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Characterizing Logistics Operations Within a Federal Staging Area for Hurricane Response: A Qualitative Analysis of Federal, State and Local Perspectives

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Characterizing Logistics Operations Within a Federal Staging Area for Hurricane Response: A Qualitative Analysis of Federal, State and Local Perspectives

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Abstract

A successful deployment of logistics operations following a disaster is a collective contribution of federal, state, and local entities to ascertain an efficient and effective response. This research analyzes data from interviews with disaster response logistics experts from these entities. The objective is to investigate the information sources and planning processes used in these organizations to plan vehicle routes for critical resource deliveries to impacted areas. Special attention is directed to the impacts of incomplete knowledge of infrastructure status, such as road disruptions due to debris or flooding. Supported by both qualitative and quantitative evidence, the study finds that incomplete knowledge of infrastructure status poses serious critical transportation risks such as delivery delays in disaster relief distribution. This research reveals both similarities and differences in logistical decision-making among these organization types and emphasizes the need for improved information sharing and coordination among emergency response organizations. The findings of this research are expected to guide future initiatives aimed at disaster relief routing thereby enhancing emergency response capabilities and outcomes.

Acknowledgments

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I am profoundly grateful to my family members back in Bangladesh. No words can truly capture the depth of sacrifices they have made to support me in chasing my dreams. I want to express my heartiest appreciation to the love of my life, Xames, who has been my rock and my steadfast support, constantly motivating me to keep pushing forward during the countless late nights and overwhelming moments.

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1. Introduction

Though hurricanes originating in the Atlantic are an annually recurring threat to the United States, the 2017 storm season still stands out with its 18 named storms that further transformed into 6 major hurricanes. Hurricane Harvey, a category 4 storm, hit Texas, while Hurricanes Maria and Irma, categories 4 and 5 storms, respectively, struck Florida, Antigua and Barbuda, Puerto Rico, the Commonwealth of Dominica, the British Virgin Islands, and St. Maarten (Lawrence et al., 2022). This scenario recurred in 2018 with Hurricanes Florence and Michael, both category 4 storms, bringing colossal damage in the Carolinas, Georgia, Florida, and Alabama. This trend continues with 20, 31, and 21 tropical storms in 2019, 2020, and 2021 respectively; several of them escalating into hurricanes each year (*U.S. Hurricane Strikes by Decade*, n.d.).

In light of these records and the ongoing projection of climate change, understanding the means of improvement of post-disaster response is essential because these disasters impact all dimensions of human existence, including damage to communities, individuals, physical infrastructure, and natural ecosystems. They can disrupt societal or community functioning and result in extensive losses that exceed the affected community's ability to cope with its own resources (Pandey, C.L., 2019). Relief operations are crucial because they serve to provide the immediate needs of affected people and communities, such as shelter, food, water, and medical care. Meeting these needs in a timely manner can prevent further loss of life, alleviate suffering, and help people to recover from the disaster's impact.

The three phases of disaster relief operations discussed in Lee and Zbinden (2003) include those activities that occur pre-disaster (preparedness), during operations, and post-operations. The concentration of the research described in this thesis lies in the activities occurring during operations. The performance of humanitarian relief operations largely depends on the efficiency of logistics activities. As a matter of fact, logistics efforts relate to approximately 80% of disaster relief activities (Trunick, 2005).

Logistics in humanitarian aid is substantially different and more challenging in comparison with logistics in commercial applications (Çelik et al., 2012). While assessment of need and accumulation of different resources in the affected region are of prime focus, the distribution of relief goods to impacted areas within a short lead time poses a critical challenge to disaster response teams. Relief distribution becomes even more difficult due to infrastructure damages caused by the disaster, heavy outward evacuation traffic, severe weather conditions, and incomplete information on road conditions, among other things [8]. Another complexity of humanitarian logistics is that it often involves multiple stakeholders such as governments, militaries, nongovernmental organizations (NGOs), private companies, and social and voluntary organizations, some of whom may have conflicting objectives. Further, the information shared among stakeholders often might not be reliable.

To maximize the effectiveness of humanitarian logistics activities in highly dynamic, uncertain, and resource-constrained environments, it is important to investigate the various techniques used by different stakeholders in performing humanitarian logistics activities. Understanding how uncertainty affects route planning and the practice of information sharing inside and across various entities functioning as emergency responders should be given particular attention. To deal with these concerns, this study's purpose is three-fold. First, occurrences of road disruptions encountered in disaster response logistics operations are identified. Second, the impact of incomplete knowledge of infrastructure status is assessed. Third, information sources and processes used in disaster response organizations to plan vehicle routes for the delivery of critical resources to impacted populations in the immediate response phase of a disaster are investigated. The following research questions (RQ) are answered to address these goals.

RQ 1: What uncertainties regarding transportation network infrastructure exist during the immediate response phase, at the time planning of vehicle routes to deliver critical supplies to impacted populations is conducted, and what are the consequences of these uncertainties?

This research question is related to road conditions. Routes planned with complete knowledge of infrastructure status should be reliable; that is, a driver should be able to finish the route without discovering any previously unknown road damages or blockages that prevent traversal. However, anecdotally, we have heard several first responders and other disaster response logistics personnel recount stories of drivers encountering blockages, such as flooded roads, and either remaining stuck or needing to re-route. This question is focused on discovering how frequently this occurs, and the consequences to the response operation when it does. We seek to understand the practical implications of road closures and blocked routes and how they impact drivers' travel time and route planning. This will provide insights into the significance of incorporating road damage considerations in planning relief supply chains and developing contingency plans to address the variety of road blockage scenarios.

RQ 2: What recourse actions are taken when a disruption is discovered on a planned route?

This question centers around understanding the behavior of emergency responders in response to the discovery of flooded roads and seeks to understand how new information about flooded roads spreads through the response enterprise through sharing with other stakeholders, vehicle fleet managers, drivers, and logistics providers. It aims to investigate the specific actions that drivers take when faced with this situation, such as turning around, asking for a new route, or relaying information to others. Additionally, the research question is interested in the communication channels that drivers use to relay information to others, including whether they communicate with other drivers, headquarters, or fleet manager. Finally, this question explores how incoming information about road conditions is exchanged both within and between various organizations in addition to operations/command centers' actions in response to disrupted roads.

RQ 3: What sources of information regarding road conditions are used to plan routes in disaster scenarios when road conditions are dynamic and uncertain?

This question explores the common information sources used by different levels of emergency responder organizations, such as local, state, and federal levels, in the event of a disaster. It extends its focus on whether the frequency and variety of information sources vary at different levels of organizations. Furthermore, it seeks to determine the information sources that have the highest usage rates across all levels of organizations.

RQ 4: How is route planning conducted in disaster scenarios where road conditions are dynamic and uncertain?

This research question examines the various information sources and planning tools that are utilized for initial route planning and how they differ from the sources used for route modification in the aftermath of updated road condition information. It also attempts to study the technical tools and systems that are employed to gather and analyze information, such as real-time traffic updates and weather forecasts. Additionally, we will discuss the role of the driver in providing critical information on road conditions and how this information is used to modify routes. Through this analysis, we aim to gain a deeper understanding of the factors that influence route planning and modification, and how they impact transportation operations.

The remainder of this paper is structured into four main sections: literature review, research design, findings, and conclusions. In the literature review section, we will explore the existing literature on humanitarian logistics to provide a comprehensive understanding of the current state of the field. In the research design section, we will describe our research methodology, including our data collection and analysis techniques. The findings section will present the results of our study, highlighting the practices and challenges faced by humanitarian organizations under uncertain road conditions. Finally, the conclusions section will summarize our findings and provide recommendations for future research and practice in this important area.

2. Literature Review

This section aims to provide an overview of the existing literature on three main topics: humanitarian logistics, the usefulness of qualitative research in humanitarian logistics, cooperation and collaboration between disaster response organizations, and disaster relief routing . Through an exploration of the main themes, concepts, and theories that underpin these topics, we seek to provide a comprehensive understanding of the current state of the field while also identifying gaps in current knowledge.

