepal. On 2 June 2015, UNOCHA released a revised Flash Appeal [1], a document that expressed the current conditions of the nation, needs assessments provided by each cluster, and a formal appeal for monetary donations to support the continuing response efforts. In that document, the following educational initiatives were outlined:

1. Structural assessment of existing school buildings
2. Establishment of temporary learning centers (TLCs) in areas where current schools are deemed unsafe
3. Acquirement of essential learning and recreational kits to supply TLCs
4. Special training for teachers regarding safety, preparedness, and other life-saving messages, both for temporary and permanent schools

Notice that all of the core commitments overlap with at least one other cluster or subcluster, as shown in Figure 3, meaning that inter-cluster coordination is a necessity. However, no cluster overlaps as much as the Protection cluster, mainly due to the fact that safety is highly integrated in all educational programming. Buildings are assessed with child safety in mind, teachers are trained to promote safety, and school kits emphasize safety. Furthermore, while TLCs are mainly provided to satisfy children's educational rights, the centers do indeed provide both a physical and psychosocial safe space for children.

Child Protection

The Child Protection subcluster, much like the Education Cluster, proposed specific initiatives for Nepal. This subcluster was activated due to the fact that children were particularly vulnerable, and therefore needed special attention beyond that of the foremost Protection Cluster. UNICEF

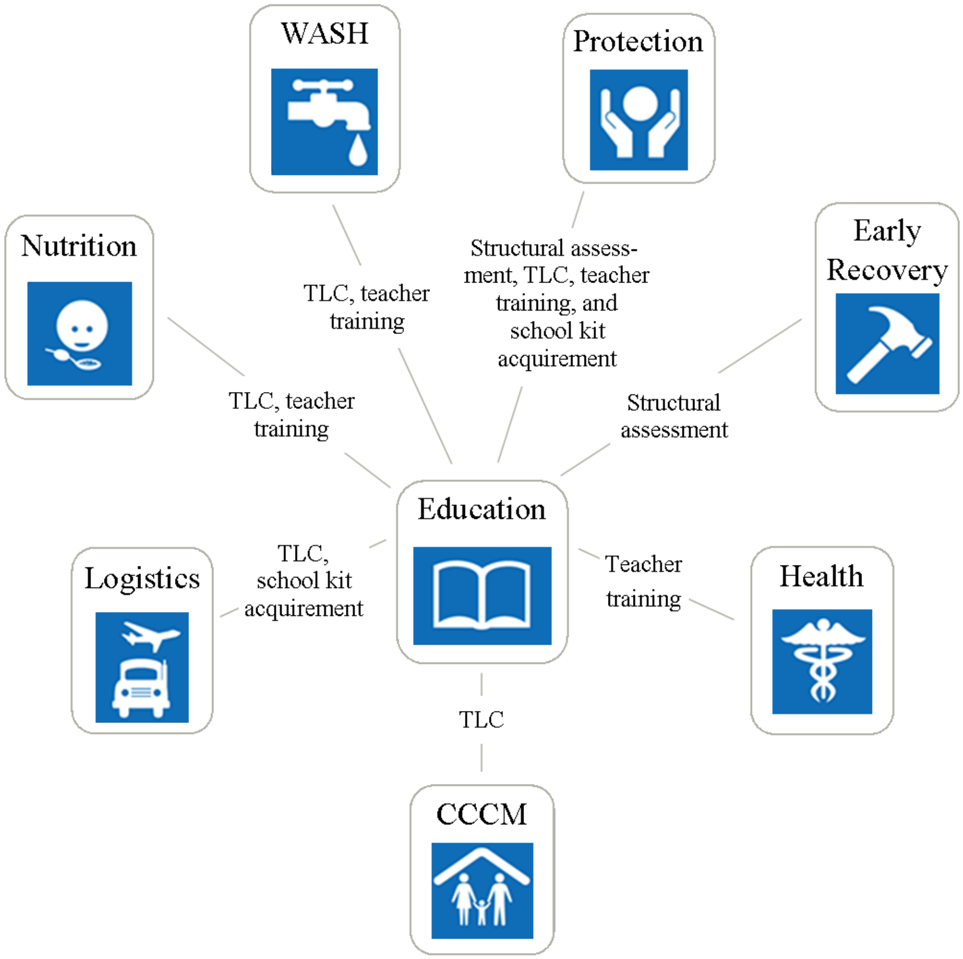

Figure 3: Cluster coordination with Nepal education initiatives

released the Child Protection subcluster action plan [6] on 15 June 2015 that outlined the following seven major objectives:

1. Facilitate coordination between and among clusters to advocate for the protective needs of children
2. Implement child friendly spaces (CFSs)
3. Increase awareness, documentation, and emergency support for separated and unaccompanied children; implement reunification strategies
4. Provide awareness and community-driven psychosocial support and counseling for women and children

5. Implement anti-trafficking support for women and children, including strengthened border checkpoints
6. Distribute non-food items (NFIs) for children
7. Work with the GBV subcluster to prevent and respond to gender-based violence concerns

Clearly these core initiatives are numerous and quite broadly defined, and some are time-sensitive, such as establishing checkpoints to monitor trafficking. There is a lot of overlap, however, within these seven initiatives, particularly through the establishment of child friendly spaces. By implementing CFSs, officials are able to more easily identify and monitor unaccompanied or separated children, and decrease the risk of child trafficking simply by providing a space for them. Furthermore, CFSs routinely work as hubs to distribute NFIs and disseminate important information that children can relay back to the community [7]. Finally child friendly spaces act as a major form of psychosocial support for children.

Psychosocial support has many overlaps with mental health support, which is why guidelines for practicing both forms of aid were established in the same manual [8] by the Inter-Agency Standing Committee (IASC). Mental and psychosocial support is defined as "any type of local or outside support that aims to protect or promote psychosocial well-being and/or prevent or treat mental disorder [8]." This type of support is often needed following a disaster like the earthquakes in Nepal, since such crises can cause severe psychological stress and upset the normal social practices of survivors. While some may be resilient toward psychosocial stressors, all are considered at-risk, with certain subgroups of the affected population, such as children, being considered at higher risk of experiencing either psychological or social trauma. Some factors that increase this risk can be preexisting conditions, such as the existence of a caste system; other factors may stem from the disaster itself, such as separation or loss of family members [8]. Still further, humanitarian presence may unintentionally create problems if not implemented correctly, causing stress due to lack of access to humanitarian services or items, for example [8]. While each disaster is unique and may or may not require extensive mental or psychosocial support, the Child Protection subcluster in Nepal deemed this support beneficial for children, and therefore made it a key priority.

1.1.4 Connection between CFS and TLC

There are many similarities between CFS programming and temporary learning centers. In fact, child friendly spaces often provide informal education, and harmoniously TLCs may be used as a form of psychosocial support in the best case scenarios. The two complement each other through the support they provide so well that it may seem unnecessary to provide both to the same population of children. While formal education has been prioritized in the past, the importance of CFSs has just begun to be realized through field practices and formal studies. The guidelines for implementing child friendly spaces written by UNICEF argue that CFSs should be used in conjunction with TLCs. The guidelines highlight the importance of psychosocial support by asserting, "The emphasis on recreation and play and the development of related creative activities is as important as the support and provision of reading, writing, numeracy and life skills education activities [5]." Ideally, children should have access to both formal education and stimulating spaces for play and social growth.

Considering CFSs have only been implemented as a humanitarian strategy since 1999, there has not been much research evaluating the effectiveness of these spaces. The greatest benefits that have been found in practice and in the research show that CFSs provide a low-cost way to mobilize and involve the community in their children's lives. That is, CFSs provide the flexibility to let parents, community leaders, and children themselves design a space and suggest activities that are needed, really giving survivors a sense of ownership and empowerment [7].

The efficacy of CFSs has also been validated through field studies conducted by World Vision, Columbia University, and other humanitarian partners. Six studies were conducted over three years in nations housing refugees or IDP camps, including Iraq (two studies), Jordan, Ethiopia, Uganda, and the Democratic Republic of Congo (DRC). These studies took a traditional treatment design approach, using interviews to compare the wellbeing of children who participated in CFS and those who did not or could not participate due to lack of access; or comparing children who had long-term access versus short-term. Researchers found that CFSs had an overall positive impact, with some instances showing larger gains than others. The authors indicate that CFSs that follow quality standards are indeed more effective, and that it is important to consider local needs to have greater impact [9]. These studies highlighted areas where child friendly spaces could improve, but also showed that studies examining CFSs are lacking both in quantity and rigor of analysis. While the research presented here does not examine the effectiveness of the CFS or TLC programming, this research does examine efficient and equitable access to CFS and TLC facilities for children in need.

From a coordination standpoint, CFS and TLC programming overlap significantly, as they are ideally trying to solve the same type of "problem," that is, knowing where and when to implement one of these facilities essentially boils down to solving a facility location problem. Due to the high similarities between the services that CFSs and TLCs provide, and that implementing either requires a similar process, this research does not make a distinction between the two in terms of modeling. Essentially, even though two separate clusters are responsible for providing the two types of interventions, in practice it makes much more sense to plan for both services together rather than separately.

1.2 Research Goals

This research examines the impact coordination and humanitarian organizations' decision making have on disaster response, specifically through meeting the educational needs of children. This author hypothesizes that an increase in collaborative efforts between humanitarian actors will improve the overall efficiency of the response, and that spatial inequities in the relief provided will be affected by the actors' decisions on where to initially provide aid. By testing this hypothesis, the results may benefit the humanitarian community by offering improved coordination strategies. The first major goal of this thesis is to learn more about how humanitarians coordinate through an online survey. The second goal of this work is to investigate how the efficiency and equitability of a response are associated with coordination mechanisms using agent-based modeling.

1.3 Contributions

This thesis advances the field of humanitarian logistics in five ways. First, this work represents, to this author's knowledge, the first use of agent-based modeling to investigate trade-offs between efficiency and equity objectives in humanitarian response. This is accomplished through modeling the response to children's educational needs following the 2015 Nepal earthquakes. The special attention paid to education in emergencies is also an important contribution, as educational response has not historically been considered a logistical problem in the literature. Another contribution is the gathering and analysis of information from humanitarians in the field through a survey, results of which help inform the agent-based modeling framework. This work also addresses the gap that exists in solving the post-disaster facility location problem, whereas previous work primarily considers facility location a pre-disaster decision. The greatest contribution, however, is incorporating all of the above aspects into the study of coordination between humanitarian relief providers, the progress of which is vital for improving humanitarian response.

2 Literature Review

This chapter reviews the current topics that contribute to decision making in humanitarian relief on a broad scale, specifically the considerations of equity and efficiency when making decisions. Next, it provides a review of how the facility location problem has been addressed in the humanitarian context. This chapter also discusses significant factors that have been shown in the literature to be important in improving coordination between humanitarian organizations, along with challenges in coordination. Chapter 2 ends with a review of research that has been conducted specifically using agent-based modeling in the humanitarian sector.

2.1 Equity Versus Efficiency

In the humanitarian sector as well as the greater realm of public health, there exists a trade-off between making decisions that are efficient and those that are equitable. Efficiency is broadly defined as the ability to do something without wasting necessary resources, time, or energy. In a mathematical context, efficiency can be thought of as the ratio of output to input. More specific to humanitarian work, efficiency can also be viewed as using limited money or resources to help the most people or do the most good following a disaster or epidemic. It is important to note that efficiency is generally easy to quantify using optimization models via the minimization of cost or time required to meet a given need, or maximization of need met given resource limitations.

While most humanitarian organizations try to be as efficient as possible and consciously consider efficiency when making decisions, issues regarding equity and fairness are much more difficult to quantify. As a result, decision makers are more likely to make ad hoc decisions when it comes to fairness, rather than rely on mathematical formulae or a standard best practice [10]. Part of the reason for this could be due to the fact that equity is more difficult to define than efficiency and does not have a standard form of measurement [11]. Indeed, Stone introduces nine distinct principles to define equity; however there does not exist an equity measurement that satisfies all principles [12].

Equity can be defined as providing near-equal service for relatively equal need, which may mean supplying an increased amount of aid or relief for certain subgroups that are most vulnerable. Specifically in the public health sphere, equity refers to the "absence of systematic disparities in access between different groups of people, identified by location or underlying socioeconomic variables" [13]. In other words, there should be no difference in health care availability or quality based on either spatial or social factors. Variations of this definition are widely accepted in the humanitarian field as well, such as the World Health Organization's definition, which substitutes "systematic" disparities with "avoidable or remedial" disparities [14]. However, just as it can be hard to measure equity itself, it may also be difficult to determine which disparities or inequities are avoidable. Using this wording may halt aid efforts for problems that are deemed too hard or ill-defined to solve [13].

Adding to the difficulty of defining or understanding the idea of fairness in health, is that health inequities are not the same as health inequalities, but are often treated as such. Rather, inequities in health are specific inequalities that are unfair or unjust [13]. For example, gender or aged based afflictions are often considered as health inequalities due to their nature of affecting specific populations, such as ovarian cancer in women or increased risk of falling in the elderly. There is however, no systematic reason for these inequalities that would qualify as emerging due to some injustice. It is important to make the distinction between these two terms so that the afflictions that arise due to unjust practices are addressed and revised. This is another main differential between how equity and efficiency are measured, as efficiency is much less ambiguous and is almost unquestionably addressed in decision making.

Effectiveness is another measurement used to evaluate performance in health and humanitarian scenarios. Something is considered effective if it is successful in producing the desired result. In a mathematical model, an effective objective may be obtained by maximizing some service measurement, or creating a contraint that guarantees a minimum percent of needs are met [15]. However, just using this standalone objective may fail to achieve an efficient or equitable response. For example, suppose one task in providing humanitarian aid is to distribute blankets to everyone in an IDP camp. A strategy is put in place to do so, and is considered effective if everyone actually receives a blanket. However, efficiency may be measured by how quickly the blankets are distributed, or how little time families had to wait to receive their distribution. Similarly, equity may be assessed by observing if some people had to wait a disproportionate amount of time compared to others due to a systematic problem in the camp, or if some did not receive their blanket at all. Ultimately, effectiveness is a necessary metric for transparency, but it is not sufficient in that it misses key pieces of information describing the more complex measurements of efficiency and equity. It is because of this that equity, efficiency, and effectiveness are all analyzed together in this present research.

2.1.1 Modeling Equity and Efficiency

There are several applications of models that consider both equity and efficiency in humanitarian decision making and public health. Leclerc et al. give a thorough overview of different objectives and constraints that account for equity in optimization models specifically applying to emergency medical services (EMS) [11]. Several equity constraints have also been considered for EMS dispatching, uniquely assessing both customer and server overall equity, using Markov decision processes in linear programming models [16]. This field is analyzed further by use of a p-envy model, a model used to minimize dissatisfaction among customers, where the actual number of lives saved is maximized in the objective function. This method was found to be more equitable than when maximizing the area covered or minimizing distance traveled to a patient [17].

There have also been efforts to improve equity in last-mile humanitarian logistics. McCoy and Lee analyze different strategies for resource allocation to rural areas in sub-Saharan Africa via the organization Riders for Health. They specifically test three different approaches: utilitarian, egalitarian, and a proportionally fair approach [18]. A utilitarian approach is one that seeks to help the greatest amount of people as possible, an efficient method, while an egalitarian approach may advocate for specific vulnerable subgroups that may otherwise be neglected. A proportionally fair approach seeks to provide the same amount of service for everyone, regardless of need or status. De la Torre et al. [19] give an overview of operations research models and interviews with aid organizations using this same terminology to assess the trade-offs of using more efficient or equitable objective functions specific in routing logistics. Huang et al. also look into last-mile logistics and the vehicle routing problem in regard to efficiency, efficacy, and equity, yielding practical heuristics that consider the trade-offs of all three factors [20].

More relevant to this paper are the efforts that have been considered in facility location to provide humanitarian relief. Muggy and Heier Stamm suggest a retrospective robust optimization model in which a minimum access threshold is set for deciding where to place treatment facilities in response to the cholera outbreak after the 2010 earthquake in Haiti [21]. Zhan et al. also provide a multiple-objective optimization model to account for equity in both facility location problems and vehicle routing problems [22]. The next section will further discuss the facility location problem beyond the scope of the equity-efficiency conversation.

A main finding of most papers that analyze the trade-off between efficiency and equity is that given the different objectives, and how equity and efficiency are considered, solutions can be dramatically different regardless of the type of problem. It is clearly difficult to find a balance between these two important and influential factors. Starr and Van Wassenhove articulate the need of a proper quantitative measure for equity, arguing that doing so is crucial to the advancement of the humanitarian operations field [23]. Therefore this research considers a different view of the equity/efficiency trade-off by using agent-based simulation methodology rather than traditional optimization methods. Rather than optimizing or constraining a model to maintain a certain level of either efficiency or equity, simulation allows for a more exploratory type of analysis. This type of modeling is advantageous since it allows for stochasticity, or randomness, and evaluates how individual behavior impacts the equity and efficiency of the system as a whole.