2.1 Humanitarian logistics

Humanitarian logistics can be defined as "the process of planning, implementing, and controlling the efficient, cost-effective flow and storage of goods and materials as well as related information from the point of origin to the point of consumption for the purpose of alleviating the suffering of vulnerable people" (Tomasini and Wassenhove, 2009). Humanitarian organizations seek to alleviate the suffering of people brought on by disasters, in contrast to the commercial sector, which seeks to minimize expenses or increase profit. In commercial logistics, supply matches or exceeds demand, while humanitarian logistics prioritize fostering the greatest social good which may lead to a scarce or excessive supply of resources (Holguin-Veras et al., 2013). The environments in which humanitarian supply chains operate are often characterized by chaos and insecurity, and humanitarian supply chains are usually in the early stages of their lifecycle, while commercial supply chains are typically more developed. As a result, humanitarian supply chains face the difficulty of establishing and running a supply chain in very unstable environments, limiting the ability to optimize their processes (Blecken et al., 2009).

High staff turnover, particularly among expatriate staff on short-term contracts, results in frequent team reorganizations and loss of knowledge in humanitarian aid organizations. Limited opportunities for institutional learning and knowledge transfer also hinder their ability to capture lessons learned and improve their work (Van der Laan et al., 2009). Some of the other crucial characteristics of humanitarian logistics that exert high challenge and dynamics in its operations are the temporal, locational, and categorical unpredictability of demand, the unprecedented occurrence of high demand for a wide variety of supplies with short lead times, high risks associated with timely and prompt delivery (Kovács and Spens, 2009), and multiple stakeholders' and participants' involvement and coordination (Balcik et al., 2010).

Disruptions to transportation infrastructure can have significant impacts on the delivery of critical resources, emergency services, and the ability to shelter. Certain roads may be hard or even impossible to navigate because of various factors such as collapsed bridges, water accumulation on roads, and debris accumulation due to landslides, fallen trees, and damaged structures. These obstacles can create significant challenges for transportation in affected areas, making it difficult for emergency responders to reach those in need and hindering the distribution of critical resources. In some cases, the damage can be so severe that rebuilding the transportation infrastructure becomes a significant priority in the recovery effort (FEMA, 2020). These difficulties can be further intensified by obstacles in sharing information among various organizations (Auf der Heide, 1989).

2.2 Disaster relief routing under uncertain road conditions

In this section, we present insights from two review papers focused on disaster relief routing. We also survey the literature published since the time of the last review in 2014, using the following keywords to identify relevant papers in the SCOPUS database: disaster relief routing under uncertain road conditions; disaster relief routing under road disruption; disaster relief routing under infrastructure damage; transportation risk in humanitarian logistics. After reviewing the titles, abstracts, introductions, and conclusions of papers identified by these search terms and excluding irrelevant or overlapping papers, 18 papers remained for inclusion in our review.

De la Torre et al. (2012) conducted a review of academic and practitioner papers on disaster relief routing and emphasized the significance of being able to create models for distribution systems that are characterized by disorder, unpredictability, and limitation of information, regardless of the specific context in which the models are developed. The authors also highlighted the comprehension of the actual issues that practitioners encounter, particularly as their practices change over time. This was echoed by Anaya-Arenas et al. (2014) in their systematic review of contributions related to disaster relief distribution networks. This study pointed out the need to align the hypothesis and considerations used to design relief distribution networks with the actual decisions made within those networks. They suggested that the next step in optimizing relief distribution networks is to bridge the gap between research and practice, with the goal of improving crisis managers' decision-making capabilities.

Since 2014, researchers in the field of disaster relief routing have explored two main categories of inquiry. The first category addresses the joint problem of determining the optimal locations for facilities (e.g., warehouses, distribution centers) and designing the most efficient routes for vehicles to transport goods between these facilities and customers. Nodoust et al. (2023) proposed a mathematical programming model to solve the warehouse location problem and vehicle routing problem for humanitarian relief distribution under uncertain demand and road conditions. The study used fuzzy logic to add uncertainty to a scenario-based stochastic approach and employed robust possibilistic programming to account for road disruptions. A scenario-based stochastic multi-objective location-allocation-routing model was proposed by Ghasemi et al. (2022) for a real humanitarian relief logistics problem considering the probability of the relief routes being blocked or destructed after the earthquake. Sabouhi et al. (2021) aimed to reduce the expected arrival time of relief vehicles to affected areas while considering route destruction and disruptions caused by disasters. To accomplish this, the study proposed a two-stage stochastic programming model for distributing relief items from distribution centers to affected areas. The model determined the locations of the distribution centers and the assignment of vehicles to reach the affected areas in the first and the second stage respectively.

The second category of papers is focused on routing problems without explicitly addressing facility location. These papers aim to find the most efficient routes for vehicles to travel between a given set of locations, subject to various constraints. Chang et al. (2022) developed a model and solution method for the inventory and vehicle routing problem that occurs in large-scale disasters where regional relief centers support each other, and uncertain traffic flow conditions are present after earthquakes of varying magnitudes. To determine optimal routes under uncertain road conditions, Toathom et al. (2021) suggested a route planning model that combines a genetic algorithm and the expected value technique. This study considered scenarios in which roads that were disrupted between nodes or routes become impassable after the vehicles started their travels.

Uncertainty in travel time because of road disruption, damage to infrastructure, traffic and/or several other factors was incorporated in the modeling and optimization of relief supply chains by several additional studies. For example, papers such as Aliakbari et al (2022), Zhang et al. (2021), Mohammadi et al. (2020), Chang et al. (2017), and Bozorgi-Amiri et al. (2016) introduce decision variables or parameters to quantify road condition uncertainty. Other papers address uncertainty in road conditions in disaster settings using the concept of route reliability, for example, Sirbiladze et al. (2022), Beiki et al. (2021), Khorsi et al. (2021), Veysmoradi et al. (2018), and Vahdani et al. (2018).

Baharmand et al. (2017) took a comprehensive approach by combining both qualitative and quantitative methods to identify transportation risks within Nepal during the response to the earthquake. Unlike the previous paper discussed which solely relied on quantitative data, this study employed a mixed-methods approach to gain a more in-depth understanding of the situation. Risks to the performance of the humanitarian supply chain were evaluated through an expert-driven risk assessment grid. In the research study, delivery delays and unreliable information were identified as two of the seven major risks associated with transportation in disaster scenarios. Delivery delays were caused by factors such as unfavorable weather conditions, high traffic density, and infrastructure breakdown. On the other hand, unreliable information was a result of infrastructure breakdown, limited availability of information sources, and inadequate use of technology. These findings suggest the importance of developing effective strategies to address these risks and improve transportation infrastructure to enhance disaster response efforts.

2.3 The need for qualitative studies

While Section 2.2 described a number of conceptual papers and model-based studies that rely on assumptions and hypothetical data, there remains a strong need for exploration and empirical evidence on the challenges of disaster relief routing in practice (Kovács and Moshtari, 2019). Since disaster response is highly dependent on the ability of practitioners to handle the unique and often unpredictable challenges that arise during disaster situations, it is critical for researchers to understand how they do so. To accomplish this goal of research well informed by practice, several strategies have been suggested, including engaging with humanitarian organizations, formulating research questions, and utilizing real and field data, among others (Kovács and Moshtari, 2019).

Authors have pointed to drawbacks of using hard OR methodologies in humanitarian logistics due to reasons such as their inability to address the unstructured nature of emergency problems, limited stakeholder identification and involvement, and case studies that rely on unrealistic assumptions (Amideo et al., 2019). In addition to that, the hard OR methodologies have limited capability to enable policy-maker involvement in the modeling process, encourage a sense of ownership, and ultimately lead to an impact on policymaking. As a result, there is a scarcity of truly high-impact applications of results emerging from Hard OR methodologies (Simpson and Hancock, 2009). Kovács et al. (2019) suggested the use of qualitative empirical methods to offer genuine data to comprehend research phenomena and validate assumptions and hypotheses in analytical and theoretical models. To effectively use these methods, they also suggested researchers need to collaborate with humanitarian organizations to access data and interact with practitioners and managers to formulate problems and develop conceptual models and hypotheses.