2.2 Facility Location Problem

Many major disasters require setting up temporary or permanent facilities, and choosing where to place these facilities is not a trivial task. Research has been conducted in the humanitarian field and the broader field of public health in regard to the facility location problem through a range of p-median, p-center, and various covering models. The p-median model minimizes the total distance between facilities and sources of demand, an efficient method by nature [24]. The p-center model is more equitable by decreasing disparities in access to facilities, minimizing the maximum distance between facilities and sources of demand. A general covering model can guarantee equity by guarenteeing all sources of demand are covered at minimum cost, while a maximal covering model covers as much demand as possible with a fixed number of facilities [25]. Other robust optimization methods have also been implemented with similar objectives that minimize total regret, or attempt to find a good outcome regardless of high levels of uncertainty, in demand-weighted access to a facility for beneficiaries [21].

Typically in the humanitarian field where fairness and equity among beneficiaries is highly important, a covering model is implemented with some threshold level of service that must be satisfied, that is, to ensure access or ease of distribution to all people in the affected area. Examples of the covering or maximal covering methods have been applied to optimizing the number of distribution centers to be opened in the relief chain [10], and to specific case studies of where to place facilities such as in Istanbul in preparation for a potentially destructive earthquake [26]. See [27] for an in-depth overview of other facility location optimization models in the humanitarian sector. For an overview of facility location problems, algorithms, and solutions in a non-humanitarian context where equity may not be an issue, see [24, 28, 29].

The facility location problem is often referred to in the literature as a pre-disaster logistics problem, meaning determining locations of where to place warehouses to pre-position relief inventory is optimized before a disaster strikes [27]. There are many factors that go into selecting both candidate and final locations for these types of facilities. Roh et al. [30] find that when selecting warehouse facility locations, cooperation between aid providers is the most important element, followed by national stability, cost, and logistics; with physical location surprisingly listed as the least important element. Balcik et al. [31] also express the need for coordination in the overall relief supply chain, specifically noting pre-positioning warehouses as a critical decision due to its long-term tactical nature.

While generally a pre-disaster problem, facilities may also need to be placed after an event occurs or as it is unfolding. Sudden disease outbreaks represent one such situation. For example, the cholera outbreak following the 2010 earthquake in Haiti led to the establishment of over 100 treatment facilities across the nation. Similarly, the 2014 Ebola epidemic in West Africa motivated the placement of over 70 treatment facilities by the World Health Organization (WHO) alone, along with several mobile testing labs [32]. Furthermore, the facility location problem may need to be addressed post-disaster in cases where evacuation is necessary and temporary housing must be set up for displaced persons [27]. Finally, as described in Chapter 1, the establishment of temporary learning centers and child friendly spaces are also instances of post-disaster facility placement.

The literature is lacking in attempts to optimize facility location decisions of these sudden post-disaster events. While retrospective analyses have been conducted, there are not many proposed models that are generalized enough to implement. The reason for this is most likely due to the difficulty in coordination, lack of a centralized decision maker, high uncertainty, and short time-frame to create and implement models in real time.

Another reason the post-disaster facility location problem is usually solved through ad-hoc methods instead of formal mathematical models is due to the fact that the optimization methods used to solve the problem, such as the covering model, are classified as NP-hard [24]. This means that the amount of time to solve the problem with any known algorithm grows exponentially with the size of the problem. In the humanitarian field it is highly likely that a facility location problem will be quite large with many possible candidate solutions, and would therefore be computationally expensive to attempt to solve. Truly, there is a reluctance in the literature to implement multi-objective models due to their high level of complexity [27]. Similar to the equity/efficiency problem, it is hard to capture the complexity of the post-disaster facility location problem in a traditional deterministic optimization model. Therefore this research offers simulation as a tool to deal with the complexity.

Facility placement decisions may also depend on the actions of other organizations within the relief network, such as where they are placing facilities themselves, or where they are willing to supply. Ideally, those that make decisions about where to place facilities would be able to coordinate with others that are doing the same. Specifically, an agent-based simulation, such as the one offered in this thesis, would be useful to account for these interactions and decisions made at the agency level. The next sections describe benefits of coordinating, factors that can lead to higher levels of coordination, along with the challenges that interfere with organization coordination.

2.3 Factors Improving Coordination

Much of the literature surrounding humanitarian research emphasizes the importance of coordination among all actors involved. The term *coordination* refers to the alignment of relief actors' aid efforts in such a way that efficiency and efficacy are maximized [3]. In some relief chain contexts it may also be necessary to further classify the types of relationships depending on the type of relief that is being provided. Supply chain literature often suggests using the terms *vertical* (coordinating with those that perform different activities on other segments of the relief chain) and *horizontal* (coordinating with those that perform the same activities) coordination, as well as breaking down the types of engagement to the *strategic*, *tactical*, and *operational* levels (long, medium, and short-term) [31, 33]. Other authors use similar language such as *collaboration* [34] or *cooperation* [30, 35] to describe a specific type of coordination. While the three terms have subtle differences in definition, increasing any really develops the same benefits. For this reasoning, the term coordination will be used throughout this thesis.

Several types of coordination can occur in a humanitarian response, including coordinating the flow of resources, finances, or information through a network of organizations. While all three are important in regard to the facility location problem, information sharing is arguably the most important and time-sensitive type of coordination. Some important factors leading to effective information management and coordination include the timeliness in which data is collected and distributed, its validity, and its relevance and practicality at the field level [36].

Since the need for coordination is so heavily emphasized in the humanitarian field, the following subsections discuss the benefits of coordinating efforts, along with factors that can aid in enhancing coordination. A specific emphasis is placed on information management coordination.

2.3.1 Benefits

Coordination plays a critical role in the decision making process, as it can often change who is actually making decisions. While coordinating can pose challenges, many of which will be discussed in the next section, there are also many benefits to consider when relief organizations work together. First, it is important to note that generally no single actor has the capabilities to provide effective relief after a major disaster [37]. With the necessity for multiple actors, it is logical that efforts are coordinated so as to avoid duplicated efforts or gaps in service. Indeed, it has been shown in the literature that these are some of the main benefits of coordination, along with increased efficiency [3, 38]. Increasing efficiency may also result from synergies such as economies of scale in transportation, or sharing warehousing space with public or private sector organizations [33, 38].

Some retrospective analyses show what the overall benefit would have been, had more organizations chosen to coordinate [21, 39]. Furthermore, Holguín-Veras et al. [40] found in their interviews that after an event, organizations felt the need to take steps to improve communication and coordination, showing that the importance of coordinating efforts is often realized in hindsight. Parmer et al. also conducted interviews, and found that many organizations believed their most successful and effective coordinated efforts took place in the field. The authors reported a consensus that partnerships form frequently at the field-implementation level where the situation is more informal [38]. It is important to further study this information and to pinpoint other factors that influence coordination as the benefits are clearly numerous.

2.3.2 Factors

Key factors contributing to coordination have been found by interviewing organizations about their work in the field as well as their planning efforts before a disaster strikes. Aside from the knowledge that coordination can improve efficiency and in turn lower costs, the literature has found some other factors that could influence coordination, including communication, trust, perceptions such as size and centrality, and risk assessment.

Several researchers attribute fast and effective collaborative efforts to proper communication between organizations. Altay and Pal [35] discuss how the UN's cluster approach could be used to increase information flow across the humanitarian relief chain network. The authors propose that if cluster leads filled the role of information hubs that gather, filter, and distribute information, the initial humanitarian response to an event could be much more efficient.

Zhao et al. [34] propose a theoretical agent-based model that considers communication as a prerequisite to formulating collaborative project teams. They study the collaboration network and the teams that emerge depending on the interactions between groups in the inter-organizational communication network. An inter-organizational system is a specific type of collaborative environment between organizations in which information is shared, usually in the form of electronic data. They find that increasing communication is beneficial between larger organizations and peripheral organizations (smaller agencies that are not well known or well established), and between two organizations that are both peripheral.

Specifically for inter-organizational systems, the literature indicates that an organization is more likely to work with another if the latter is larger and has a good reputation [34, 41, 42]. This perception of other organizations can be derived from an overall factor of trust. In a humanitarian context, Kapucu [43] uses social network analysis (SNA) on the agencies involved in providing relief after the September 11, 2001, terrorist attacks, and finds that after a disaster there is often a collective sense of pain or loss which can lead to an increase in trust and cooperative efforts. Kapucu also notes that continuous collaboration raises trust over time. Centrality metrics in network analysis are often used to measure the size of an actor's communication network, which can translate to their overall size as an organization. Other SNA metrics such as degree, betweenness, and closeness are used to indicate the structure of an organization's connections to others in the network, reflective of their influence or strength. Although these metrics will not be discussed at length here, see [39] for formal definitions and proper use. Moore et al. [39] also study the centrality of international organizations in response to the 2000 Mozambique floods. These researchers postulate that the more central or visible actors are in the network, the more likely they are to form alliances and become even more powerful. Trust, visibility, and centrality, all factors of overall perception, are highly likely to be considered when an agency is evaluating whether or not to collaborate with another organization.

Closely related to the assessment of trustworthiness of an organization is the assessment of risk in collaborating with others. Reynolds [44] finds that in order to communicate, factors like risk, trust, and reputation of an organization are essential. In a time of crisis, both the public and other organizations will be more likely to cooperate with another organization if they are considered trustworthy, because high levels of trust are strongly associated with low levels of risk perception. Conversely, an agency that is considered untrustworthy will have a more difficult time communicating information, as they will not be considered as credible.

Typically, collaborating on a project reduces the amount of overall risk involved since burdens such as costs and responsibilities are now being shared among two or more organizations [31]. Indeed, Garnett and Kouzmin [42] note that in the case of inter-organizational networking, the risk of a lone planner with limited information or ideas is mitigated by the involvement of multiple contributors. The authors go on to note that having multiple organizations involved in a response effort can reduce risk by creating unofficial checks and balances between agencies in regard to key attributes such as accountability and conduct. The simulation methodology proposed in this present research focuses more on risk-sharing rather than trust perceptions between actors as a central motivation for coordination.

2.4 Challenges With Coordination

The main challenge that arises in the literature associated with coordination is competition among agencies for donor support. This problem is summarized well by Heier Stamm and Muggy [45] and Garnett and Kouzmin [42]. Other challenges arise specifically with information sharing and management, including information accuracy, relevance, and timeliness. Finally, loss of autonomy has been found to be another major barrier to overcome in humanitarian coordination.

2.4.1 Donor Challenges

It is not difficult to see how donor influence can affect a humanitarian organization's work in the field. Donors are more likely to give to organizations that they have seen more frequently in the action of an event response, or in other words, agencies with high visibility or centrality.

Just as organizations prefer to work with others who are highly visible, donors tend to support organizations that are highly visible [45]. Agencies are therefore likely to serve where there is a high concentration of media exposure, potentially leaving some populations under-served. This problem poses a real challenge as many agencies strive to serve with neutrality and impartiality, and yet cannot successfully serve in this manner without donor support [46].

2.4.2 Information Sharing Challenges

While supplying spending decision information is helpful in some cases, many times donors react negatively to being shown too much information [47]. Some donors may explicitly ask for certain information before donating, or put restrictions on donated funds, while other donors may have a higher level of trust with an agency, meaning they are more likely to trust that the organization is using funds appropriately. It can be difficult for organizations to predict just how much information to share with donors or with the public in general. Due to agency competition, the issue with information sharing becomes even more complicated. While sharing stories of successful efforts in the field is usually beneficial, sharing information about what made fieldwork so successful always brings the risk of others copying strategies or ideas, which could in turn attract limited donors.

Maitland et al. use qualitative case studies of three coordination bodies to analyze the benefits and barriers of coordinating information management systems. They find that the key to overcoming the information management barrier relies heavily on changing the organizational structure of the coordinating body itself. Furthermore, they find a strong positive correlation between the degree to which the organizational structure must change to overcome the coordination barrier and the significance of said barrier. This means that while it may be difficult to change the inter-organizational structure between collaborators, doing so may have a higher payoff than taking on easier challenges [36].

2.4.3 Challenges Related to Autonomy

One last major issue with collaborating is a decrease in autonomy and flexibility. By the nature of collaboration, organizations give up some form of decision power in order to gain some other type of benefit, usually in cost efficiency or information sharing [31]. However, this limitation has a positive trade-off with donor issues, as collaborating with other organizations is a marketable act and can lead to meeting more potential donors. Still, the loss of autonomy can lead to confusion and uncertainty regarding the role an organization will have in a response. When first implemented, the UN cluster system led to lower levels of autonomy or ownership for smaller humanitarian agencies. Although there have been several benefits from implementing clusters, Humphries reports that having one coordinating body has interfered with creating a sense of involvement for many NGOs [48].

All of the challenges described in this section need to be consciously addressed when building models that could potentially inform field-level standards. For this research, the challenges listed here along with results of the survey discussed in Chapter 3 are used to help conceptually design an agent-based model. The next section will describe agent-based models that are able to account for complex behavior such as the challenges listed above.

2.5 Agent-Based Modeling

One potential modeling tool that could be used to address the issues described thus far is agent-based modeling (ABM). This type of computational modeling simulates the interactions between autonomous agents that follow their own sets of *rules*, or strategies, and allows behaviors to emerge from the ground-up versus a traditional top-down approach. This allows for interpretations to be made on a global scale. While there is no universally accepted definition of an *agent*, scholars tend to agree on the main attributes that agents share, which are autonomy, heterogenity, and that agents are active [49]. This last attribute encompasses many more detailed attributes, which suggest that agents are usually goal-oriented, can react to their environment and other agents, can interact with other agents, can be mobile, have bounded rationality, and can adapt or learn [49]. Based on these broad characteristics, agents can be individual people, aggregated groups, inanimate objects, locations in space, businesses, cells that make up a tissue, or a number of other things.

Similar to discrete event simulation, agents typically have *states* between which they may transition during the simulation. However, in agent-based simulation agents may change states based on explicit decision rules defined by the modeler rather than through a discrete process. Agents' decision rules are often informed through conditional statements, meaning their states can alter based on the state of their environment, interactions with other agents, a scheduled event, or as a result of the agents' heterogeneous makeup. These rules can be derived from the literature, survey or interview findings, other forms of collected data, or a mixture of sources [49].

The *environment* is the space in which the agents live and interact. This modeled environment can range from a highly detailed space with real physical attributes to an abstracted theoretical space with virtual characteristics [50]. An environment can also be classified as either a discrete, continuous, or a geographic space. Based on the objective of the model, the location of agents within an environment may or may not be relevant [49]. It is important to note that like all models, no environment can exactly replicate real life, although one may be more appropriate than others given the scenario.

2.5.1 Relevant Models

Specific public health disciplines such as epidemiology have embraced the use of ABM for both predictive and prescriptive purposes in controlling the spread of diseases. This modeling tool is attractive to public health officials due to its behavioral aspects as well as its ability to identify social and spatial inequities that emerge due to public policies or lack thereof [51]. Some examples of ABM in public health have addressed agent movement in spatial epidemics [52], walking behaviors and interventions in adults [53], geographic disparities of health food supply and its influence on obesity [54], and risk assessment and sexual behavior regarding HIV transmission [55].

In Coordination

Agent-based modeling has only just begun to be utilized in humanitarian research, therefore there are very few references in the literature compared to more classical methods such as linear programming (LP) or discrete event simulation (DES). However, some ABM researchers have looked specifically into the coordination network of humanitarian agencies. For instance, Zhao et al. [34] examine how the communication network in an inter-organizational system can affect the collaboration network. In this model, agents make decisions about forming collaborative project teams based on who they are connected to in the communication network, similarities in mission and focus region with other NGOs, as well as perceptions of other organizations. Son and Rojas also use ABM, along with game theory and social network analysis, to model the evolution of collaborative project teams in the construction industry rather than a humanitarian network [56]. Another model created by Altay and Pal examines which roles humanitarian cluster leads should have in regard to information sharing in order to enhance overall coordination in a response. The authors find that factors such as information quality and trust play an important role in increasing cooperation [35].

While all three of these models are useful in understanding the roles of coordination or collaboration in complex environments, they all offer a theoretical framework of agency networks, and do not attempt to model an actual event. Coles and Zhuang [57] have studied interactions and strength in organization partnerships in a real event, a case study involving Hurricane Sandy, but steps have not been taken to implement this information in a model. Creating an ABM of a grounded, applied problem is essential to enhance understanding of coordination in the humanitarian field, and to further the progress of ABM in both humanitarian logistics as well as the greater operations research community. Therefore the model presented in this thesis attempts to address this gap by implementing an applied model rather than a theoretical one.

In Facility Location

Turner et al. employ ABM to solve a variant of the facility location problem, that is to optimize resource placement in post-disaster humanitarian missions. They specifically examine distribution of aid at the individual agent (person) level, including ethnic makeup, social attributes, crime rate, population density, and risk of migration in the model. The authors find that placing more distribution centers at lower capacity is better in terms of these variables, but doing so does not take into account ease of supplying the centers, which would likely favor fewer larger facilities [58]. To this author's knowledge, this is the only source that attempts to solve the facility location problem in humanitarian work using agent-based modeling, although there are several facility location ABM models in a non-humanitarian context [59, 60].

Agent-based modeling is particularly useful for modeling facility location problems given its capability of fusing with the geographic information system (GIS) environment. O'Sullivan et al. [50] discuss the advantages and disadvantages of using spatial agent-based modeling over a simpler modeling structure. While there is no generic problem that agent-based modeling is suited for, given the complex behavioral nature of geographic systems, especially following a disaster, ABM would be an appropriate avenue for future research into humanitarian geographic systems and networks. Crooks and Castle supply a thorough overview of how GIS can be integrated into the ABM framework [61].

2.5.2 The Importance of ABM

Furthermore, ABM is a more realistic modeling choice than many optimization models, as it can directly account for the often imperfect nature of autonomous decision makers. As previously noted, many optimization models shy away from addressing multiple objectives, and even fewer include stochasticity or dynamic factors [27]. In ABM however, these features are not only addressed, they are considered some of the most important design concepts of an agent-based model [62]. Finally, there is an ongoing debate whether the extra effort needed to model complex systems is worth the potential benefits, especially if the benefits may be minimal [50]. In this author's opinion, the extra effort put into creating a complex model over a simpler one is surely justified in the humanitarian context as the benefits may range from cost savings to the improvement or saving of human lives.

2.6 Summary

This chapter described the current state of the literature in the humanitarian field in terms of coordination and its impact on decision making. As discussed, modeling humanitarian problems can be particularly hard given that not only efficiency and effectiveness need to be addressed, but equity as well. Facility location placement is a problem that many relief providers face, and there is a substantial need for solving facility placement problems in post-disaster scenarios. Benefits and challenges that emerge when agencies coordinate efforts were also addressed, and the literature suggests that the benefits overwhelmingly outweigh the challenges presented. Therefore steps need to be taken to improve the ease of coordination between humanitarian organization. This thesis proposes that agent-based modeling has the potential to both better understand the concept of coordination as well as analyze ways to improve equity, effectiveness, and efficiency, which would in turn improve aid efforts overall and lead to better outcomes for beneficiaries.

3 Survey Design and Analysis

In order to better understand how actual humanitarian actors think about topics such as coordination, facility placement, and motives behind decision making, a sample of active humanitarians were surveyed. The goal of this survey was to help design the conceptual framework of an agent-based simulation model. These survey results, along with information found in the literature and publicly available data regarding the Nepal response, were used to build a well-informed simulation model.

3.1 Justification for Survey

A wealth of information regarding the Nepal earthquake response has been publicly shared and updated since early after the disaster occurred. While these data give a relatively detailed depiction of the who, what, when, and where surrounding the response, better known as 4W Analysis, the fifth W, the *why*, is more difficult to find publicly. The main reason for this may be that establishing why an NGO chose to provide a certain type of relief is often not asked. Neither is it asked why a relief provider would choose to serve one population over another. These questions remain unasked and go unanswered for many reasons, a main one being that donors do not often require this level of transparency.

It could also be that those collecting data may see their needs assessments as obvious to the average person. For example, if district X needs 10,000 pounds of rice, it should be inferred that there is a significant number of people in that location without food. While this may be obvious, other important information may not be clear or may be missing. To add to our example, perhaps district X has enough food to sustain the original population, but needs extra food due to mass migration into the district. This information is vital as it affects all clusters' decisions as well as the needs of neighboring districts.

Another reason the fifth W my go unreported is that time simply does not allow for that level of detail in data collection. Some pieces of information are so time sensitive that even the few extra hours it may take to collect more granular data could drastically change the outcome for beneficiaries, such as in urban search and rescue (USAR) efforts [63]. In the case of Nepal, while the revised Flash Appeal [1] released a wealth of information regarding why certain initiatives were needed, this style of reporting gives a broad overview of the aggregate response, versus the decisions made at the individual organization level.

The other aspect of humanitarian aid that one cannot easily decipher from hard data is the *how*. Unless humanitarian workers are specifically interviewed on their methodology, or there is a publicly available guidebook describing how field personnel should make decisions (such as [5, 7]), the rationale behind some decisions may seem rather opaque. Due to the chaotic nature of emergencies, many humanitarian operational processes are not standardized. For instance, shipping standards practiced in the transportation industry that ensure quality and efficiency are often unable to be implemented in emergencies due to damaged roads and infrastructure or lack of resources. A notable exception is the set of minimum standards regarding human rights issues agreed upon by humanitarian organizations and stated in the Sphere handbook [64], and the newer Core Humanitarian Standard [65]. Nevertheless, the lack of technical and operational standards make it difficult to quantitatively model the rationale behind an individual organization's decision making process. In order to better inform both the *why* and the *how* in a simulation model, it was appropriate to collect firsthand data from humanitarian decision makers themselves.

3.2 Overview of Survey

An online survey (included in the Appendix), was administered through Qualtrics. The overall goal of the survey was to obtain information about the trade-off between equity and efficiency in practice, the facility location problem, and coordination strategies and challenges from the humanitarian organization perspective. The survey was designed to ask questions of these specific topics, along with general humanitarian decision making strategies, to complement what was discovered in the literature.

The survey consists of six sections, including demographic information; temporary facility planning and placing; motivations behind decision making; coordination practices, challenges, and desired attributes of collaborators; data collection and analysis methods; and a scenario-specific section that combines two or more of the above topics together. These topics are addressed through rank-based, short answer, multiple choice, and open-ended questions. Most questions include an *other* option where respondents could write in their desired answer if it was not an option in a multiple choice or ranking list.

3.3 Respondent Characteristics

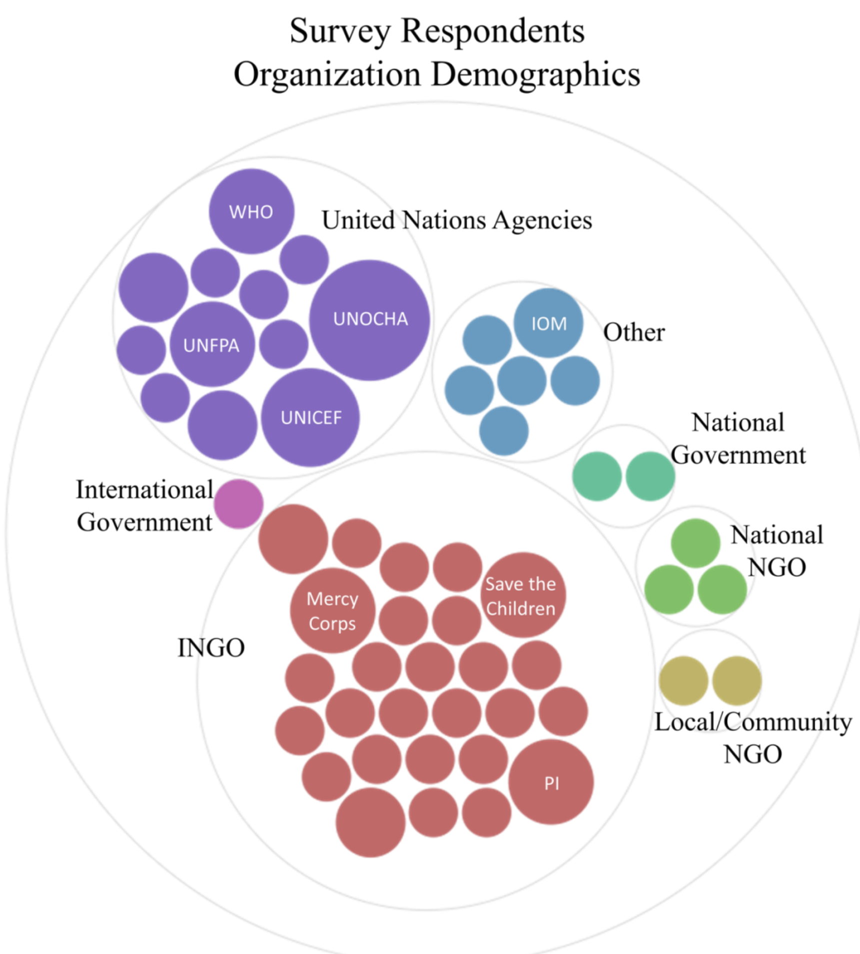

Figure 4: Type of respondents to humanitarian survey

This survey targeted international humanitarian workers who were currently active in the field at the time of contact. Exactly 1,016 potential contacts were gathered from the open-source website humanitarianresponse.info, which gathers reports, relevant data, and major points of contact within the cluster system for several ongoing response efforts. Of these contacts, 100 people opened the survey link and thus were given an identifier; 87 of these answered at least one question. The lowest response rate to a question was 41 people. Two types of questions received the lowest response rates: qualitative, open-ended questions near the end of the survey, and questions that were only asked if the respondent had answered in the affirmative to a previous question (i.e, conditional logic was used). Apart from these two question types, all other questions had between 61 and 87 responses.

Over 50 organizations and a wide range of agency types were represented in the responses, shown in Figure 4. Those in the *Other* category identified their organization type as intergovernmental, church affiliated, or a social or private enterprise. Respondents had various job titles or roles, some of which identified as: Program Officer, Field Staff, International Consultant, Analyst, Child Protection Officer, Director of Operations, Education Cluster Coordinator, and many more.

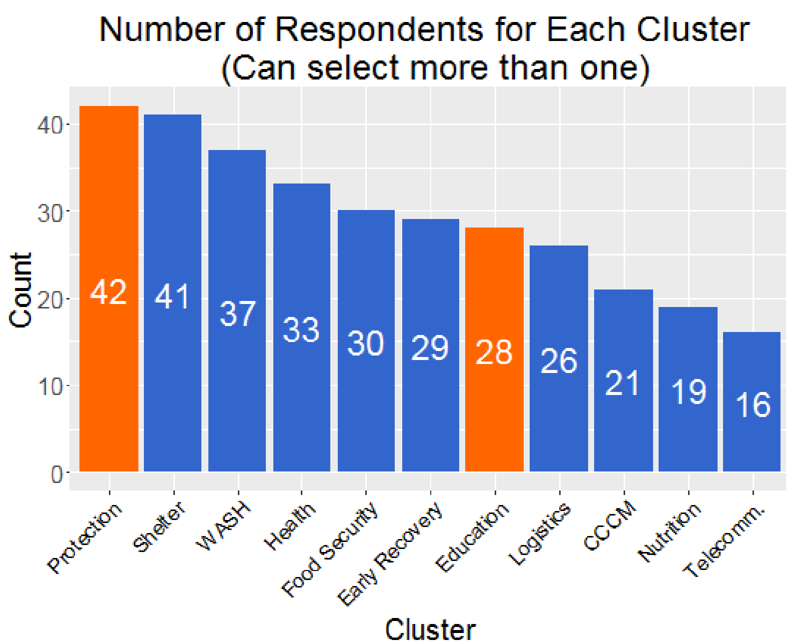

Figure 5: Clusters with which respondents are associated

Figure 5 shows that there is a good representation of all 11 clusters. While the survey was geared toward education and child protection, respondents were certainly not limited to just these particular clusters. Due to the high nature of cluster overlap, it makes sense that some of the respondents are affiliated with several different clusters.

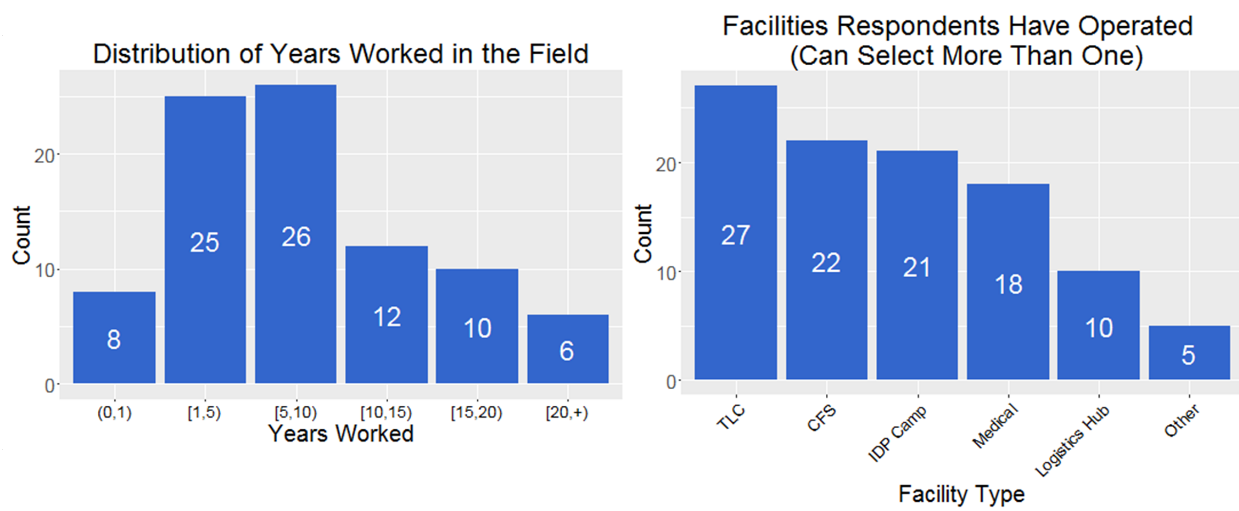

Figure 6: Other characteristics of survey respondents

The survey data also show that respondents are fairly experienced in the humanitarian logistics field in general and with establishing facilities in particular. The histogram in Figure 6(a) illustrates a wide range in years of field experience among respondents. This plot expresses number of years in mathematical notation, where $[5, 10)$ means that respondents have worked between five years inclusively and ten years exclusively. Figure 6(b) summarizes the types of facilities that respondents had established.

3.4 Connection to Simulation Model

The literature reviewed in Chapter 2 has shown that there are a vast number of topics that are relevant and influential in decision making for humanitarians. This survey was used to help narrow that broad range of topics to a few specific elements that could be used in the modeling process. The questions geared toward equity and efficiency in decision making were the most important findings from the survey used to influence the conceptual design of the simulation model. As Figure 7 shows, factors such as effectiveness, efficiency, and equity are regarded with higher importance by more respondents than autonomy, centralized decision making, and having a coordinating body make most decisions. Having this knowledge influenced the framework of the model in that the agents modeled would follow rules focused more on efficiency and fairness rather than following rules that allowed agents to remain autonomous. Essentially, organizations in the model would operate in a more selfless way, meaning that they are not selective about whom they are coordinating with, whether they are giving or receiving help when collaborating, or if information is being spread in a centralized or decentralized manner.