Hence, qualitative research has been increasingly applied in disaster management and in humanitarian logistics. For example, Gralla et al. (2016) studied a simulated emergency response scenario organized by the World Food Program (WFP) to show how sensemaking facilitates action as the formulation develops in humanitarian transport planning. Pedraza-Martinez et al. (2011) investigated how four large international humanitarian organizations (the International Committee of the Red Cross, the International Federation of Red Cross and Red Crescent Societies, the World Food Program, and World Vision International) manage their field vehicle fleets and listed the critical factors that determine the performance of field vehicle fleet management. Nelan et al. (2018) focused on the organizers of disaster donations to understand the value of agility in the disaster response supply chain and demonstrate that, despite the agreement of all participants on the significance of agility in the disaster donation supply chain, there exist differences in how agility is achieved in terms of donation method and structured timeline. Other recent applications of qualitative research to disaster management and humanitarian logistics include, for example, Saïah et al. (2022), Ruesch et al. (2022) and Jahre et al. (2012). Qualitative research is particularly applicable in this study, which seeks to characterize how response actors deal with uncertainty in transportation routing. To our knowledge, only a few studies have investigated this topic based on a rich understanding of the practice context.

2.4 Cooperation and collaboration

Understanding disaster relief transportation routing under uncertain conditions also requires an understanding of cooperation and collaboration among relief organizations, since the practice of relief routing depends on information sharing and cooperative efforts among different organizations. It is well understood that coordination and cooperation between all parties involved in the humanitarian crises (such as donors, suppliers, government entities, non-government agencies, etc.) require special attention during the response phase (Cozzolino, 2012; Kovács and Spens, 2009). Holguín-Veras et al. (2007) shed light on the roles and contributions of different key participants in disaster response, such as government agencies, volunteer organizations, the private sector, and individual citizens, and the existent coordination systems between them. An initial effort to investigate current and developing practices related to the coordination of relief chains was presented by Balcik et al. (2010). Specifically, it investigates how international relief organizations, donors, private sector companies, local governments, militaries, and local relief organizations collaborate. Additionally, the study examines coordination methods utilized in commercial supply chains, while considering their advantages, drawbacks, and obstacles. Heaslip et al. (2012) suggest using the systems analysis and design technique (SADT) as a means of illustrating how better coordination of disaster relief efforts among military and civilian organizations can be achieved across all phases of the humanitarian aid cycle. Bealt et al. (2016) combined qualitative and quantitative research methodologies to examine the challenges and benefits of forming partnerships between humanitarian organizations and logistical service providers. Leiras et al. (2014) find that the use of electronic systems should be emphasized to facilitate the sharing and control of information within and between organizations to improve outcomes throughout relief supply chain.

2.5 Addressing the research gap

It is evident that the existing literature indicates a pressing need for practical solutions that cater to the challenges experienced by practitioners in disaster relief routing. The aim of this research is to address the gap in the existing literature by providing a comprehensive and realistic understanding of the stakeholder perspectives on information and tactics used in disaster relief routing, specifically in the context of hurricane disaster relief routing under disrupted road conditions through a qualitative approach. By assessing the disaster relief distribution system from diverse perspectives, this research aims to provide insights into the actual practices and underlying issues in disaster relief routing, particularly under uncertain road conditions. Ultimately, the study aims to contribute to the development of effective disaster relief routing models and practical solutions that address the challenges encountered by practitioners in this field.

3. Research Design

Both qualitative and quantitative methods were used to add breadth to the discussion and reinforce greater in-depth analysis to answer the research questions. The research design is illustrated in Figure 1.

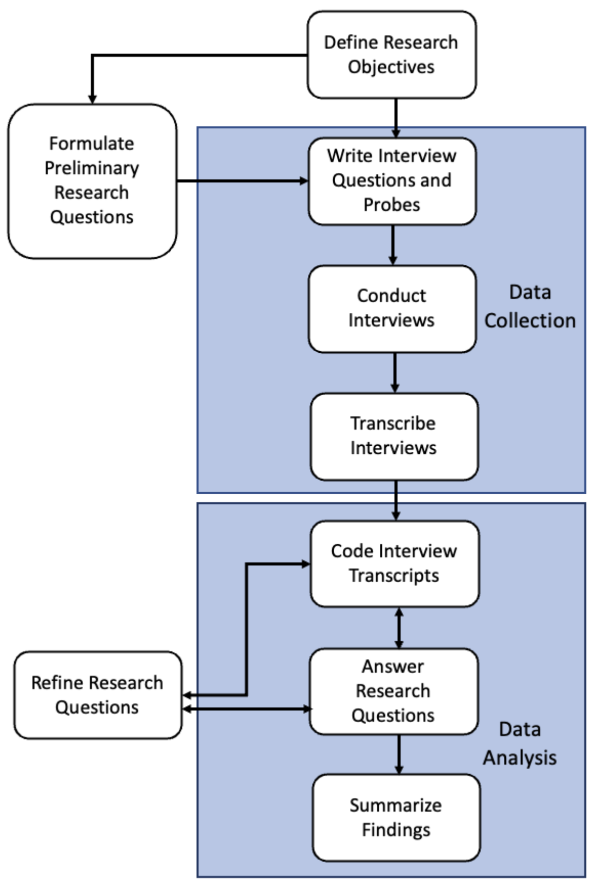


Figure 1. Schematic overview of the research design incorporated in this study

Figure 1 is represented by two main phases: data collection and data analysis. The data collection phase is preceded by the definition of research objectives and the formulation of preliminary research questions and is carried out by writing interview questions and probes and conducting and transcribing interviews. This phase is followed by the data analysis phase which contains the coding of interview transcripts followed by an iterative step of answering research questions and finally summarizing the findings.

Once the research objectives were set and research questions were identified, the next step was to gather information from different relevant sources to prepare for data collection. Information sources at this stage consisted of existing literature plus informal initial conversations conducted with emergency responders regarding road disruptions and how they affect disaster logistics operations.

The primary data collection method of this research was to interview personnel from entities at different levels who actively participated in disaster logistics operations, especially during the 2017 and 2018 storm seasons in the United States. A formal interview questionnaire was structured based on insights from the literature review and initial conversations. The questionnaire is included in Appendix A. Due to the inductive nature of this study, the questionnaire consisted of a set of open-ended questions focused on key aspects of disaster response transportation activities, grounds that instigate modification in primary transportation planning, and factors that influence and work as determinants to the achievement of emergency response goals. The investigators' professional networks were used to identify initial participants for the interviews. Those participants suggested additional possible interviewees, following a snowball sampling technique. Identification of participants concluded once all leads were exhausted and at least two interviews for each organization type were conducted. Consequently, over the six-month period from January to June 2019, 14 in-depth interviews were performed with participants from 14 different organizations, comprised of three federal-level entities (denoted F1, F2, F3, F4, and F5), three state-level organizations (denoted S1, S2, and S3), four private companies (denoted P1, P2, P3, and P4), and two non-profit organizations (denoted N1 and N2). There were a total of 21 participants, as many of the interviews included more than one person from the participating organization.

Most of the interviews were conducted by two interviewers. One primary interviewer asked the questions while the second interviewer took important notes and ensured the flow of conversation remained on track and conformed to the research objective. The duration of the interviews ranged from one to one and a half hours. Although the interviews were structured by the base questionnaire, any relevant lead was pursued with follow-up questions to reveal additional information. In all cases, the findings are presented in a manner that does not disclose information that could expose or be linked to the identity or affiliation of the respondents. Interviewees were identified only by their scope of engagement and responsibility such as local, private, state, or federal. All the interviews were recorded with the consent of the interviewees for documentation. Approval for this study was obtained from the University of Arkansas Institutional Review Board under Exempt Protocol #1512439.

The interview audio recordings were transcribed into text using software and checked manually to ensure proper conversion. The transcription of all interviews was completed within one month of the last interview and their lengths ranged from 4,600 to 14,000 words each. The interview notes and other relevant data were also documented before proceeding to further steps. The research questions and the corresponding answers did not follow one-to-one mapping, hence a systematic approach called Content Analysis (Elo & Kyngäs, 2008) was used to deal with the high volume of scattered information from the interviews.

The Content Analysis method begins with a preparation phase, where all interview transcripts were thoroughly reviewed several times so that the authors were able to build a solid familiarization with the contents. The next phase is organization, which was carried out via an open coding, categorization, and abstraction process. In open coding, headings were attached to the text reflecting the description of the corresponding content. A systematic protocol was followed to achieve consensus among authors about the codes to be used and their definitions. Then final coding of the documents was carried out by one author. This process is depicted in Figure 2.