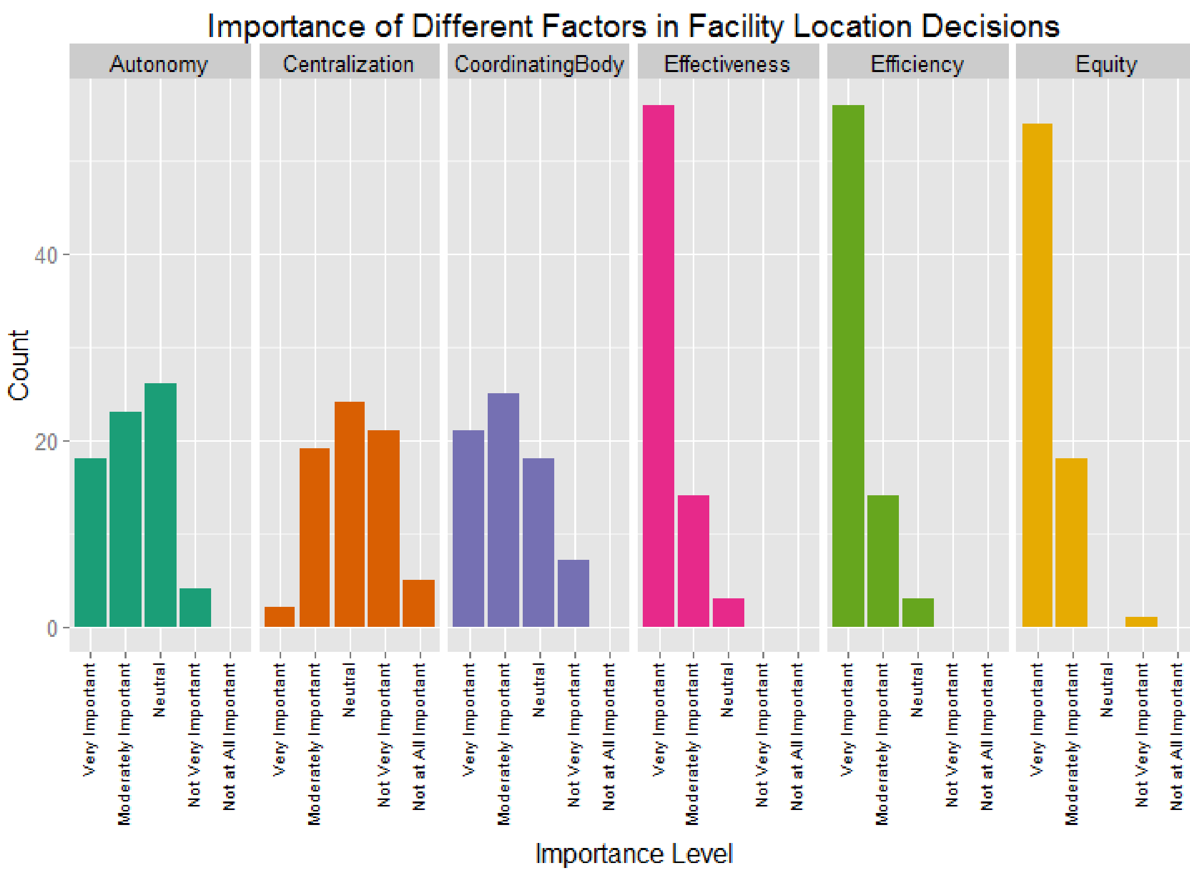

Figure 7: Importance of factors in decision making

One question examined the importance of effectiveness, efficiency, and equity specifically in the context of a child-centric facility; it received 48 responses. The respondents were asked to rank

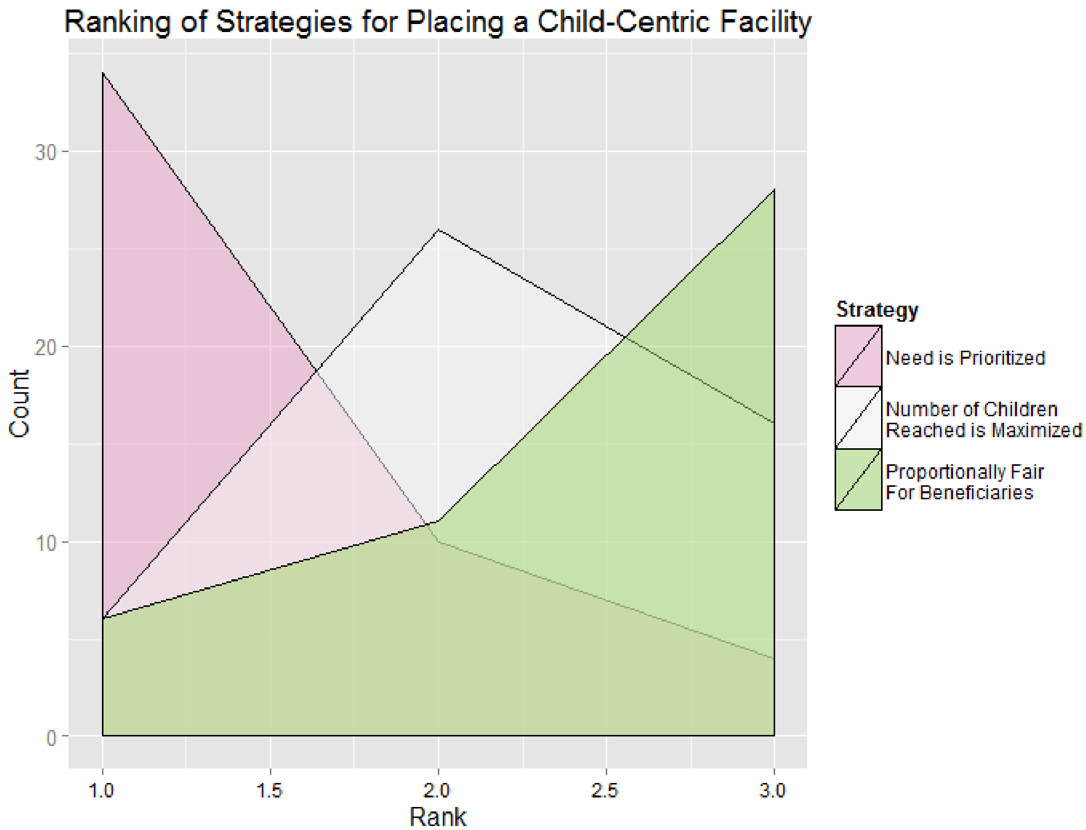

Figure 8: Results of scenario-based ranking question

three different strategies focused on effectiveness, efficiency, and equity, respectively, for placing a facility such as a CFS or TLC. The graph in Figure 8 shows that placing the facilities in a way where those who need it the most are prioritized (effectiveness), is the highest ranked among the three choices, followed by maximizing the number of children reached (efficiency), and finally placing a facility in a way that is proportionally fair for beneficiaries (equity). In that sense, we see that effectiveness is highest rank, efficiency second, and equity third. The nonparametric Friedman rank sum test was used to assess whether there is a significant difference between any of the three factors. The test found that at the 95% confidence level, there is indeed a significant difference between at least two of the groups ($\chi^2 = 35.38$, df= 2, $p < 0.0001$). Using Dunn's test, however, to make pairwise comparisons with a Bonferroni adjustment showed that it cannot be concluded that the

Table 1: Results of Dunn's multiple comparison test with Bonferroni adjustment

	Need is Prioritized	Children Reached is Maximized	Proportionally Fair
Need is Prioritized	-	4.84, $p < 0.0001$	6.88, $p < 0.0001$
Children Reached is Maximized	4.84, $p < 0.0001$	-	2.04, $p = 0.083$
Proportionally Fair	6.88, $p < 0.0001$	2.04, $p = 0.083$	-

last two groups, that is maximizing the number of children reached and placing a facility in a way that is proportionally fair, are significantly different in means (at the 95% confidence level). These results are shown in Table 1 with the test statistic and corresponding $p-$value for each comparison. Essentially this question shows that these respondents specifically value effectiveness most when it comes to establishing facilities for children, and equally value efficiency and equity.

4 Simulation Methodology

The first three chapters demonstrate a need for further study into decision making strategies and coordination between humanitarian relief providers. This chapter introduces an agent-based modeling framework for investigating these issues in the context of post-disaster child-centric temporary facility placement. The model description contained in this chapter follows the “ODD” (Overview, Design Concepts, Details) protocol, developed by Grimm et al. [66, 67] to promote standard reporting in the field of agent-based modeling.

4.1 Overview

This model was created in AnyLogic 7.3, a simulation software that supports discrete event, agent-based, and system dynamics simulation [68]. The run-time of the model is approximately 5 seconds on average.

4.1.1 Purpose

This model examines the interaction and coordination between humanitarian organizations following a disaster. The goal of building this model is to better understand how individual decisions made by organizations could affect coordination on a broad scale. Specifically this model examines how both geographic location and information sharing strategies can influence the efficiency, equitability, and effectiveness of the overall response to address post-disaster educational needs of children.

4.1.2 Entities, State Variables, and Scales

There are two main types of agents in this model; the first type are the organizations involved in establishing TLC and CFS services (organizations from other clusters, such as Health or Nutrition, are excluded). Secondly, populations of children are also considered agents, either through the schools with which they were previously connected before the disaster, or the internally displaced person (IDP) camps to which they have moved. Ultimately the two agent types represent supply

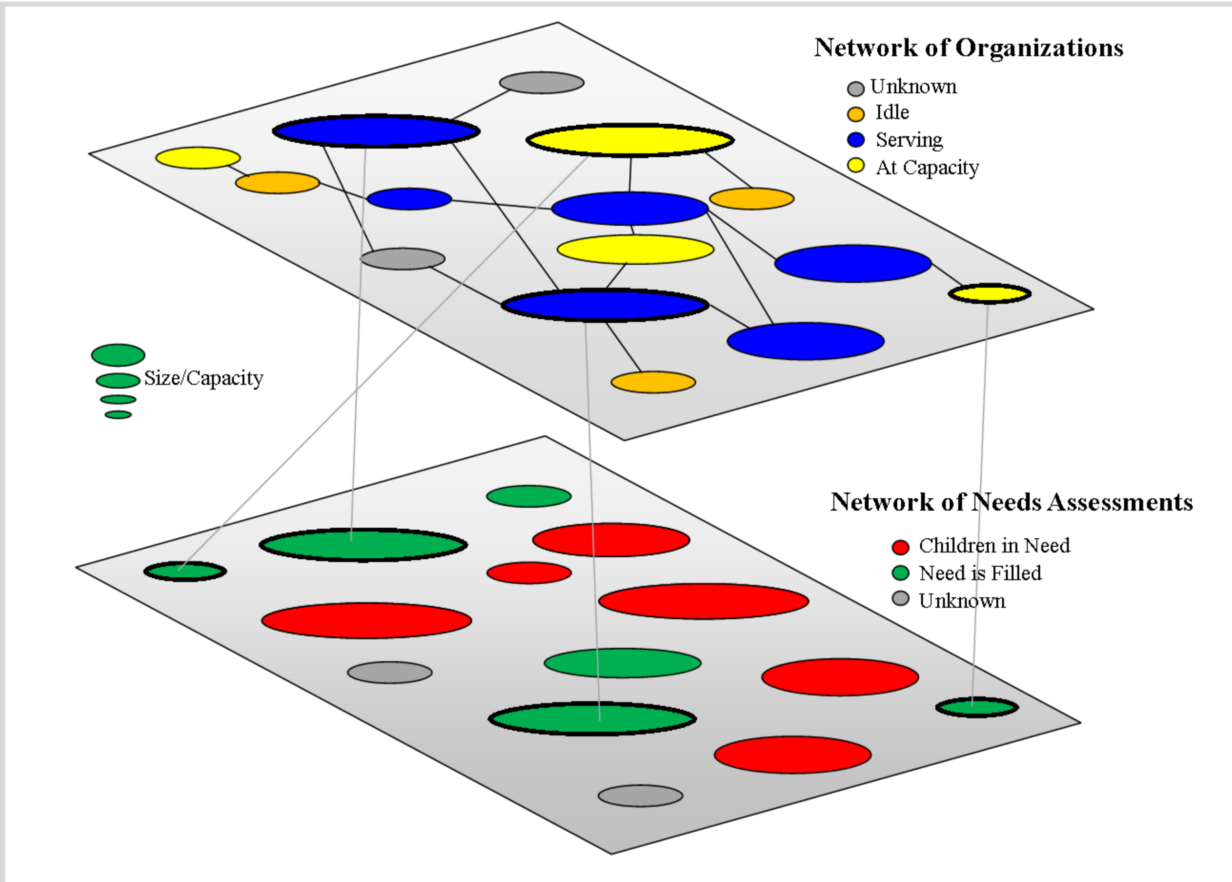

Figure 9: Visualization of agent networks in the model

and demand in the model; the organizations that establish TLC and CFS services are the suppliers, while the populations of children in need represent demand.

These agents' state variables are best represented visually through a two-layered network, as illustrated in Figure 9. The top layer comprises the network of organizations, where their size and color represent their state variables. The node color represents the agent's current *status*, and changes dynamically throughout the simulation. Agents colored gray are *unknown* and have yet to arrive in the system, orange agents are *idle*, meaning they have arrived, but are not yet serving. Agents that are blue are *serving*, and yellow agents are serving *at capacity*. The size of the circles representing agencies corresponds to the size or capacity of a given organization, defined as the number of facilities they have the means to establish. These organizations also have a state variable that determines their collaborative nature. The variable *strategy type* is a binary variable, where agents that never try to collaborate have a value of zero, and agents that are open to collaboration have a value of one. Of those that do collaborate, they have another parameter called *take probability*, which corresponds to the probability with which they will seek to collaborate when given the opportunity. All of these variables are summarized in Table 2. Note that only agents with strategy type of one seek out collaboration, while both types can accept requests for collaboration.

The bottom layer depicted in Figure 9, or the needs assessment layer, is the representation of the geographical space in which populations of children exist. Like the top layer, size and color represent the two main variables of these agents. The first variable represents the status of the need, where the agents initially have gray nodes and are *unknown*, and become *in need* red nodes as their needs become known. As services are provided to the red nodes, they become green and enter the state *need filled*. The second variable is an estimate of the size of the population that must be served. Also similar to the organization network, the size of the nodes represent the size of the child population in need, or *need amount*. These variables are also summarized in Table 2. Both the organization's capacity and the child population's need amount are integer values, where capacity is in the range [1,200] and need in the range [1,61]. The selection of these values is discussed further in the *Details* section.

Both agent types exist in a GIS environment, meaning their location and movement is established in physical space. Since input data are taken from the 2015 Nepal earthquakes, the main environment is created by importing a map built into AnyLogic and restricting agent placement and movement to occur only within the districts of Nepal affected by the disaster. Agents are connected to each other through links, which are established or destroyed based on physical distance from each other. The organizations' parameter *reach* determines the distance in which it can connect to the other agents (of both population types) around it. As Figure 2 shows, the organizations in the top layer have links connecting agents to each other. There are also links connecting agents in the top layer to the child populations in the bottom layer. There are no links formed between the needs in the bottom layer as these agents only communicate with organizations. If a link is established between a child population and an organization, the child population can send its need

Table 2: Description of agents' state variables and parameters

Agent Population	Variable Name	Values	Description	Type
Organizations	Status	Unknown	Agent has yet to arrive in the system	Initial State
		Idle	Agent has yet to establish a facility	State
		Serving	Agent has established at least one facility	State
		At Capacity	Agent has established as many facilities as they have the capacity to do so	Absorbing State
	Capacity	$[1, 200]$	The number of facilities the agent has the ability to establish	Numeric double (Random)
	Strategy Type	$[0, 1]$	0 if: agent is not collaborative 1 if: agent is collaborative	Numeric binary
	Take Probability	$[0, 1]$	The probability with which an agent will ask for a collaborator when faced with the decision	Numeric double
	Reach	$[5000, 6500]$	The distance in which organizations can form a link to another agent	Numeric double (Random)
Needs	Status	Unknown	The needs of the population are not yet assessed	Initial State
		In Need	The population has been assessed and the need amount is known	State
		Need Filled	The need has been met by agent(s) in the organization network	Absorbing State
	Need Amount	$[1, 61]$	The amount of facilities needed for a particular population	Numeric double

Table 3: Description of global variables and parameters

Variable Name	**Values**	**Description**	**Type**
Organization Arrival Rate	5 per day	Number of Organizations arriving per day	Rate
Assessment Rate	10 per day	Number of Child Populations' needs assessed per day	Rate
Search	$[-0.5, 0.5]$ degrees	The range in latitude and longitude in which organization agents can move from their current position	Numeric double (Random Variable)
Impatience Rate	Twice a month	The rate at which organization agents will leave their current area to search for needs to fill	Rate
Contact Rate	1 per day	The number of organization agents a child population will contact within their network per day	Rate

information to the organization. The organization can fill the need, pass the information to other connected agents, or ask one of them to collaborate, depending on their rules. This process will be discussed further in the *Process Overview and Scheduling* section.

Other global variables and parameters are shown in Table 3. The *organization arrival rate* describes the rate at which organizations arrive to the system, and the *assessment rate* is the rate at which child populations' needs become known. These rates represent the transition time from *unknown* to *idle* for organizations, and *unknown* to *in need* for child populations. The *search* parameter represents the search space in which organizations can move and look for work; agents' movements are random variables drawn from a uniform distance with this range. Paired with the search parameter is the *impatience rate*, or the rate at which organizations become impatient with their current location and decide to move somewhere else. The reason for moving is due to lack of incoming messages from the child needs population. Finally, the *contact rate* is the rate at which the needs population, once in the state *in need*, ask a random organization within their network to fill their need.

Time in the simulation is measured in days, and runs from the start of the earthquake to the day where the dataset that is used in this analysis was published, that is 25 April 2015 until 19 January 2016, a total of 269 days. Time step length is not specified in the model, but rather is event-driven, where events include sending or receiving messages or an agent transitioning states.

4.1.3 Process Overview and Scheduling

The model processes can be conceptualized at a high level using Figure 10. As child population needs become known, messages are randomly sent from these agents to those they are connected to in the organization population. The organizations' rules differ based on their coordination strategy type attribute. Agents of strategy type zero (non-collaborative type) accept any need that they have the capacity to serve, otherwise they pass the need information to another organization in their network.

Agents of strategy type one (collaborative type) perform different actions depending on what type of message is received. If they receive a direct message from the needs population or a passed message from a fellow organization, they examine the need amount compared to their own capacity and do one of the following:

1. If at capacity, they pass the need.
2. If the need is sufficiently small (need $= 1$) and they have the capacity to fill it, they do so.
3. If the agent does not have the capacity to take on the full amount of the need, they ask a fellow organization to collaborate, meaning they split the need.
4. If the need is of sufficient size (need > 1) and the agent has the capacity to take it, they accept the need with *take probability* k or ask for others to collaborate with probability $(1 - k)$.

Upon receiving a collaborative message from a fellow organization, these agents follow the same rules as those of strategy type zero. For this research, "sufficiently small" is a child population with need $= 1$, meaning a single facility is needed. This value was chosen because it is the smallest amount of need in the model that any one organization can provide, and therefore it would not be possible to split the need with a collaborator.

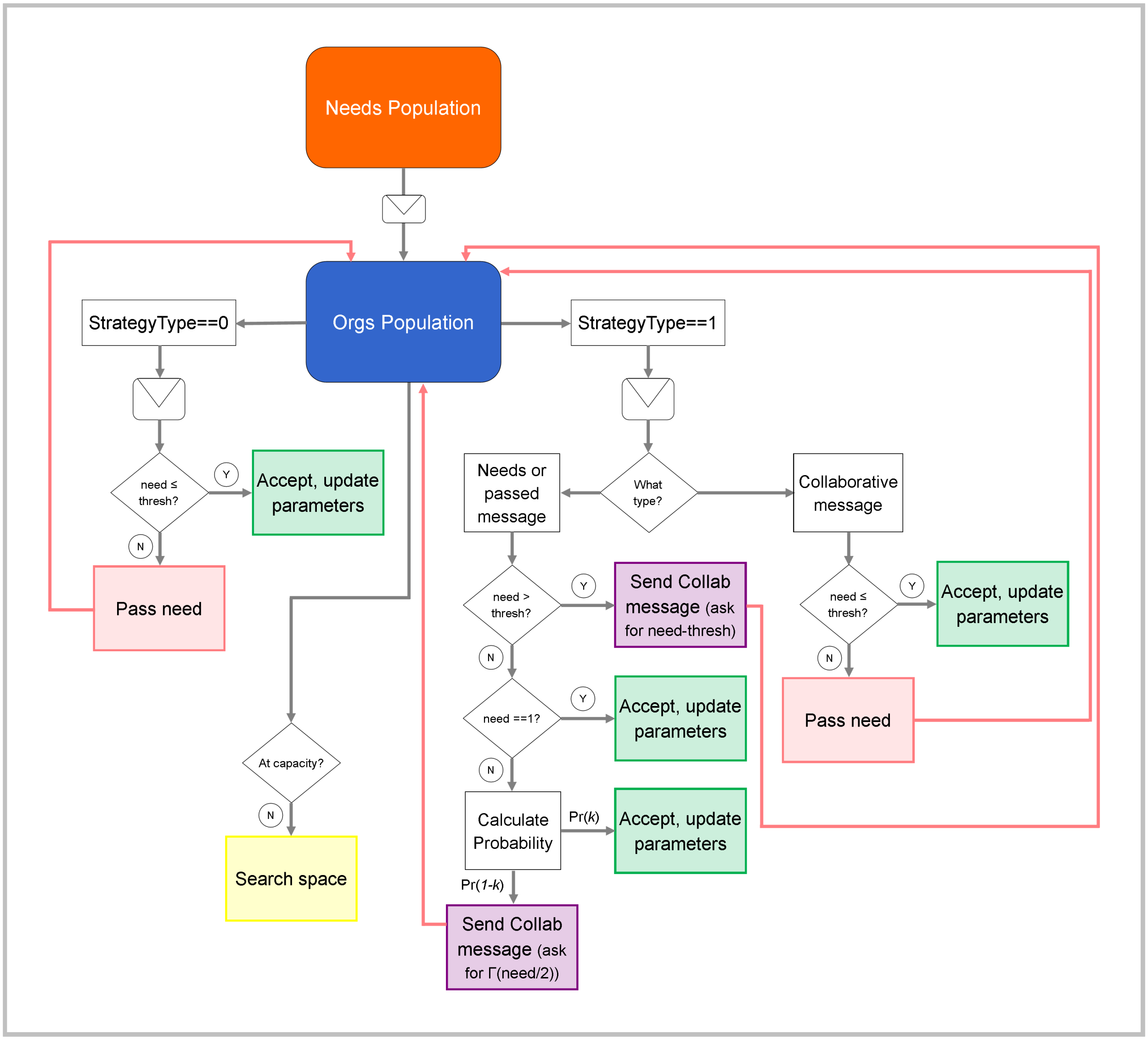

Figure 10: Flowchart of simulation model

All organizations who are not at capacity move through the GIS environment looking for populations to serve. This process, along with the main agent rules and interactions, will be discussed further in the *Details* section. This model has time units measured in days and the only scheduled events are triggered by arrival and transition rates. Other events are triggered by conditions or through the sending of messages. These will also be explained further in the *Details* section.

4.2 Design Concepts

The design concepts of this model are summarized in Table 4. Out of the 10 comprehensive design concepts developed by Grimm et al. [66, 67], the most important elements to this model include emergence, adaptation, objectives, sensing, interaction, stochasticity, collectives, and observation.

4.2.1 Emergence

Emergence is perhaps the most emphasized design concept for an agent-based model, and refers to a pattern or behavior that occurs due to how agents change and evolve throughout the simulation. For this model, it is difficult to distinguish between what is considered emergent and what is imposed, or enforced based on parameter settings and experiment rules. For instance, agents forming collaborations could be considered emergent since some agents' rules allow them to adapt and seek help to fill needs. However, given how the some parameters are set, agents may be forced to always seek collaboration, meaning the number of collaborations would be imposed. The clearer emergent behavior is geographic disparity that emerges due to the organization agents' initial geographic layout.

4.2.2 Adaptation

In agent-based modeling, *adaptation* is defined as agents changing their rules or strategies during the simulation due to changes in the environment or through interacting with other agents. In this model, organizations adapt as their states change. The biggest adaptation is how their rules change when they reach capacity, in that they receive messages differently and no longer move around in

Table 4: Design concepts of the model

Variable Name	Description
Emergence	- Geographic disparity across districts - Number of collaborations formed
Adaption	- State changes for agents - Exploring the space
Objectives	- Organizations try to reach capacity - Certain organizations want to form collaborations - Child populations try to get needs filled
Sensing	- Agents sense other agents in their vicinity - Links are formed and destroyed through sensing
Interaction	- Agents communicate through links - Interactions may be direct or indirect
Stochasticity	- Initial geographic layout of both agent types - Agent movement - Random variables used for some parameters - Message recipients (partially random)
Collectives	- The number of needs populations for each district - Collaborations
Observation	- Utilization - Amount of need filled - Total number of collaborations - Geographic disparity

space. Agents that are not yet at capacity adapt to their surroundings each time they search the space looking for work. The child population agents only adapt through state changes.

4.2.3 Objectives

An agent's *objective* is its purpose or goal in the model. The organization agents' objective is to find work and utilize their full capacity. Some may also have a goal of collaborating frequently, depending their strategy type. As mentioned previously, this is motivated by the reduction in risk when sharing a project. Needs agents only have the goal of getting their need filled. Measures of these objectives include organization utilization, total number of collaborations, and total number of needs met.

4.2.4 Sensing

Sensing in an ABM can refer to any information that an agent intrinsically knows, or is able to find out given the time or its position in space. For example, both agent types in the model can sense when other agents are in their vicinity. This sensing establishes a link in their individual networks. As agents move through space, links are created and destroyed based on agents' distance from others, using the global *reach* variable defined previously.

4.2.5 Interaction

In agent-based modeling, *interaction* can represent both how agents communicate and interact to each other, as well as how they interact with their environment. In this model, it is necessary for a link to exist between two agents for them to directly interact with each other. Agents communicate by passing messages to one another through these links. The child populations pass their needs messages to organizations with which they are connected, and these organizations can pass the message along to others or pass and receive collaborative messages. Due to this type of message passing, it is possible to have indirect interactions, meaning an organization can fill a need of a child population to which they are not connected by a link, or two organizations can collaborate together even if they are not connected.

4.2.6 Stochasticity

Stochasticity refers to any parameters, variables, or other component that has randomness incorporated in its definition. Another way to look at stochasticity is anything that could change from simulation run to simulation run that is not part of the experimental design. For this model the initial layout of the organizations is random, along with the layout of needs (the number of needs for each district is known, the actual layout within each district is random). The organization variables *capacity* and *reach* are random variables with specified distributions, as is the global variable *search*. Finally, any agent that sends a message randomly chooses an agent in its network to receive the message.

4.2.7 Collectives

A *collective* of an agent-based model can be defined as any group or collection of agents that either emerges or is imposed in the model, with the latter meaning the collective is part of the original design. Collectives in this model are the different districts of Nepal in which child populations exist, that is, each district is its own collective made up of the needs agents that exist inside of it. Organizations that form collaborations are also considered collectives.

4.2.8 Observations

The last main design concept important to this and any agent-based model are the observations. These are usually the output statistics or datasets to be collected from the simulated experiment. The output statistics in this model include the ratio of filled to total need at the end of the simulation run, the number of collaborations formed, geographic disparity between districts, and individual organization utilization. In this case, these metrics can also be considered evidence of emergent behavior if their values depend on results from agents' adaptations.

4.3 Details

The final section of this chapter goes into detail about how the model is built and how it may be replicated by stating the initialization conditions, input data used, and submodel descriptions.

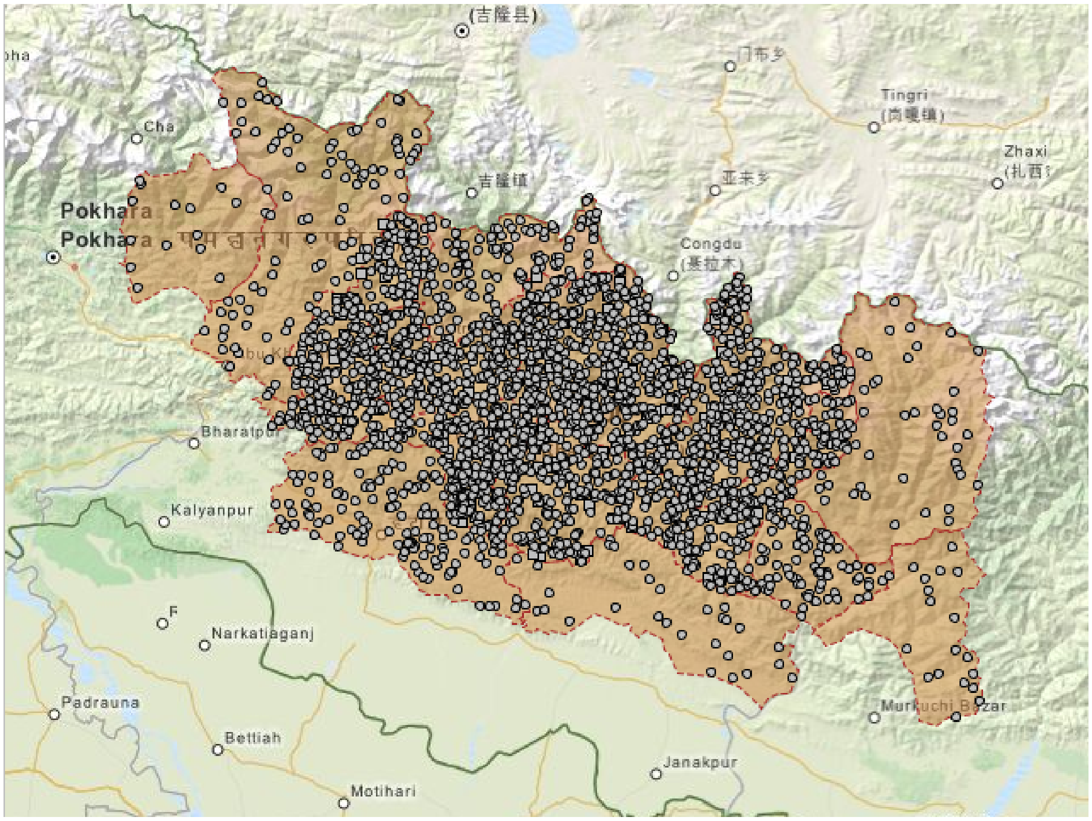

Figure 11: Initialization of child population agents' layout

4.3.1 Initialization

The most crucial component to the initialization of this model is the geographic layout and network of the agents, shown in Figure 11. For each of the 17 affected districts, the number of agents is equal to the exact number of needs populations found in the published data [69]. In the absence of geographic location data for needs populations in Nepal, the placement of the agents within each district for the model is random. As for the population of organizations, these agents are also placed randomly on the map, based on the layout strategy that is being tested. The three initial layout structures are defined as:

- Layout 1: Initial location of organizations is uniform across all 17 affected districts
- Layout 2: Initial location of organizations is uniform across the 14 priority districts, established by cluster leads in the Nepal Flash Appeal [1]

- Layout 3: Initial location of organizations is uniform across the eight most affected districts

Locations of all agents are set in the initialization. The initial states of both agent types are *unknown*, meaning needs have yet to be assessed and organizations have yet to arrive. Organization capacity and initial child populations' need amounts are set upon initialization. The simulation start date is set to the date of the first earthquake, 25 April 2015.

4.3.2 Input Data

All of the input data used in the model are taken from data published in the humanitarian information sharing platform `HumanitarianResponse.info`. Nepal's Education Cluster published their final 3W (who, what, and where) analysis on 19 January 2016, listing all of their activity since the beginning of the response until year end [69]. Some model parameters are informed by this dataset, while assumptions about other parameters are required. In cases where there is not sufficient data, parameters are calibrated for the model based on certain system features.

Parameters Informed by Data

As mentioned above, the total number of needs populations are entered directly for each district from the given count data [69]. The *need amount* parameter that specifies the number of facilities needed in the district is informed through a column in the dataset indicating how many TLCs or CFSs were targeted for each population of children. The distribution of facilities was found to vary across districts and across populations within those districts, as Table 5 shows. Due to large differences in needs both between and within each district, the *need amount* parameter for each needs population agent was informed deterministically rather than randomly. However, as stated previously, these agents' actual location within the district is random. For example, the district of Bhaktapur has 41 agents randomly spread out across the district representing needs populations. Each of these 41 agents has their own deterministic need amount, which sums to 91 total facilities.

Similarly, the capacity parameter for the organization agents is fit using the same Education Cluster 3W analysis dataset [69] The cluster report contains three columns representing different roles of organizations in establishing a facility, specifically, reporting organization, project owner,

Table 5: Information used to inform *need amount* parameter

District Name	Number of Facilities	Number of Needs Populations
BHAKTAPUR	91	41
DHADING	459	300
DOLAKHA	483	358
GORKHA	178	91
KATHMANDU	218	96
KAVREPALANCHOK	338	187
KHOTANG	18	18
LALITPUR	260	113
LAMJUNG	18	15
MAKWANPUR	170	143
NUWAKOT	466	242
OKHALDHUNGA	110	84
RAMECHHAP	277	237
RASUWA	178	117
SINDHULI	40	30
SINDHUPALCHOK	834	455
SOLUKHUMBU	54	43

and implementing partner. For a given location, each column lists one to three organizations (and occasionally zero for implementing partner), along with a column specifying the number of facilities targeted. For instance, suppose project owner UNICEF, partnering with Plan International (PI) and having Finn Church Aide (FCA) designated as the reporting organization, had a target of establishing 18 temporary learning centers in the district of Bhaktapur. Then the capacity of each organization is determined by dividing the target (18) by the number of organizations (three), yielding a capacity of six for each.

Some organizations worked in only one district, while other much larger organizations worked in several of the affected districts. A separate agent is created for the same organization in different districts. Therefore instead of thinking about agents as UNICEF or PI, it is more appropriate to view them as UNICEF(Bhaktapur) or PI(Dhading). Using this method yields a total of 218 agents with the following summary statistics for agency capacity:

Min	1st Quartile	Median	Mean	3rd Quartile	Max
0.25	4.67	11.33	19.23	23	200

A probability distribution is generated for this parameter using MathWave EasyFit [70]. While no distribution fits extremely well, the Lognormal distribution was found to be suitable with $\mu =$ 02.3996, $\sigma = 1.1007$. A chi-squared goodness of fit test finds that at a Type I error rate of 0.05, the alternative hypothesis (see below) is accepted ($\chi^2 = 15.662$, critical value = 14.067 $p = 0.028$, df = 7). However, the Kolmogorov-Smirnov nonparametric goodness of fit test yields a test statistic = 0.0801, compared to a critical value of = 0.0920 and corresponding $p = 0.116$, meaning the null hypothesis cannot be rejected. Therefore the Lognormal distribution is accepted to be implemented in the model. However, the distribution is rounded to produce integer values since a whole facility must be established in order for the need to be met.