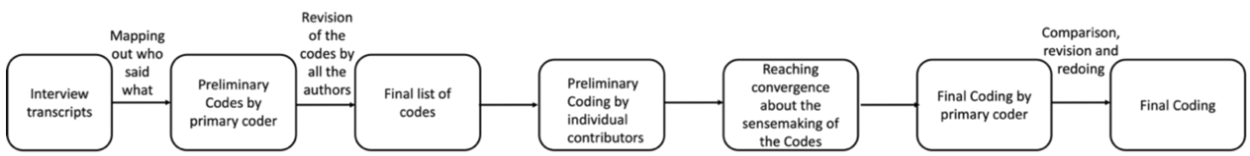


Figure 2. Systematic protocol while performing open coding

After completing open coding, the individual codes were grouped under higher-order headings (referred to as a generic category) according to their belongingness to a particular context. Some of the codes were linked to multiple categories as they share information across diverse contexts. This step is preceded by the abstraction process where a general description of the research topic was formulated through the fusing of the generic categories. An example of the abstraction process is represented in Figure 3, which illustrates that the codes are grouped under three generic categories named Route Planning, Road Disruption, and Information Flow which together lead to the characterization of disaster logistics operations.

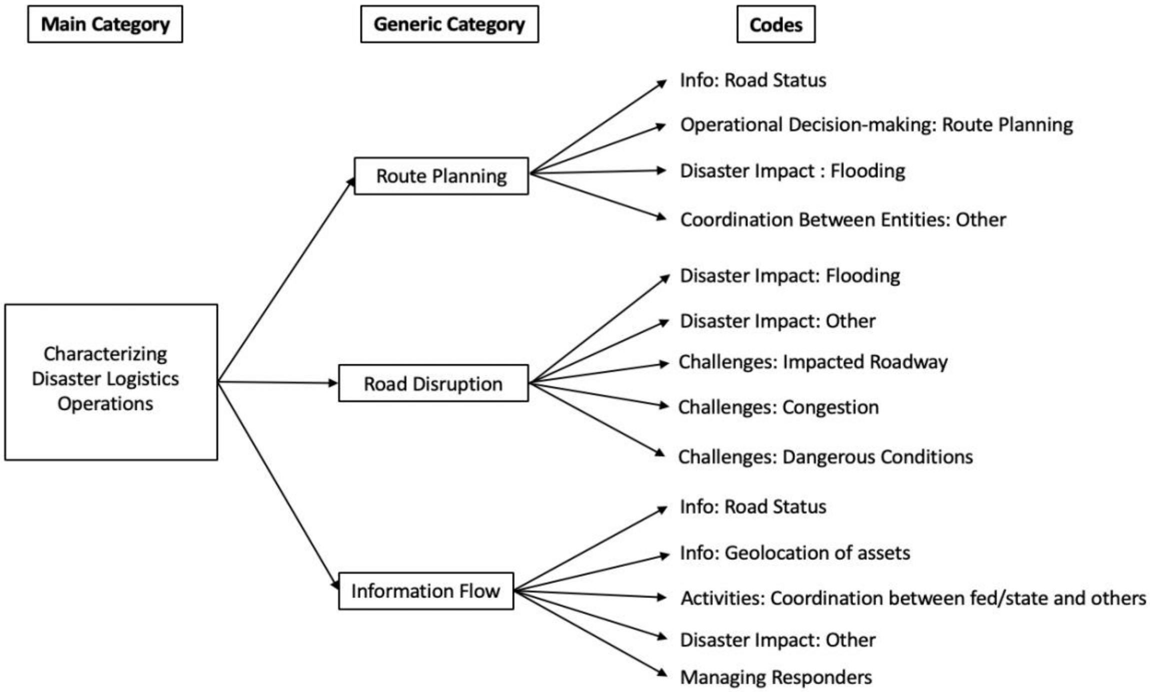


Figure 3. An example of the abstraction process

Finally, key findings of this research were illustrated by qualitative and quantitative data and results were reinforced by various visual aids where appropriate. This mixed method approach allows the provision of a greater breadth of information compared to using one approach and offsets the shortcomings that are inherent to mono-methods contributing to increased credibility of the results (Bealt et al., 2016).

4. Findings

This section presents the findings of this research with respect to the research questions. For each question, findings from interviews conducted during the data collection phase are narrated in detail and compared between different entities, where applicable.

4.1 Research question 1

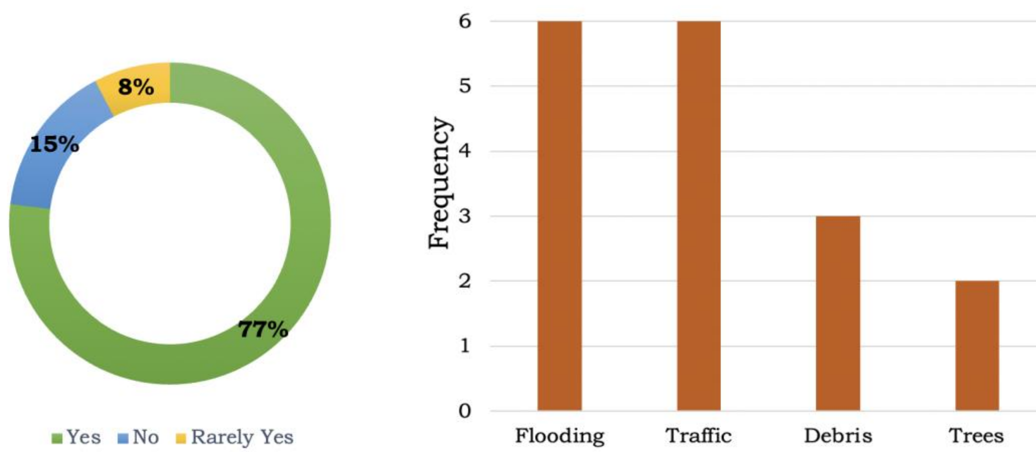
What uncertainties regarding transportation network infrastructure exist during the immediate response phase, at the time planning of vehicle routes to deliver critical supplies to impacted populations is conducted, and what are the consequences of these uncertainties?

Interviewees were asked whether drivers for their organizations have encountered disrupted roads during the execution of disaster logistics operations. Their responses have been categorized as either *yes*, *yes but rarely*, or *no*. Figure 4a depicts the distribution of categorized responses. Out of 14 responses to this question, the majority (77%) are categorized as *yes*, confirming these respondents have observed drivers encountering road disruptions during disaster relief routes. Only 2 responses were categorized as *no* and 1 as *yes but rarely*. The following interview excerpts provide additional context for the disruptions:

"Because there have been situations where trucks have sat for extended periods of time, because their access is blocked, and there's no way for the truck to turn around. That has absolutely happened."

"[…] what comes to mind is Hurricane Harvey, when we were initially putting our trailers into Houston, it was flooded. And there was like, there was one road that was open. And it kept changing."

Organizations mentioned several phenomena as the source of post-disaster road disruptions. Figure 4b depicts the commonly described causes of road disruptions during disaster relief operations and how many respondents mentioned each cause. Flooding, rising water, and heavy evacuation-related traffic were mentioned most often, by 6 respondents each. Roads blocked by debris and fallen trees were also frequently reported in this regard, mentioned by 3 and 2 respondents, respectively. Other causes mentioned by only 1 respondent were vehicle accidents, congestion, mud, and damaged bridges.



(a) (b)

Figure 4. (a) Distribution of categorized responses to whether organizations have encountered disrupted roads during disaster operations, (b) frequently mentioned causes of road disruptions

Based on the interviews conducted, there seem to be discrepancies between the federal and other levels of emergency responders with regard to their awareness of road disruptions during emergency response situations. All respondents from the state-level and private entities are categorized as *yes*, with the two non-profit organization responses split between one *yes* and one *no*. The latter non-profit organization acknowledged the possibility of road disruptions during disaster response operations. Nevertheless, they noted that they did not encounter significant challenges as the agencies affected by flooding or inaccessible by truck did not request resources, resulting in the vast majority of routes being accessible without issue.

In contrast with these organizations, two of the four of the federal-level responders are categorized as *no* and *yes but rarely*, with the latter mentioning not seeing or rarely seeing such an occurrence taking place in their experience. For the one federal-level interviewee who acknowledged encountering disrupted roads, they attributed the primary cause to the heavy outbound evacuation traffic. This is in contrast to the perspectives of emergency responders at other levels who cited road damage and flooding as the predominant factors leading to such disruptions. A possible reason for the discrepancies between the federal and other levels of emergency responders with regard to their awareness of road disruptions could be that federal responders are not actively involved in executing routes, leading to less knowledge about the actual scenario on the ground. This inference is supported by the fact that all other levels of emergency responders acknowledged the road disruptions, and many of these other organizations work "on the ground" for or with federal organizations. Another potential explanation could be related to the nature of the point of distribution for federal organizations. Often, federal organizations do not provide direct support to the affected area but instead, transport relief supplies to the local- or state-level staging areas. Transporting materials to such staging areas is typically less susceptible to disruptions than delivering directly to the impacted areas, given the relatively long distance of staging areas from impact zones, which can be as much as 250 miles away. As a result, federal responders may not have firsthand knowledge of the road conditions and disruptions that other levels of responders' experience when delivering supplies or providing support directly from the staging areas to impact zones.

Another contributing factor to the differences in awareness of road disruptions between federal and state/local emergency responders is the scope of their respective response efforts. Unlike state and local organizations, federal responders can only become involved when requested to do so by the state. Therefore, if there is a delay between when a state responds and when they later request federal aid, the state may have more knowledge of the infrastructure and road conditions in the earliest stages of the response.

Organizations experience varied levels of consequences as a result of road disruptions that can lead to significant increases in delivery times. For example, one of the organizations reported that a route typically 30 minutes in duration required three to four hours due to damaged road conditions. Another organization described a 6-hour route that became a 17-hour route due to heavy evacuation traffic. A third organization described having a truck stranded at a location for a prolonged period of time; even up to one week. One organization reported that a 6^{th} or 7^{th} rerouting was needed to find a passable route, in some situations where the original route was unavailable due to road disruptions. The following interview excerpts further portray the severity of the consequences from uncertain road conditions:

"[…] The problem is that we have one entrance into this place and the entrance that we have is not hardball (pavement), it is a dirt road. In this dirt road, we have four inches worth of rain, […] if one truck gets stuck in the mud, we've lost the mission because it can take three days to get it out of there.''

"At some point in Harvey, 50% of our missions were rerouted […] either they could no longer go through, and/or we had to take this just this elongated route to get to where we wanted to go. And that is at least 50% either turned around or dramatically rerouted to be able to get where we need to go.''

4.2 Research question 2

What recourse actions are taken when disruption is discovered on a planned route?

When a driver encounters a disrupted road, or an organization comes across information about one, the recourse actions undertaken by different organizations are varied. These are summarized in Table 1.

Table 1. Courses of action resulting from road disruption by different organizations

Entity Level	Entity	Action
Federal	F3	Road closure information is obtained from the Department of Transportation as a part of Emergency Support Function which is relayed to the drivers.
State	S1	Drivers are rerouted by S1.
	S2	Drivers are rerouted by S2.
	S3	Drivers are rerouted by S3.
Private	P2	Drivers contact the local command center, and they are redirected to a changed route with help of senior NCO or military police. If there is no viable route, the operation may in some situations be terminated. The local center also contacts FEMA, and the road status information is relayed to FEMA Headquarters from where that particular route is marked as a no-go route until updated information is available about the changed status.
	P3	The drivers decide on rerouting. Drivers notify the road status to the people on the ground who in turn inform FEMA. FEMA arranges for the removal of the debris.
NPO	N2	Rerouting decision is managed locally by the drivers and updated information about road status is accessed through the drivers' network. Drivers notify the local command center if the situation cannot be managed locally. The local command center contacts either the local police or national guard resources to escort vehicles stuck in closed routes.

As shown in Table 1, a federal organization described receiving road information from the state Department of Transportation and making it available to drivers. Private organizations reported taking rerouting actions guided either by the organization or the drivers themselves, plus then also informing FEMA about the condition of the roads. A nonprofit organization reported taking rerouting actions guided primarily by drivers, considering updated road information from the driver network, and calling in assistance from the local command center if help from local police or National Guard resources becomes necessary. All the state organizations reported rerouting their drivers once they encounter a disrupted route, and did not mention coordinating with other types of organizations to share and receive information.,

A generic view synthesizing the different courses of action carried out by various organizations after encountering road disruptions is presented in Figure 5. The immediate action after a driver encounters an impassable road is one of the following: driver is rerouted by their respective organization; driver makes the reroute decision on their own; driver informs their respective organization and the organization marks the route as a no-go route until they are informed otherwise; driver informs the local command center (LCC) about the road condition. If the latter occurs and the driver informs the LCC about the road condition, the next action in the sequence is one of the following: the LCC makes the reroute decision for the driver; the LCC relays the information about the road status to other drivers who are out for delivery; the LCC contacts the federal entity to relay the information about the road status; the LCC makes arrangements to escort the vehicle affected by the road disruption. Finally, if the federal entity has been contacted by the LCC, then the federal entity either makes the decision to rectify the disruption and/or relays the road status information to the federal entity headquarters (HQ) and the federal entity HQ marks the route as a no-go until the status is changed.

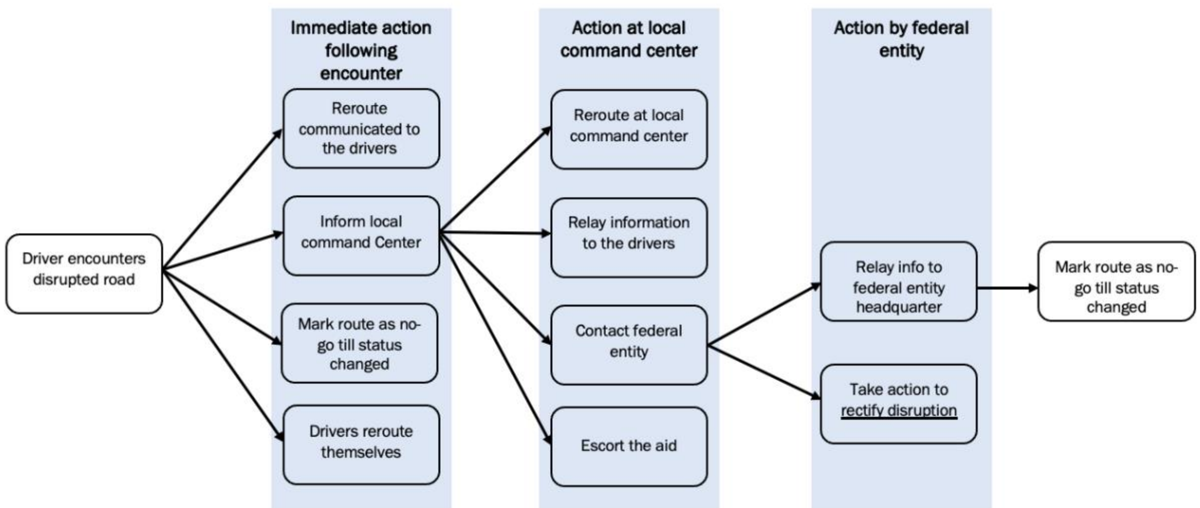


Figure 5. Synthesized view of courses of action resulting from road disruption

Table 1 and Figure 5 highlight a lack of information sharing among different levels of emergency response organizations. Private organizations were observed to share information about road conditions with FEMA, which is then centrally updated and used for further route planning. However, this sharing of information appears to be most robust when private companies are working in collaboration with FEMA. Apart from this situation, there appears to be limited information sharing among organizations. Non-profit organizations (NPOs) only notify the LCC when they require an escort, indicating a lack of proactive sharing of information. The following comment by an NPO respondent further explains the scenario.

"There was in Hurricane Florence when we were moving things from Charlotte into North Carolina, there was only one route that would work and that was a very circuitous route. But again, that information is being fed by our driver network, so we don't need to manage it. The only time that we get involved is if there's an issue with local or federal law enforcement, or if we need an escort to be provided to that driver because the area's closed off."