Null Hypothesis (H_0):	The Lognormal distribution is a good fit for the data
Alternative Hypothesis (H_A):	The Lognormal distribution is not a good fit for the data

Calibrated Parameters

Some of the parameters do not have robust data with which to inform or validate the model, so they are calibrated such that a similar amount of need is met over the given time of the simulation as that of the actual response. Such parameters include the arrival rate of the organizations and the needs assessment rate. These are calibrated so that all agents would in fact arrive in the system early in the simulation. This is justified since none of the output statistics of interest are time-based, and in order to examine agent interaction, it is crucial that all the agents are present for the majority of the simulation.

The contact rate, or the rate with which the needs layer sends messages to organizations in its network, is calibrated in a way that makes intuitive sense. Once a need is assessed, the population asks for help from one of the agents in its network every day until the need is met. This contact rate also leads to a ratio of needs filled to total need that is relatively close to the actual response.

Finally, the organization movement parameters including *reach*, *search*, and the *impatience rate* are calibrated to fit the model based so that the ratio of needs filled to total need was similar to that of the actual Nepal response. Using this method essentially resulted in a reach distance that allows agents to have enough connections to pass information and make collaborations, but not so many connections where the needs of the entire population is met.

4.3.3 Submodels

Most of the submodels discussed in this section are more detailed descriptions of the processes introduced in Section 4.1.3. Refer to Figure 10 for a broad overview of the process as whole.

Establishing Links in the Network

Organizations in the model are initialized in the state *unknown*, meaning they have yet to arrive in the system, although their initial destination is already known. They arrive at a rate simply known as *agent arrival rate*, and enter the state *idle*. It is upon entering this state that the organizations first establish their network based on their distance from other agents. Figure 12 shows a visualization of this process. Notice that the square organization agents have connections only if they are orange. This means they are currently in the state *idle*. Those that are white have not arrived yet. The circles represent needs, and they are either gray (*unknown*) or red (*in need*). While it is the organizations that establish the links, it is up to the needs to send initial messages to these agencies.

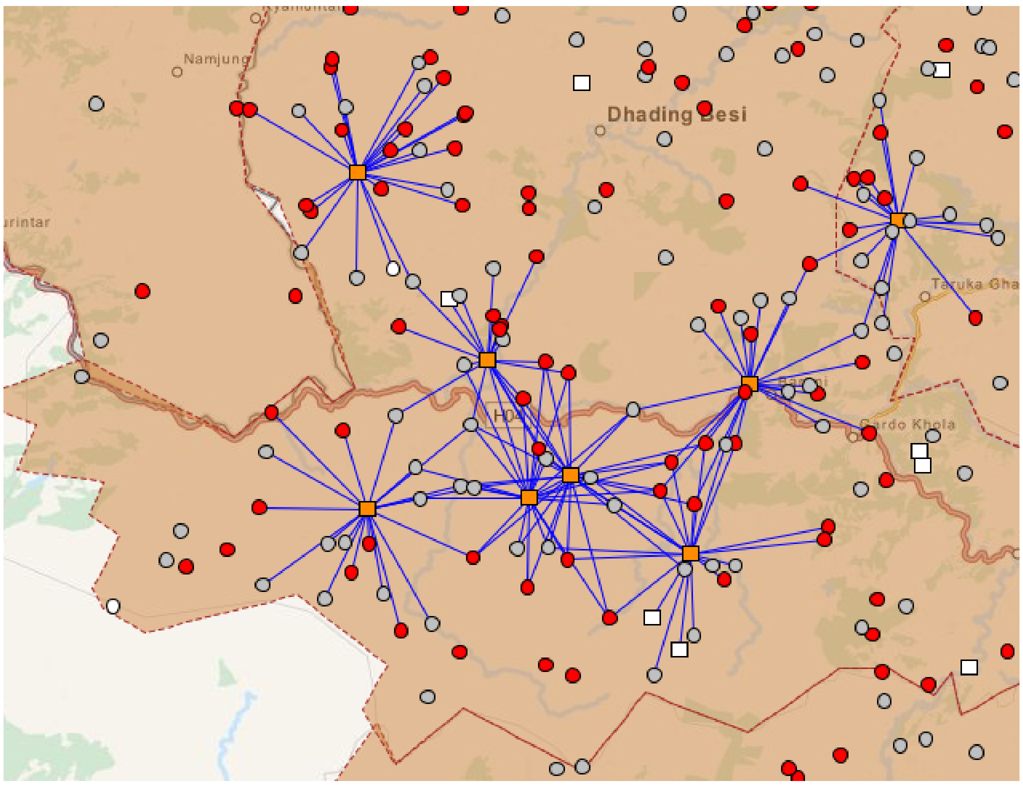

Figure 12: Distance-based network for organizations that have arrived

Message Passing

The message passing system is the most complex aspect of the model, mainly because it includes the logic for most of the organizations' decisions. The needs populations enter the system as *unknown*, but become *in need* according to the needs'*assessment rate*. Once they are in this *in need* state, they send messages randomly to organizations with which they are connected. Based on their strategy type, the agents follow one of two processes. If the organization is of strategy type zero, it follows Process Pseudocode 1. Agents of strategy type one receive the same type of messages, but follow slightly different rules as outlined in Process Pseudocode 2.

Notice that depending on the message type received, the message itself has different components. If the message is an original needs message or a passed message, the only information given is the need amount and an identifier describing which agent the need belongs to. However, if the message is collaborative, rather than receiving the direct need amount, the agent receives the amount that the partner is asking for, the amount the partner is willing to take, and the ID of both the original need and the partner organization.

Upon receiving a message, an organization then goes through its decision process shown in the main step. It first calculates its own threshold, which is its original capacity minus the number of needs it has already filled, and then compares this value to the amount that is being asked for. Whether or not it accepts the need is dependent on the strategy type of the given agent. If the agent does decide to fill the need, the need amount of the child population with which it is filling is immediately reset to zero, and the threshold of the organization is updated as well.

Agent Movement

The last major submodel involves the agent movement. Organizations that are in either the *idle* or *serving* states, basically those that are not yet operating at capacity, have an internal rate that does not let them stay in one spot for an extended period without filling a need. This rate is called the *impatience rate*, and is the same for all organizations in the system. When triggered, the agent will generate a random set of coordinates within a certain radius of its current location, based on the global variable *search* radius. It is important to note that even though agents start out in a certain district, they are not limited to staying in that district, but they cannot go beyond the 17 affected districts. This last statement is significant because it is the same for all simulation runs, regardless of the layout type agents were placed in on initialization. This means that if agents were limited to only the eight districts with the most need, they can still move to any of the other districts once they become impatient.

Process Pseudocode 1: - *For Strategy Type* == 0

```
Message Received:
if (needs message or passed message)
{
  needs message = passed message = {needAmount, needID};
}
elif (collaborative message)
{
  collaborative message = {askingAmount, needID, partnerAmount, partnerID};
}
Main Step: begin
{
  threshold := capacity−TLCcounter;
  if (needs message or passed message)
  {
    if (threshold ≥ needAmount)
    {
      TLCcounter := TLCcounter + needAmount;
      needID.needAmount := 0
    }
    elif (threshold < needAmount)
    {
      sendToRandomConnected(passed needs message);
    }
  }
  elif (collaborative message)
  {
    if (threshold ≥ askingAmount)
    {
      TLCcounter := TLCcounter + askingAmount;
      needID.needAmount := 0
      partnerID.TLCcounter := partnerID.TLCcounter + partnerAmount;
    }
    elif (threshold < askingAmount)
    {
      sendToRandomConnected(passed collaborative message);
    }
  }
}
end
```

Process Pseudocode 2: - *For Strategy Type* == 1

```
Message Received: (same as Process Pseudocode 1)
Main Step: begin
{
    threshold := capacity−TLCcounter;
    if (needs message or passed message)
    {
        if (threshold < needAmount)
        {
            collaborative message := {needAmount−threshold , needID, threshold, self.ID}
            sendToRandomConnected(collaborative message);
        }
        elif (threshold ≥ needAmount)
        {
            k = uniform(0, 1);
            if (needAmount== 1—takeProbability≤ k)
            {
                TLCcounter := TLCcounter + needAmount;
                needID.needAmount := 0
            }
            else
            {
                {With probability (1 − k)}: collaborative message
                := {needAmount−threshold , needID, threshold, self.ID}
                sendToRandomConnected(collaborative message);
            }
        }
    }
    elif (collaborative message)
    {
        if (threshold < askingAmount)
        {
            sendToRandomConnected(passed collaborative message);
        }
        elif (threshold ≥ askingAmount)
        {
            TLCcounter := TLCcounter + askingAmount;
            needID.needAmount := 0
            partnerID.TLCcounter := partnerID.TLCcounter + partnerAmount;
        }
    }
}
end
```

For the sake of keeping the model run time reasonably low, the agents jump to their new location rather than moving with a certain speed, and then re-establish their connections. The amount of time it would take them to move to this new location is assumed to be absorbed in their impatience rate.

4.3.4 Conclusion

The proposed agent-based model is informed by the survey results described in Chapter 3 and by data from child-centric facilities established in Nepal. Having described the components of the model, the thesis turns to discussion of simulation results.

5 Simulation Experimental Design and Results

This chapter describes the experimental design and synthesizes the results obtained from the ABM described in Chapter 4. The main output statistics collected from the simulation highlight the key metrics discussed throughout this thesis, that is, effectiveness, efficiency, and equity. While the extent of coordination can be loosely inferred from these metrics, it is also important to know the number of actual partnerships that are formed during the simulation. These metrics of interest include:

1. Ratio of need filled to total needs (effectiveness metric)
2. Disparity between districts (spread of ratio from Measure 1) (equity metric)
3. Organization utilization (efficiency metric)
4. Total number of collaborations (coordination metric)

These statistics are generated by testing different geographic layout strategies for organizations upon initialization of the simulation, and different levels of collaborative efforts among organizations. The next subsection explicitly defines the experimental framework of the simulation, followed by the analysis of the results.

5.1 Experimental Design

Two elements are tested in this experiment. The first experiment tests three different initial geographic layouts of the organization agents. As described in the previous chapter, organizations were either placed uniformly across all 17 districts, (Layout 1) were placed uniformally across the 14 priority districts, (Layout 2) or uniformly distributed across the eight districts with the highest amounts of need, (Layout 3). Of course, while these strategies give the initial placement of organizations, the organizations are certainly not constrained to these districts. For instance, if Layout 3 is enforced, agents may still move to any of the other nine districts without the highest need, as their movement logic allows them to travel a random distance from their current location.

All the parameters described in Chapter 4 are held constant during all simulation runs, meaning aside from changes caused by stochasticity, the only parameter being tested in the experiment is

Table 6: Descriptions of collaborative treatments for experimentation

Scenario Name	Strategy Ratio (% Collaborative)	Take Probability
No Collaboration	0	-
Neutral Collaboration	0.5	0.5
Medium Collaboration	1	0.5
High Collaboration	0.5	0
Full Collaboration	1	0

the initial geographic layout of organizations. Each layout strategy is simulated 15 times, and each layout type uses the same 15 random number seed values.

The second element that is tested is the coordination aspect. While there is a level of coordination associated with all agents through their message passing logic, meaning that even if agents do not work together on a project they still pass information to each other, some agents follow more collaborative rules than others. This depends on the organizations *strategy type*, a binary value that says if agents are collaborative-seeking or not; and their *take probability*, or the probability that collaborative agents will fill a need outright instead of actually seeking a collaborative partner. Five combinations of these parameters are tested, as shown in Table 6, to examine the resulting impact on the metrics of interest. The first option is *No Collaboration*, meaning organizations are only of strategy type zero and never form partnerships. *Neutral Collaboration* means that 50% of the organizations will seek collaborations 50% of the time (in cases where the size of the need being filled is sufficiently large, or > 1). *Medium Collaboration* means that all organizations are collaborative by nature, but only seek collaboration 50% of the time. In the *High Collaboration* experiment, half of agents are collaborative and seek a collaborative partner 100% of the time the need is greater than one. And finally, *Full Collaboration* is when all agents are collaborative by nature and seek a partner 100% of the time the need is greater than one.

Similar to the geographic layout experimentation, the collaboration experiments also hold all other parameters constant and are analyzed over 15 simulation runs. The *Neutral Collaboration* type is used for the geographic layout experiments, and *Layout 2* is used for all collaboration experiments.

5.2 Analysis of Results

This section summarizes the effectiveness and equity of the actual response in Nepal, after which the simulation results are discussed.

5.2.1 Nepal Response Results

While it is contextually important to note the results of what actually happened in Nepal to show that these results are comparable to the results from experimentation, it is not appropriate to formally rank the different simulation results to the actual response using statistical analysis as the data itself was used to calibrate the model. Furthermore, note that metrics for utilization and number of collaborations are model-specific results, and are not metrics that can be calculated from the actual response.

The first metric of interest determines the effectiveness of the organizations, by measuring the amount of need they are collectively able to fill. This statistic is very useful for getting a broad view of how successful agencies were at providing services. The actual response estimated the need for 4,192 temporary learning centers or child friendly spaces, and in the almost nine months of the response, the agencies involved were able to establish 3,429 facilities, or 81.8% of their target. The maps in Figure 13 show just where these facilities were most needed, and consequently where they were established by district.

The main equity metric of interest is how well this need was filled across districts. Ideally, the need would be filled uniformly across all 17 districts, especially since it was noted that due to the multitude of aftershocks and varying population sizes, severity of need across districts was considered to be relatively uniform [1]. Geographic disparity in service is measured by examining the ratio of needs met to needs targeted across all districts, and then recording the spread of that ratio. For example, the actual response saw its highest coverage of needs of 100% in five separate districts, as shown in Figure 14. The lowest coverage existed in the district of Kavrepalanchok with

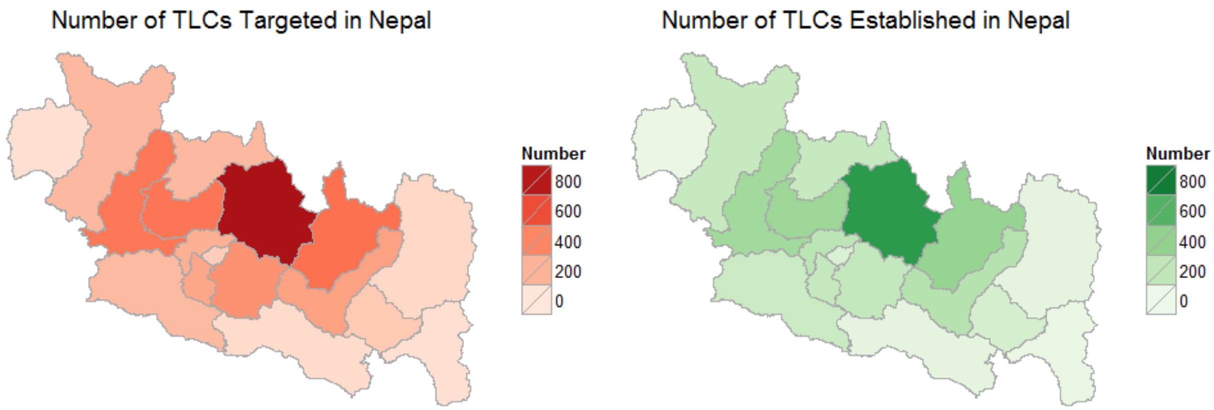

Figure 13: Maps of initial targets of educational facilities vs. actually established in Nepal

only about 55% of its targets met, that is, 186 out of 338 targeted facilities were established. The overall spread, or disparity metric, is then calculated by subtracting the highest coverage from the lowest. For the actual response, the geographic disparity was 44.97%.

5.2.2 Geographic Layout Testing

All four metrics of interest were tested by experimenting with the different initial layouts of organizations across the affected districts. These layouts are reiterated in Table 7, along with the results of the main effectiveness metric–the ratio of needs met to total targeted need. The *Needs Met* statistic for each layout type is averaged across 15 simulation runs and then the ratio is calculated. Since multiple comparisons are being made, an analysis of variance (ANOVA) test is first used to determine if there is at least one significant difference between any of the layouts in terms of effectiveness. At a Type I error rate of 0.05, the ANOVA test is significant ($F = 4.66$, $p = 0.015$, $df = 2$), meaning it is appropriate to do a formal multiple pairwise comparison of means test. Tukey's Honest Significant Differences (HSD) test [71] was chosen because it has been shown to be a fairly conservative test. This test confirms that Layouts 2 and 3 are significantly different from Layout 1 ($p = 0.026$, $p = 0.036$ respectively), but are not significantly different from each other ($p = 0.99$).