This limited sharing of information among responders could potentially lead to redundancies in effort and a lack of coordination during emergency response situations. It is worth noting that the only factor that appears to enable some level of information sharing among emergency response organizations is the drivers' network. Drivers from different organizations maintain updated road condition information by communicating with other drivers on the roads. Drivers utilize a variety of tools while driving to stay informed on the state of the road. These tools can be grouped into two main categories: mapping software and person-to-person communication. Commercial GPS software, Google Maps, custom GPS software, and Waze are reported by different organizations as the mapping software in use by drivers while on the road. Drivers employ CB Radio, transponder, satellite communications, and Waze to stay in direct communication with the command center, their immediate supervisor, or other drivers on the roads.

There is no guarantee that this information shared within driver networks is relayed to the upper hierarchy or shared with other levels of responders. This highlights the importance of creating formal channels of information sharing among emergency response organizations to ensure effective coordination and collaboration during emergency situations which is also suggested by different levels of emergency responders.

4.3 Research question 3

What sources of information regarding road conditions are used to plan routes in disaster scenarios when road conditions are dynamic and uncertain?

This section discusses the sources of information that are used to plan routes during disaster relief routing and presents the recommendations provided by the emergency responders to enable better access to updated road conditions.

4.3.1 Sources of information used to assess road condition

Other than drivers who face impeded routes, planners can learn about the status of the routes from a variety of information sources. These information sources fall into ten broad categories: driver network, maps, scouts, weather forecast, Department of Transportation (DOT), local entities, public knowledge, state entities, private parties, and broadcast. Figure 6 depicts the spectrum of these categories in terms of their level of popularity. The three leading sources of information are maps, entities, and the Department of Transportation. Numerous organizations use maps, including Google Maps, the DOT Map, Emergency Response Routes, and live roadmaps from software. Organizations mentioned state officials, troopers, police, the highway patrol, state-level highway officials, and the Texas Commission on Environmental Quality as the state entities that are sources of road information. In addition to providing information through its website and maps, the DOT deploys representatives and liaison officers, who update information about accessible routes to the emergency responders. Drivers who are on the road, regardless of their involvement in emergency response, are crucial sources of information on real-time route status. Through various communication means, these drivers maintain connections with the organizations and with one another. Emergency responders and private parties, including commercial industries, transporters, FedEx, UPS, and other parties who are using the same route for transportation, collaborate to share information on road conditions. The local entities include local officials, law enforcement, sheriffs, and fire and rescue teams; the broadcast includes TV and/or radio news and scouting includes sending a drone, a person, or a team to assess the road condition before deploying the logistics on that particular route. Government officials, posts from social media users (Facebook, Twitter, etc.), federal highway officials, and the Lower Colorado River Authority (LCRA) was cited by organizations in addition to information sources falling under these key categories.

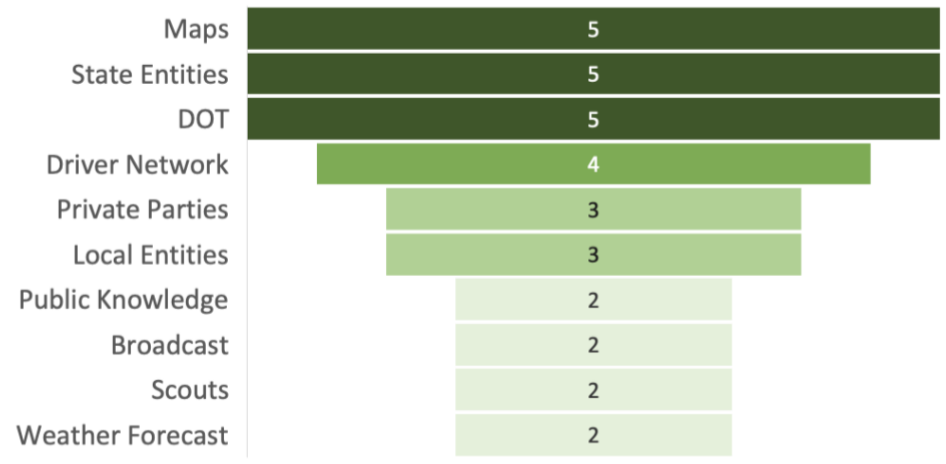


Figure 6. The popularity of information sources for road conditions

Information sources used by various organizations are shown in Table 2. Evidently, federal entities primarily rely on official information from different tiers of organizations. With the exception of the driver network and private parties, all state entities use maps while supplementing their information with a variety of sources. In contrast to non-profit organizations, which rely on a single source of information, private organizations use several information sources.

Table 2. Information sources used by individual organizations

No.	Entity Type→	Federal		State			Private			NPO	
	Source of Info↓	F3	F4	S1	S2	S3	P1	P2	P3	N1	N2
1	Driver Network						✓	✓			✓
2	Maps			✓	✓	✓	✓			✓	
3	Scouts			✓			✓				
4	Weather Forecast					✓		✓			
7	Public Knowledge			✓				✓			
5	DOT	✓	✓	✓	✓		✓				
6	Local Entities	✓				✓			✓		
8	State Entities	✓	✓			✓		✓	✓		
9	Private Parties		✓					✓	✓		
10	Broadcast		✓					✓			

Figure 7 shows the average number of information sources used by different levels of organizations. According to these data, it can be observed that nonprofit organizations utilize the fewest sources of information, private entities use the most, and federal and state organizations lie somewhere in the middle.

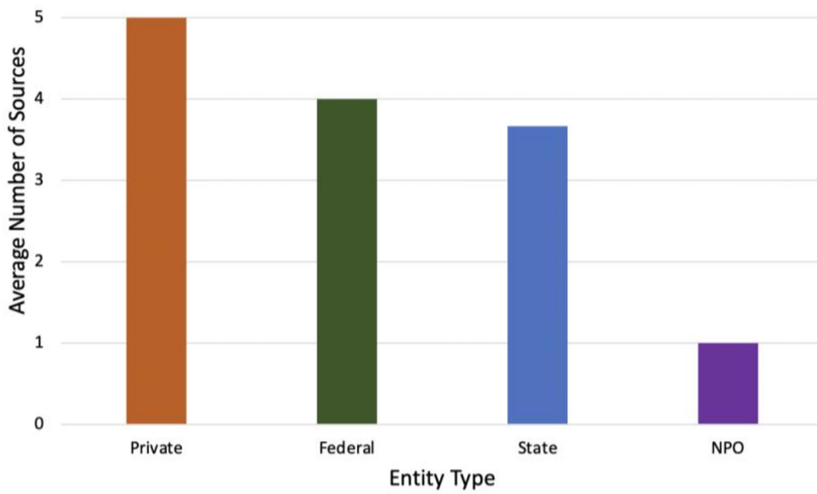


Figure 7. The average number of information sources used by different levels of organizations

4.3.2 Recommendation for better access to information about road condition

The research further focused on exploring the needs of emergency responders for an application that would assist them in responding to emergencies. Several interviewees have emphasized the need for a centralized system that offers real-time data and mapping capabilities regarding road conditions.

The current systems rely on manual updates by higher-level personnel, which can be time-consuming and occasionally overlooked, leading to inadequate sharing of information with other responders. To address this issue, interviewees have proposed a system that permits ground-level responders to input and update pertinent information, which can be accessed by all parties involved in emergency response efforts. In essence, a more efficient and collaborative approach is sought for ensuring accurate and up-to-date information about road conditions.

Several strategies have been suggested by the interviewees that technology could potentially automate the process of updating infrastructure status in real time based on information received from the people on the ground. Apart from the road conditions, they pointed out a need for accurate and up-to-date information about future route availability, weight restrictions of roads, bridge heights, etc. to ensure the safe and efficient delivery of goods and services. Two interviewees provided additional insight into this matter, as evidenced by their remarks below:

“Under normal circumstances, you can just assume that every federal highway has a bridge that is at least 14 feet tall. But you cannot make that assumption when you're delivering to Pine Gap, Louisiana during Katrina, right? I mean, that information is not available in a central location, so that you could route. Somebody has to control all of those inputs too.”

“There are some common themes that have popped up regardless of if we're talking to state planners or regional planners or the private sector. This is the idea of a map that has some information about what routes are available right now, and what routes are going to be available three hours from now.”

The use of geographic information systems, electronic log devices, and cell phones was suggested to track and broadcast road closures and obstacles. They exert tracking devices on trailers could also be used to know the exact location of closures.

A private sector respondent imagines a system that is monitoring road conditions in which information from some specific sort of communication media such as radio transmission could be interpreted. Then, the travel restrictions could be automatically updated on that particular highway, without the need for a person to physically handle the restriction. The potential use of technology, such as machine learning and cellular-based tracking, could be employed to further automate and improve information management. This would allow for more efficient and real-time updates to road conditions, improving the logistics and transportation of goods and services during disaster scenarios. However, this respondent also acknowledges the potential privacy concerns, and the limitation of current technology to implement such a system.

Another pressing concern that has been mentioned several by several respondents is that connectivity issues can cause problems with tracking trucks and communicating with drivers, especially in areas with poor cell service. The use of multiple options was suggested to be adapted to adjust to these limitations, such as exploring different tracking and communication options. This can be further illustrated by the following remark:

"Most of our tracking is on cell-based tracking software. […] This year, Verizon, for example, was one that went down in Florida, and we couldn't connect with any of our drivers, it was very challenging. So, we're always looking at different options as far as that goes. Because you have to be able to communicate, that is the most important."

The recommendations from varied levels of responders to improve the availability of information during emergency response are summarized in Table 3.

Table 3. Summary of recommendations to improve the availability of information during emergency response

Criterion	Recommendation
Expected information	▪ Road status ▪ Availability of future routes ▪ The exact location of the road closure ▪ Weight restrictions on roads ▪ Bridge heights
Means of implementation	▪ Interpreting radio transmission ▪ Multiple options to maintain communication ▪ Input from ground-level responders ▪ Machine learning and cellular-based tracking ▪ Geographic information systems ▪ Electronic log devices ▪ Tracking devices on trailers

4.4 Research question 4

How is route planning conducted in disaster scenarios where road conditions are dynamic and uncertain?

The information sources utilized for route planning fall into four main categories that are further divided into individual information sources as shown in Table 4. This summarizes the differences between the prime categories of information sources utilized for initial route planning and route modification in terms of percentage.

The first category represents different real-time maps used by organizations including Google Maps. It is evident that the dependence on maps significantly decreases during route modification (9%) in comparison with initial route planning (16%). A similar change in the utilization of different means of broadcasting is observed in initial route planning (12%) and route modification (9%). In addition to the traditional broadcasting methods such as television and radio news, and weather forecasts, it is very intriguing to learn how organizations use social media to monitor road conditions which can be reflected by one of the federal emergency responders as follows:

"We do have a kind of social media monitor so they can listen in on Twitter or Facebook, you know, they like the hashtag I-35 is closed or something like that."

The next category denotes the official information sources including local police/officials, state officials, and the DOT. It is clear that during both initial route planning (36%) and route modification (36%), the official information sources are considered to be highly significant. The DOT is most frequently mentioned (7 times) by emergency responders during initial route planning, which significantly downgrades (2 times) during route modification. This could be an indication of decreased reliability of the DOT in terms of providing updated road conditions.

The final category denotes the word of mouth from civilians, troopers, highway patrol personnel, commercial industries, people traveling from relief destinations, and the drivers engaged in relief operations. This category remains the most prevalent during both initial route planning (36%) and route modification (45%). Particularly, the reliance on the information provided by the drivers increases significantly during route modification (from 16% to 27%). This is due to the fact that they are on the roads, where they have firsthand knowledge, and they have a strong network that allows them to communicate and stay informed on the condition of the roads. The following comment provided by one of the interviewees further reflects the dependability on the drivers' information.

"There are several different ways that you assess road traversability. But the one that we have always used in the past is we rely on our drivers because they're the ones that are there. And nobody at a higher-level question was being seen in the ground. Okay, so if my driver calls in and says, “This road is a no-go road” and I call it in higher. They're not going to question that. That's no go as far as they're concerned until they can re-clear it.”

Table 4. Information sources used during initial route planning and route modification

Category	Source	Frequency (Initial Route Planning)	Frequency (Route Modification)
Maps	Live Maps	4 (16%)	1 (9%)
	Google Maps		
Broadcast	Social Media	3 (12%)	1 (9%)
	Weather Forecast		
	News		
Official Sources	Local Police/Officials	2 (8%)	2 (18%)
	State Officials		
	Department of Transportation	7 (28%)	2 (18%)
Word of mouth	Civilians	5 (20%)	2 (18%)
	Troopers		
	Highway Patrol		
	Commercial Industries		
	People from destination		
	Drivers	4 (16%)	3 (27%)

Nine out of fourteen entities acknowledged utilizing technical tools such as software and mobile applications to help with route planning which is represented corresponding to the organizations in Table 5. The employment of such tools is particularly prevalent in state-level and private enterprises. Google Maps, TXDOT Map, GPS, Live Roadmap, the FEMA app, weather apps, Waze, and custom software are among the technological aids that are used, with Google Maps and GPS being the most popular. One notable point for all these technology tools is their ability to display real-time road conditions, which aid planners in choosing an accessible route to their destination.

Table 5: Technical tools used in route planning by different organizations

Tool	F2	S1	S2	S3	P1	P2	P3	P4	N1
Google Map	■							■	■
Waze								■	
Custom software								■	
GPS		■					■		
FEMA App							■		
Weather app							■		
Live Roadmap				■					
Road Monitoring System				■					
TXDOT Map			■		■				
GIS						■			

Identifying the reliance on the drivers in route planning is another component of this research question. When given instructions on the destination, it was indicated in 4 (1 federal entity, 2 private entities, and 1 non-profit organization) out of the 12 interviews that the drivers planned the routes, which also demonstrates that emergency responders at the state level retain some degree of control on the planning of the routes.

4. Conclusion

The objective of this research is to gain a comprehensive understanding of the uncertainties and risks associated with transportation network infrastructure during the immediate response phase of disasters, particularly with regard to planning vehicle routes to deliver critical supplies to impacted populations. The study aims to identify the consequences of such uncertainties and the recourse actions taken when disruptions are discovered on planned routes. Additionally, the research seeks to identify sources of information used to plan routes in disaster scenarios, where road conditions are dynamic and uncertain, and explore how route planning is conducted under such conditions. Furthermore, we characterized and compared the viewpoints of these stakeholders and suggest improvements to current practices and policies to enhance disaster response efforts and improve transportation infrastructure. By doing so, this research aims to contribute to the development of more effective and adaptive solutions to disaster relief routing that are better suited to the complex and dynamic realities of real-life disaster situations.

To address these objectives, four research questions were formulated. The study employed a qualitative research design, which involved collecting data through in-depth interviews with emergency responders from federal, state, non-profit, and private entities. The data collected was analyzed using a content analysis approach that allowed for a detailed and nuanced exploration of the research questions and enabled the researchers to gain an in-depth understanding of the phenomena under investigation. The qualitative approach adopted in this study was appropriate to serve the purpose of this study as it allowed for a rich exploration of the uncertainties and risks associated with transportation infrastructure during disaster response.

The findings of this study revealed that most organizations experienced disruptions on the roads when transporting relief goods to disaster-affected areas, such as flooding, congestion, and traffic. The consequences of these disruptions included delivery delays, multiple re-routing efforts, and failure to supply essential goods to the affected communities. Interestingly, there was a significant disparity in the percentage of respondents reporting such disruptions between federal organizations and others. This disparity may be attributed to the fact that federal organizations are not directly involved in route execution, and their point of distribution may not always be located in the direct disaster-impacted area. The inconsistency in knowledge about road disruptions among different levels of emergency responders could have significant implications for response efforts during emergency situations. It is important for all responders to have a comprehensive understanding of the situation on the ground to coordinate and collaborate effectively.

One common theme that emerged from the discussions with all four sectors of interviewees was the need for formal channels for sharing route information among emergency response organizations. A more efficient and collaborative approach is sought for ensuring accurate and up-to-date information about road conditions. The lack of formal channels of communication was seen as a significant challenge in disaster response efforts, which could lead to delays in decision-making as well as route execution, ineffective allocation of resources, and duplication of efforts. The participants stressed the need for standardized mechanisms for sharing route information, including road status, availability of future routes, the exact location of the road closure, weight restrictions on roads, and bridge heights. These findings underscore the importance of creating effective communication and collaboration mechanisms among different stakeholders involved in disaster response efforts to ensure timely and coordinated distribution of relief goods. One important finding of this study was the role of drivers in providing real-time information about route conditions during disaster response efforts. Participants noted that drivers maintain a vast network of contacts and are often a more reliable source of information than formal channels. This highlights the importance of leveraging drivers as a valuable resource for gathering information and making real-time decisions during emergency situations.