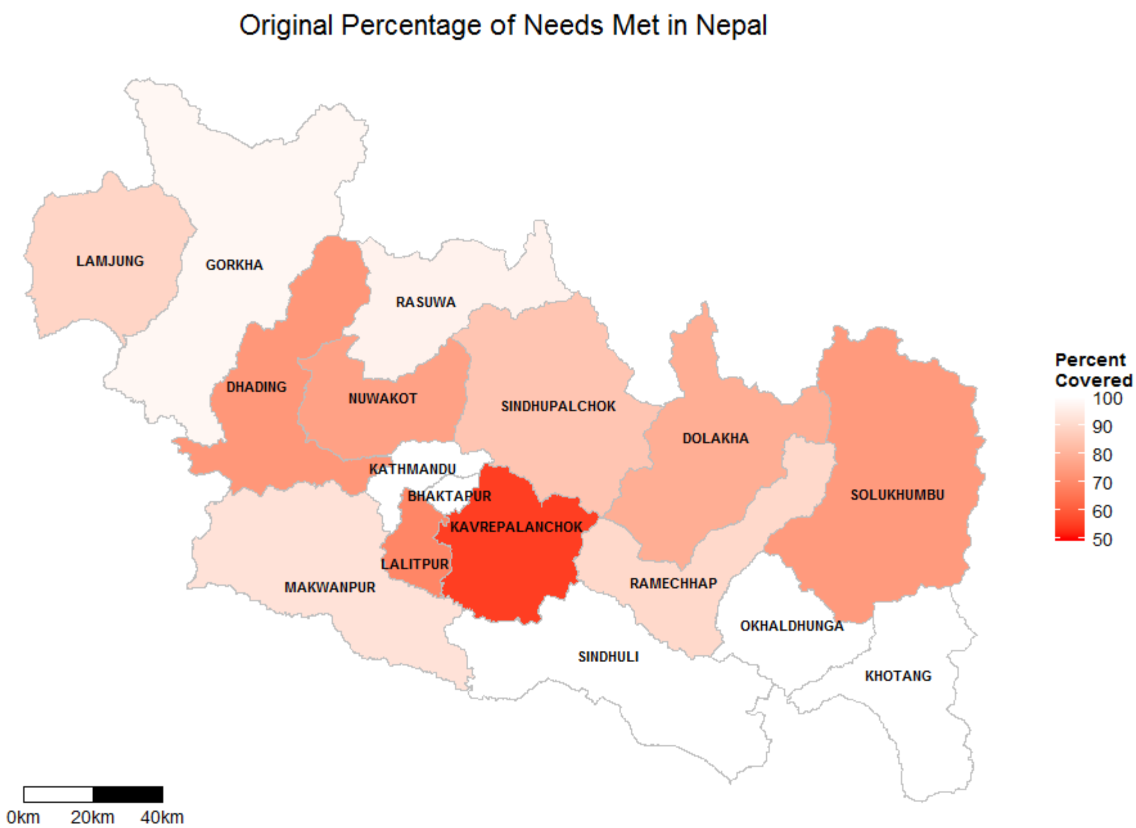

Figure 14: Actual geographic coverage

Table 7: Effectiveness output statistics

Experiment	Description	Targeted Needs	Needs Met	Ratio
Actual Response	Organization's initial location is unknown.	4,192	3,429	0.818
Layout 1: Uniform	Organization's initial location is uniform across all 17 affected districts.	4,192	3602.93	0.859
Layout 2: Priority Districts	Organization's initial location is uniform across the 14 priority districts.	4,192	3733.13	0.891
Layout 3: Most Needed Districts	Organization's initial location is uniform across the 8 districts with the highest need.	4,192	3740.6	0.892

Table 8: Geographic disparity comparison among layout types

Experiment	Minimum Coverage	Maximum Coverage	Disparity
Actual Response	55.03% (Kavrepalanchok)	100% (5 districts)	44.97%
Layout 1: Uniform	76.6% (Sindhupalchok)	100% (Okhalduhunga)	23.4%
Layout 2: Priority Districts	65.2% (Khotang)	97.3% (Okhalduhunga)	34.8%
Layout 3: Most Needed Districts	54.4% (Lamjung)	98.99% (Ramechhap)	45.6%

While Layouts 2 and 3 are shown to be more effective than Layout 1, the disparity in coverage is very different among the three layout types. This is best shown visually in Figure 15, but is also described numerically in Table 8. Notice that geographic disparity is most improved in Layout 1, but the district with the minimum fraction of need met is also the district with the greatest need, Sindhupalchok. However, least-covered districts for Layouts 2 and 3 are ones with very little need to begin with, such as Lamjung and Khotang. In fact, when Khotang's need is removed from Layout 2, disparity is reduced to just 16.9%. Since Khotang was not initially considered a priority district after initial assessment from the clusters [1], it is difficult to know if these needs must be prioritized the same as others. However, given the specific type of need being assessed, that is, educational needs for children, needs may not be able to be prioritized as they would be for health or water. While injuries, for instance, may be assessed on a continuous scale from minor to severe, the assessment is binary where children are either with or without education.

As the literature has shown, there is a trade-off in effectiveness by increasing equity. Layout 2 is found to be just as effective as Layout 3, but is more equitable in that geographic disparities are decreased by more than 10%. However, efficiency has yet to be introduced into this experiment.

Utilization is measured by averaging the ratio of needs filled to total capacity for all organizations. Table 9 shows the results for each layout type. Notice first that the standard deviation for each mean is very tight, meaning that while the results may seem very similar, the subtle differences may be significant. Indeed multiple mean comparison testing reveals that there is a marginal difference between Layouts 2 and 3, and a significant difference between both of these layouts and Layout 1 in terms of utilization (at a Type I error rate of 0.05).

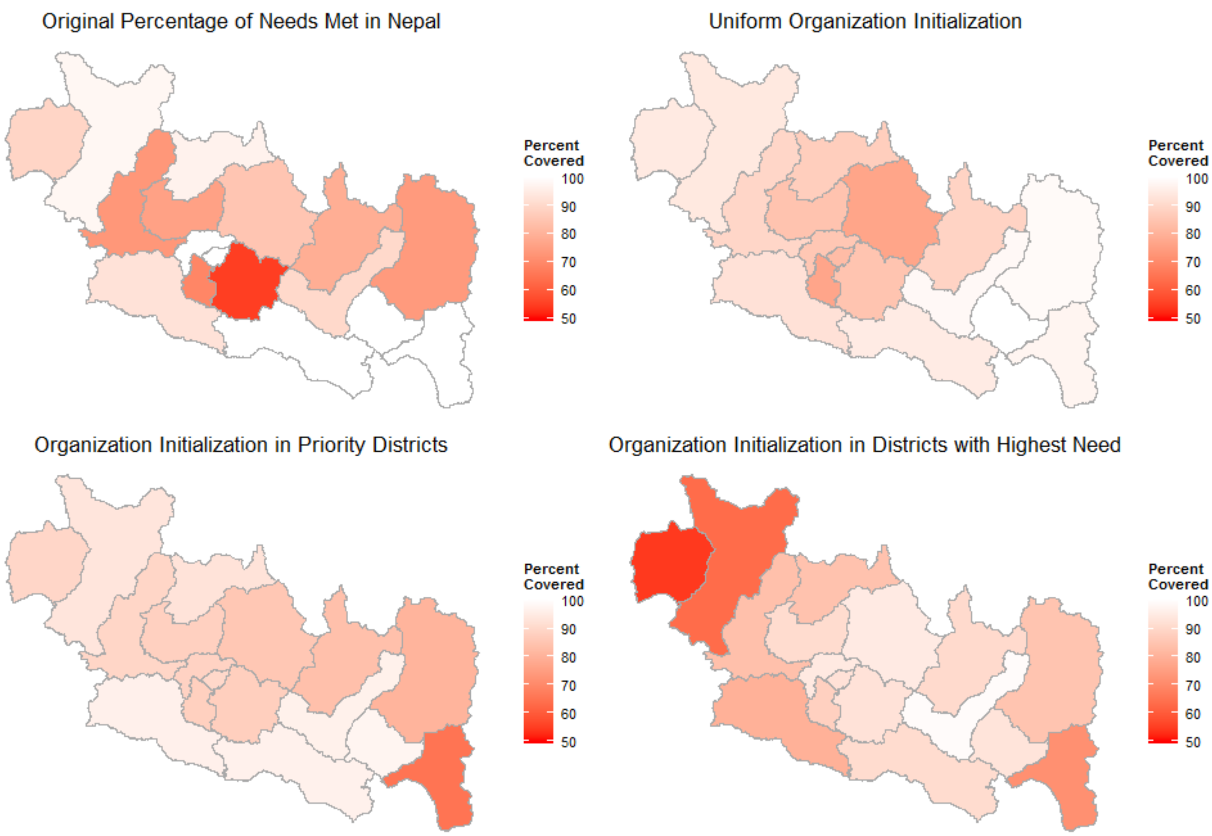

Figure 15: Geographic coverage for different organization initial placement

Table 9: Utilization with Tukey's HSD test results

Experiment	Utilization Mean, (SD)	Layout 1	Layout 2	Layout 3
Layout 1: Uniform	91.77%, (± 1.78%)	-	$p = 0.029$	$p < 0.0001$
Layout 2: Priority Districts	93.40%, (± 1.65%)	$p = 0.029$	-	$p = 0.069$
Layout 3: Most Needed Districts	94.81%, (± 1.61%)	$p < 0.0001$	$p = 0.069$	-

Table 10: Total collaborations with Tukey HSD test results

Experiment	Total Collaborations Mean, (SD)	Layout 1	Layout 2	Layout 3
Layout 1: Uniform	7.8, (±3.0)	-	$p = 0.001$	$p < 0.0001$
Layout 2: Priority Districts	13.2, (±4.2)	$p = 0.001$	-	$p = 0.25$
Layout 3: Most Needed Districts	15.3, (±3.6)	$p < 0.0001$	$p = 0.25$	-

Table 11: Ranking of layout strategies based on output statistics

Output Statistic	Metric Measurement	Best	Worst
Ratio of Need Filled to Total Need	Effectiveness	Layouts 2, 3	Layout 1
Geographic Disparity	Equity	Layout 1	Layout 3
Organization Utilization	Efficiency	Layout 3	Layout 1
Total Number of Collaborations	Coordination	Layouts 2, 3	Layout 1

Finally, while coordination is built into the organizations' decision rules through message passing, some are also programmed to be more collaborative in nature and actually form partnerships with other organizations. Parameter sensitivity analysis demonstrates that having approximately 50% of all agents be collaborative-seeking leads to more robust results than more extreme values. Therefore this parameter is held constant across all layout experiments. Since links between agents are formed due to their proximity, Layout 3 is expected to yield collaborations merely because agents are initially placed closer together. Indeed, as Table 10 shows, Layout 3 did result in more collaborations on average than Layout 1 where agents are spread out across all 17 districts. However, there is not a significant difference between Layouts 2 and 3 in total number of collaborations when using Tukey's HSD multiple comparison test.

Overall, it is possible to rank the different initialization layout strategies for agents based on these four output statistics. Table 11 shows these results, and we see that interestingly Layouts 1 and 3 are often opposite of each other, and that Layout 2 is either considered the best option or is in the middle, but is never worst.

Table 12: Results of Tukey's HSD test on effectiveness measurement

Scenario Name	Ratio of Needs Met: Mean, (SD)	None	Neutral	Medium	High	Full
No Collaboration	89.7%, (±3.4%)	-	$p = 0.98$	$p = 0.41$	$p < 0.001$	$p < 0.001$
Neutral Collaboration	89.1%, (±3.0%)	$p = 0.98$	-	$p = 0.75$	$p < 0.001$	$p < 0.001$
Medium Collaboration	87.6%, (±3.6%)	$p = 0.41$	$p = 0.75$	-	$p < 0.001$	$p < 0.001$
High Collaboration	80.1%, (±3.8%)	$p < 0.001$	$p < 0.001$	$p < 0.001$	-	$p < 0.001$
Full Collaboration	67.8%, (±2.0%)	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	-

5.2.3 Coordination Testing

As mentioned earlier, effectiveness is measured by the ratio of needs filled to total needs. To compare the five different types of collaboration levels, an analysis of variance (ANOVA) test is used to determine whether there are significant differences in means between the groups. The test was highly significant at a Type I error rate of 0.05, yielding a $p-$value of $p < 0.0001$ ($F = 124.23$, $df = 4$), meaning at least two of the comparisons are significantly different from each other. Tukey's Honest Significant Differences test [71] is then used to make pairwise comparisons of means while conservatively adjusting for the number of comparisons being made. The results of these tests are shown in Table 12. It is obvious that the Full Collaboration scenario is significantly worse than the others in terms of average needs met, and that while High Collaboration is better, it is still significantly worse than the others as well. A difference in the average needs met ratio cannot be concluded between the Medium, Neutral, or No Collaboration scenarios.

As described previously, the equity metric, geographic disparity, is calculated by subtracting the minimum needs ratio from the maximum needs ratio across districts. The results are shown graphically in Figure 16, as well as numerically in Table 13. Although formal statistical comparisons cannot be made with this metric, it is noticeable that Full Collaboration yields the worst geographical equity, and that the No Collaboration and Medium Collaboration scenarios yield the best geographic equity.

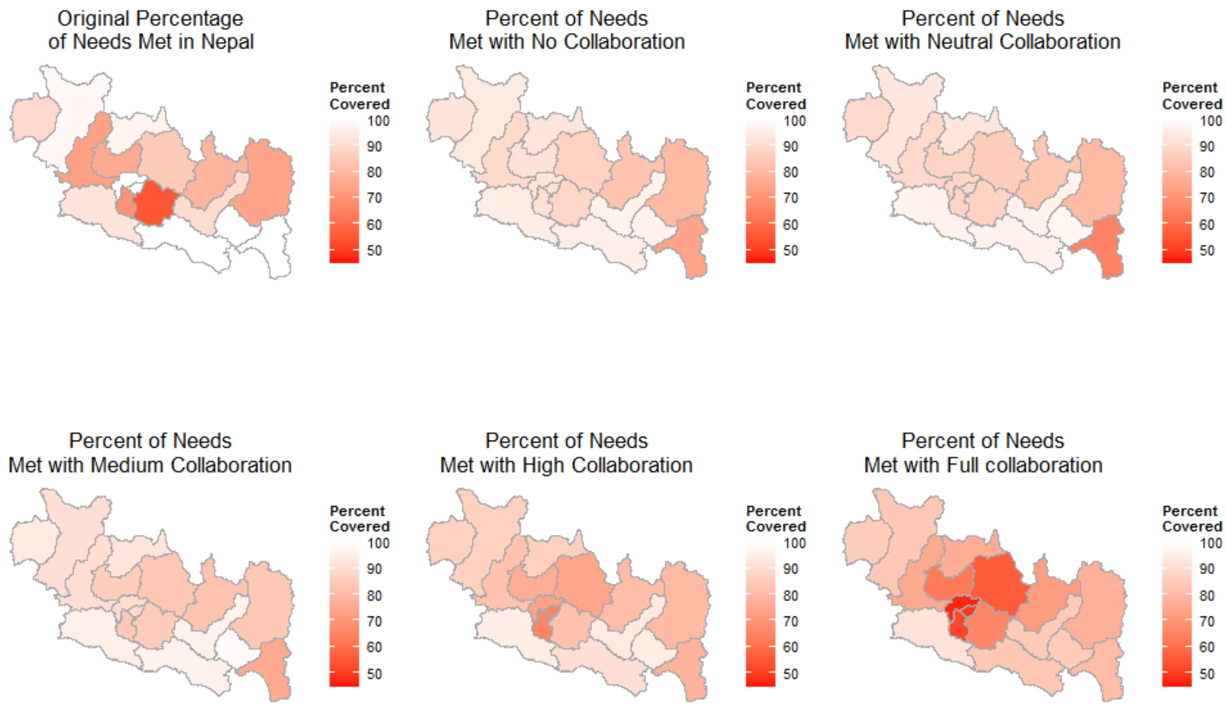

Figure 16: Disparity among districts with different collaboration levels

Table 13: Geographic disparity comparison among levels of collaboration

Experiment	Minimum Coverage	Maximum Coverage	Disparity
Actual Response	55.03% (Kavrepalanchok)	100% (5 districts)	44.97%
No Collaboration	74.1% (Khotang)	96.4% (Okhalduhunga)	22.3%
Neutral Collaboration	65.2% (Khotang)	97.3% (Okhalduhunga)	32.1%
Medium Collaboration	75.6% (Khotang)	98.7% (Okhalduhunga)	23.2%
High Collaboration	65.7% (Lalitpur)	94.7% (Makwanpur)	29.0%
Full Collaboration	47.5% (Kathmandu)	91.6% (Makwanpur)	44.1%

Table 14: Results of Tukey's HSD test on efficiency measurement (utilization)

Scenario Name	Utilization Mean, (SD)	None	Neutral	Medium	High	Full
No Collaboration	93.8%, (±1.6%)	-	$p = 0.97$	$p = 0.97$	$p < 0.001$	$p < 0.001$
Neutral Collaboration	93.4%, (±1.6%)	$p = 0.97$	-	$p = 0.99$	$p < 0.001$	$p < 0.001$
Medium Collaboration	93.4%, (±1.7%)	$p = 0.97$	$p = 0.99$	-	$p < 0.001$	$p < 0.001$
High Collaboration	89.4%, (±2.0%)	$p < 0.001$	$p < 0.001$	$p < 0.001$	-	$p < 0.001$
Full Collaboration	85.1%, (±1.6%)	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	-

Organization utilization was analyzed in the same way as the needs ratio, by first using an ANOVA test, followed by a formal multiple comparisons test, as the ANOVA showed that there is a significant difference in means between at least two of the scenarios tested ($p < 0.0001$, $F = 71.8$, $df = 4$). Once again, Tukey's HSD test was used with a Type I error rate of 0.05, and the results are displayed in Table 14. There is noticeably a similar pattern as to that observed for effectiveness, with Full Collaboration significantly worst than the rest in average utilization, High Collaboration slightly better, and no significant difference in utilization between the other three scenarios.

Finally, formal statistical comparisons of the total number of collaborations are not appropriate, since adjusting the parameters in this experiment essentially ensures more or less collaborations based on the scenario. While comparisons cannot be made, the results are still reported in Table 15. It is obvious that the number of collaborations would increase as the strategy ratio increases and as the probability of a collaborative agent taking a need outright decreases.

While the overall results may appear to indicate that less collaboration is better for a more equitable, efficient, and effective response, it is important to note that other model rules and parameters may have also contributed to these results. For instance, each individual organizations' reach is relatively small, meaning they are limited to a small number of potential candidates for partners. If this reach were increased, the metrics for the High and Full Collaboration scenarios would likely increase. However, a small reach may be more realistic in an actual disaster, where

Table 15: Average number of collaborations for different collaboration scenarios

Scenario Name	Total Collaborations Mean, (SD)
No Collaboration	0
Neutral Collaboration	13.2, (±4.2)
Medium Collaboration	24.8, (±4.5)
High Collaboration	119.9, (±26.5)
Full Collaboration	408.4, (±31.9)

many organizations may not have a broad view of needs assessments far from their location. Furthermore it is essential to note that much of the agents' coordination is directly built into their communication logic. Even if agents do not choose to formally collaborate on a project together, they still always pass along the information.

6 Discussion and Conclusions

This chapter summarizes the overall thesis and key results, provides recommendations for practice, and describes potential areas for future work.

6.1 Discussion of Results

The massive destruction of the 2015 Nepal earthquakes killed over 8,600 people, and left approximately 2.8 million people in need of humanitarian aid [1]. Many buildings were damaged or destroyed, including over 45,000 classrooms, which consequently left some 1 million children across 17 districts without access to education [1]. Humanitarian organizations have worked to establish temporary learning centers or child friendly spaces to fill this need, a task which requires a high level of coordination so that efforts are not duplicated and gaps in service are minimized. This thesis studies the coordination between actors providing post-disaster educational facilities by collecting first-hand information from humanitarians through a survey and formulating an agent-based simulation model of the response in Nepal. This research explores how coordination between many actors can influence the effectiveness, efficiency, and equity of a humanitarian response. It shows how ABM is a useful tool to better understand the complexities behind coordination and humanitarian decision making.

This work finds that initial layout of humanitarian actors that aim to establish temporary schools impacts the geographic equity of service, the efficiency of the actors themselves, and the effectiveness of the overall response. Layouts where the areas with greater needs are targeted first produce a more effective response than a more uniform layout by filling more of the overall need. The former layout also produces higher organization utilization, in that actors are closer to reaching their capacity. However, the response is more equitable across districts when actors have a broader initial layout instead of first targeting the areas with most need. Targeting 14 of the affected districts defined as *priority districts*, however, appears to be a compromising strategy, with a more equitable overall response that remains effective and efficient. This finding shows that coordination at the onset of a disaster, such as individual actors reporting where they are and the capacity they can fill, or quickly sharing information on rapid needs assessments, can greatly impact the response.

Collaboration strategies between actors can also impact the response in terms of equity, efficiency, and effectiveness. This research uses collaboration as an incentive to decrease risk encountered when filling needs. However, the results show that an increase in partnerships can decrease the overall effectiveness and utilization of actors if they spend too much time trying to find partners. This demonstrates that it is important to find a balance between seeking collaborations and saving time by filling a need outright. This result is intuitive in that the time devoted to search for partners in the field essentially takes time away from actually filling needs. While this finding is useful, it leads to many new questions and possibilities for agent-based modeling to be used.

6.2 Recommendations for Practice

Since the initial layout of organizations was found to be such an influential variable in the model, information sharing is arguably the most important in the first few weeks of response. This author recommends that practitioners use open platforms such as HumanitarianResponse.info, Humanitarian ID, OpenStreetMap, ReliefWeb, and Humanitarian Data Exchange, both for getting up-to-date needs assessments as well as reporting their own location and actions. Transparency is vital for coordination, and is the main defense humanitarians have against the potential for repeated efforts and gaps in service.

For large humanitarian organizations that operate in many locations, it is recommended that information gathered by these organizations be published consistently and distributed to other organizations, such as UNOCHA has done with their humanitarian snapshot documents [72]. For smaller organizations whose actions may not be as transparent, it is important to report assessment information as well as individual actions and location.

6.3 Future Work

There are many opportunities for future work in this complex field. Mainly, this research shows that agent-based modeling is indeed useful for studying humanitarian problems and provides unique insights into analyzing equity, efficiency, and effectiveness. First, variations of the model presented here could be examined, such as changes in the message passing system. While this research analyzed the forming of collaborations, a level of coordination was assumed through the message passing system between agents. It would be useful to further test this submodel, perhaps by introducing agents that do not pass any information at all, along with agents that have more influence than others, such as a cluster lead. It may also be useful to make the distinction between actors involved solely in the Education Cluster, actors solely in the Child Protection subcluster, and actors that overlap between the two. Doing so could provide further study into the area of inter-cluster coordination.

This work also studied the forming of collaborations as a motivating factor to reduce risk for organizations. However, it would be beneficial to incorporate factors for how agents choose collaborative partners, such as the trust perceptions discussed in Chapter 2. For instance, an organization may only choose to collaborate with partners that are larger than themselves, or agents who have already established a certain number of facilities. Doing this may give a better representation of the role information sharing plays in the effectiveness of a response.

There are also many avenues in which the post-disaster facility location problem can be explored. This work assumed that once an organization made the decision to fill a need, they were then able to establish a facility that completely met the need. It could be useful to have a greater degree of detail here, such as incorporating a discrete process in which agents actually search for a site and establish a facility in the area. This could be as simple as incorporating a distribution by which agents are delayed before being able to seek work again, or as complex as incorporating optimization methods within agents' logic for finding the optimal location to place a facility. Doing this would perhaps be more appropriate on a smaller scale, such as within one district with a high amount of need, or even in a more granular space.

Finally, it would be useful to continue to pursue research in education and child protection in the context of humanitarian logistics, the study of which has historically been neglected. Furthering this research is crucial as children are often at a higher risk than the general population following a disaster, and education is often not considered an urgent problem to be solved, even though it has been shown to be vital for a child's recovery [5]. It would be valuable to model the interaction of educational needs with other types of needs such as health, water and sanitation, or food security, as these clusters overlap with education and child protection, and prioritizing these needs is not a trivial task.

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8 Appendices

8.1 Appendix 1: Humanitarian Survey

This survey is designed to assess the decision making process of humanitarian workers in regard to logistical coordination. It is part of a research project. Your participation will help us to identify key coordination challenges in the humanitarian field and gain insight into effective coordination strategies that support swift, efficient response efforts.

Participation in this survey is strictly voluntary. The survey is expected to take approximately 20-30 minutes. You may skip any question and you may exit the survey at any time. Responses to the survey are confidential and will not be linked to individuals.

If you have questions about this research, please contact one of the investigators.

menth@ksu.edu; jlhs@ksu.edu

I have read and understand the description of this research. By checking this box, I indicate my consent to participate.

☐ Check box to continue to survey questions

Questions:

1. What organization do you currently work for?

2. What is your role or title?

3. Please indicate the type of organization with which you are primarily affiliated:
   ☐ Local/Community Non-Governmental Organization
   ☐ National Non-Governmental Organization
   ☐ International Non-Governmental Organization
   ☐ Local/Community Government
   ☐ National Government
   ☐ International Government
   ☐ United Nations Agency
   ☐ Other:__________________

4. How long have you been working in the humanitarian sector?

5. With which cluster(s) does your organization work?
   - ☐ Logistics Cluster
   - ☐ Health Cluster
   - ☐ Protection or Child Protection Clusters
   - ☐ Education Cluster
   - ☐ Food Security Cluster
   - ☐ Nutrition Cluster
   - ☐ Shelter Cluster
   - ☐ Camp Coordination and Management Cluster
   - ☐ Early Recovery Cluster
   - ☐ Water, Sanitation, and Hygiene Cluster
   - ☐ Emergency Telecommunications Cluster

6. While providing humanitarian relief, have you ever had to establish a facility? (Example: temporary housing, medical tents, temporary schools)
   - ☐ Yes
   - ☐ No

   (If 'No' is selected, then skip to Question 12)

7. What type of facility was it? (Select all that apply)
   - ☐ Internally Displaced Persons (IDP) Camp
   - ☐ Medical Tent or Facility
   - ☐ Child Friendly Space (CFS)
   - ☐ Temporary Learning Center (TLC) or School
   - ☐ Logistics Hub
   - ☐ Other:__________________

8. How many different locations did you consider to place the facility?

9. Did you consult anyone outside of your own organization on where to place the facility? Check all that apply.
   - ☐ A coordinating body (such as the United Nations Office for the Coordination of Humanitarian Affairs (OCHA))
   - ☐ Other humanitarian organizations within your own cluster
   - ☐ Other humanitarian organizations outside of your own cluster
   - ☐ Local community
   - ☐ Local government
   - ☐ Did not consult others
   - ☐ Other:__________________

10. In what ways did you evaluate whether or not the facility was needed?
    - ☐ Reports from media dictated need
    - ☐ Reports from other humanitarian organizations dictated need
    - ☐ Received a request from another organization or government
    - ☐ By holding interviews with locals
    - ☐ By forming focus groups with locals
    - ☐ By means of data analysis, either firsthand or secondhand
    - ☐ Other:________________

11. In what ways did you evaluate whether or not the facility was needed?
    - ☐ Cost
    - ☐ Accessibility for workers
    - ☐ Accessibility for beneficiaries
    - ☐ Safety
    - ☐ Size
    - ☐ Facility type (building vs. open area, etc.)
    - ☐ Other:________________

12. Which of the following influences your own general decision making (in the humanitarian field) the most?
    - ☐ Efficiency (using limited money and resources to help the most people or do the most good)
    - ☐ Equity (making sure all beneficiaries are treated equally or fairly)
    - ☐ Effectiveness (outcomes best reflect what was intended)
    - ☐ All equally influence decision making

13. From the perspective of your organization as a whole, please rate the of importance for each topic in regard to decision making in humanitarian operations from Very Important to Not at all Important.

	Very Important	Moderately Important	Neutral	Not Very Important	Not at all Important
Efficiency	☐	☐	☐	☐	☐
Equity	☐	☐	☐	☐	☐
The autonomy of your organization	☐	☐	☐	☐	☐
Having a single decision maker	☐	☐	☐	☐	☐
Having a coordinating body make most decisions	☐	☐	☐	☐	☐

14. A partnership between humanitarian organizations can be defined as collaborating with another organization on a project, sharing data or information with another organization, or coordinating with another organization in response to some event. About how many part-

nerships do you have at any given time?

15. Would you be more likely to work with humanitarian organizations that are larger or smaller, more or less established than yourself? Check all that apply.
    - ☐ Larger
    - ☐ Smaller
    - ☐ More Established
    - ☐ Less Established
    - ☐ Local to Event
    - ☐ International
    - ☐ Generally we do not collaborate with other organizations

    (If 'Generally we do not collab..' is selected, then skip to Question 19).

16. Have you ever sought out another organization to work with? If so, how?
    - ☐ Yes __________________
    - ☐ No

17. How would you best describe partnerships or collaborations that you have made in the field?
    - ☐ They are long lasting
    - ☐ They tend to only last the duration of the event
    - ☐ They do not last during the entire response to the event

18. Describe the types of organizations with which you have collaborated. Check all that apply.
    - ☐ Organizations that provide the same service as your own
    - ☐ Organizations that provide a different service than your own
    - ☐ Private sector businesses or companies
    - ☐ Government
    - ☐ Military
    - ☐ Local groups or communities

19. How important is it that the organizations with which you collaborate share similar mission statements?
    - ☐ Very Important
    - ☐ Moderately Important
    - ☐ Neutral
    - ☐ Not Very Important
    - ☐ Not Important at All

    Note for the following question(s): OCHA=The United Nations Office for the Coordination of Humanitarian Affairs

20. Where do you get your data? How reliable is it?

	Where do you get your data?	Do you consider it reliable?		
	Check all that apply:	Yes	Somewhat	No
Self-collected	☐	☐	☐	☐
A coordinating body such as OCHA	☐	☐	☐	☐
Publicly available data online	☐	☐	☐	☐
We do not collect or analyze data	☐	☐	☐	☐
Other:	☐	☐	☐	☐

(If 'We do not collect or analyze...' is selected, then skip to Question 24).

21. How do you store data?
    - ☐ Microsoft Excel Spreadsheets
    - ☐ Cloud storage like Google Documents, Dropbox, or a similar service
    - ☐ A database like Microsoft Access
    - ☐ I'm not sure
    - ☐ We do not store data
    - ☐ Other:_________________

22. How do you analyze data?
    - ☐ Microsoft Excel
    - ☐ Statistical software such as R, SAS, or Python
    - ☐ Rely on analysis done by others or found online
    - ☐ I'm not sure
    - ☐ We do not analyze data
    - ☐ Other:_________________

23. Rate the importance of the following in regard to your humanitarian work.

	Very Important	Moderately Important	Neutral	Not Very Important	Not at all Important
Data/Information Sharing	☐	☐	☐	☐	☐
Existence of Publicly Available Data	☐	☐	☐	☐	☐
Forecasting	☐	☐	☐	☐	☐
Having Access to Maps	☐	☐	☐	☐	☐
Using Data to Influence Coordination	☐	☐	☐	☐	☐
Using Data Analytics to Make Decisions	☐	☐	☐	☐	☐

The next three questions ask you to rank a list of options given a scenario. If a relevant option is not among those listed, you may specify that option in the space marked 'Other'.

24. How would you rank the importance of the following actions when considering a facility location in a humanitarian response effort, such as a hospital tent or temporary school? (Please drag and drop the most important to the top marked '1', the next most important in the second position marked '2', and so forth.)
    _______ Try to select an already standing building that meets minimum standards
    _______ Try to obtain tents or tools for a makeshift facility
    _______ Survey locals to assess where to place facility
    _______ Try to get support/help from locals to establish the facility
    _______ Search for information from a coordinating body about where to place facility
    _______ Other:_________________

25. Rank your preference for placing a facility such as a child friendly space (CFS) or temporary learning center (TLC). (Please drag and drop the most important to the top marked '1', the next most important in the second position marked '2', and so forth.)
    _______ Establish facility in a location where the number of children reached is maximized
    _______ Establish facility in a location where those who need it most are prioritized
    _______ Establish facility in a location that is most proportionally fair to beneficiaries (Example: placing a facility between two towns instead of directly in the town that is larger or has a higher need)
    _______ Other:_________________

26. Rank the importance of the following resources when establishing a child friendly space (CFS) or temporary learning center (TLC) following a disaster. (Please drag and drop the most important to the top marked '1', the next most important in the second position marked '2', and so forth.)
    _______ Access to water on site or nearby
    _______ Access to toilets on site or nearby
    _______ Access to food
    _______ Having the required amount of staff
    _______ Having adequate shelter
    _______ Having adequate non-food related items or supplies

The last section includes three open-ended questions. Any information you can give would be extremely helpful.

27. What are some of the difficulties, barriers, or challenges you have faced in regard to collaboration or coordination?

28. Do you feel that you have to compete with other response agencies for donor support? Does donor influence ever affect your decision making process? If so, in what ways?

29. Have you ever been involved with setting up a child friendly space (CFS) or temporary learning center or school (TLC)? If so, please briefly describe the process of establishing the space. Were there any unforeseen challenges that arose?

Thank you for your participation. A summary of survey results will be made available upon request after data analysis is completed. Please contact one of the investigators to request a summary.

menth@ksu.edu, jlhs@ksu.edu