One possible direction for future research is to investigate the effectiveness of different communication and collaboration mechanisms in disaster response efforts. This could involve testing different protocols and technologies in simulated disaster scenarios to identify best practices and potential areas for improvement. Future research could investigate ways to better integrate drivers into disaster response efforts and leverage their knowledge and expertise to enhance transportation infrastructure and response efforts. Another future direction could be to investigate ways to involve communities in the planning and decision-making process to ensure that their needs and perspectives are incorporated into disaster response efforts. More in-depth research can be conducted on the perspectives and experiences of NPOs as well involving investigating the varying levels of involvement and participation of different NPOs in disaster response. Finally, future research could explore the potential of emerging technologies such as artificial intelligence, blockchain, and the Internet of Things in creating a common communication platform to enhance transportation infrastructure and response efforts.

Through the use of real-life data and insights from emergency responders, this research seeks to develop more effective and adaptive solutions to disaster relief routing. By addressing the gap in the existing literature and providing practical insights and recommendations, this research can help to improve the effectiveness and efficiency of disaster relief efforts, ultimately leading to better outcomes for affected populations.

References

Aliakbari, A., Rashidi Komijan, A., Tavakkoli-Moghaddam, R., & Najafi, E. (2022). A new robust optimization model for relief logistics planning under uncertainty: a real-case study. Soft Computing, 26(8), 3883-3901.

Amideo, A. E., Scaparra, M. P., & Kotiadis, K. (2019). Optimising shelter location and evacuation routing operations: The critical issues. European Journal of Operational Research, 279(2), 279-295.

Anaya-Arenas, A. M., Renaud, J., & Ruiz, A. (2014). Relief distribution networks: a systematic review. Annals of Operations Research, 223, 53-79.

Auf der Heide, E (1989). Disaster response: Principles of preparation and coordination. St. Louis, MO: Mosby, Incorporated.

Baharmand, H., Comes, T. and Lauras, M., 2017. Managing in-country transportation risks in humanitarian supply chains by logistics service providers: Insights from the 2015 Nepal earthquake. International journal of disaster risk reduction, 24, pp.549-559

Balcik, Burcu, Benita M. Beamon, Caroline C. Krejci, Kyle M. Muramatsu, and Magaly Ramirez. "Coordination in humanitarian relief chains: Practices, challenges and opportunities." International Journal of production economics 126, no. 1 (2010): 22-34.

Bealt, J., Barrera, J. C. F., & Mansouri, S. A. (2016). Collaborative relationships between logistics service providers and humanitarian organizations during disaster relief operations. Journal of Humanitarian Logistics and Supply Chain Management.

Beiki, H., Seyedhosseini, S. M., Mihardjo, L. W., & Seyedaliakbar, S. M. (2021). Multiobjective location-routing problem of relief commodities with reliability. Environmental Science and Pollution Research, 1-10.

Blecken, A., Hellingrath, B., Dangelmaier, W., & Schulz, S. F. (2009). A humanitarian supply chain process reference model. International Journal of Services Technology and Management, 12(4), 391-413.

Bozorgi-Amiri, A., & Khorsi, M. (2016). A dynamic multi-objective location–routing model for relief logistic planning under uncertainty on demand, travel time, and cost parameters. The International Journal of Advanced Manufacturing Technology, 85, 1633-1648.

Çelik, M., Ergun, Ö., Johnson, B., Keskinocak, P., Lorca, Á., Pekgün, P., & Swann, J. (2012). Humanitarian logistics. New Directions in Informatics, Optimization, Logistics, and Production, 18–49.

Chang, K. H., Hsiung, T. Y., & Chang, T. Y. (2022). Multi-Commodity distribution under uncertainty in disaster response phase: Model, solution method, and an empirical study. European Journal of Operational Research, 303(2), 857-876.

Chang, K., Zhou, H., Chen, G., & Chen, H. (2017). Multiobjective location routing problem considering uncertain data after disasters. Discrete Dynamics in Nature and Society, 2017.

Cozzolino, A. (2012). Humanitarian logistics and supply chain management. In Humanitarian logistics (pp. 5-16). Springer, Berlin, Heidelberg.

Elo, S., & Kyngäs, H. (2008). The qualitative content analysis process. Journal of Advanced Nursing, 62(1), 107–115.

FEMA Preliminary Disaster Assessment Guide (2020). Retreived from https://www.fema.gov/sites/default/files/2020-07/fema_preliminary-disaster-assessment_guide.pdf

Ghasemi, P., Goodarzian, F., & Abraham, A. (2022). A new humanitarian relief logistic network for multi-objective optimization under stochastic programming. Applied Intelligence, 52(12), 13729-13762.

Gralla, E., Jarrod G., and Charles F. (2016). Problem formulation and solution mechanisms: a behavioral study of humanitarian transportation planning. Production and operations management, 25 (1) 22-35.

Heaslip, G., Sharif, A.M. and Althonayan, A. (2012), "Employing a systems-based perspective to the identification of inter-relationships within humanitarian logistics", International Journal of Production Economics, Vol. 139 No. 2, pp. 377-392.

Heaslip, Graham, and Elizabeth Barber. "Using the military in disaster relief: systemising challenges and opportunities." Journal of Humanitarian Logistics and Supply Chain Management (2014).

Holguín-Veras, J., Pérez, N., Ukkusuri, S., Wachtendorf, T., & Brown, B. (2007). Emergency logistics issues affecting the response to Katrina: a synthesis and preliminary suggestions for improvement. Transportation research record, 2022(1), 76-82.

Holguin-Veras, J., Pérezc, N., Jallerc, M., Van Wassenhove, L.N. and Aros-Verac, F. (2013), "On the appropriate objective function for post-disaster humanitarian logistics models", Journal of Operations Management, Vol. 31 No. 5, pp. 262-280.

Khorsi, M., Chaharsooghi, S. K., Kashan, A. H., & Bozorgi-Amiri, A. (2021). Pareto-based grouping meta-heuristic algorithm for humanitarian relief logistics with multistate network reliability. Or Spectrum, 43(2), 327-365.

Kovacs, G., & Moshtari, M. (2019). A roadmap for higher research quality in humanitarian operations: A methodological perspective. European Journal of Operational Research, 276(2), 395-408.

Kovács, G., & Spens, K. M. (2009). Identifying challenges in humanitarian logistics. International Journal of Physical Distribution & Logistics Management, 39(6), 506–528.

Kovacs, G., Moshtari, M., Kachali, H., & Polsa, P. (2019). Research methods in humanitarian logistics. Journal of Humanitarian Logistics and Supply Chain Management.

Lawrence, J.-M., Hossain, N. U. I., Rinaudo, C. H., Buchanan, R. K., & Jaradat, R. (2022). An approach to improve hurricane disaster logistics using system dynamics and information systems. In Recent Trends and Advances in Model Based Systems Engineering (pp. 699–712). Springer.

Lee, H.W. and Zbinden, M. (2003), "Marrying logistics and technology for effective relief", Forced Migration Review, Vol. 18, pp. 34-5.

Leiras, A., de Brito Jr, I., Peres, E. Q., Bertazzo, T. R., & Yoshizaki, H. T. Y. (2014). Literature review of humanitarian logistics research: trends and challenges. Journal of Humanitarian Logistics and Supply Chain Management.

Martinez, Alfonso J. Pedraza, Orla Stapleton, and Luk N. Van Wassenhove. "Field vehicle fleet management in humanitarian operations: A case-based approach." Journal of operations management 29, no. 5 (2011): 404-421.

Mohammadi, S., Darestani, S. A., Vahdani, B., & Alinezhad, A. (2020). A robust neutrosophic fuzzy-based approach to integrate reliable facility location and routing decisions for disaster relief under fairness and aftershocks concerns. Computers & Industrial Engineering, 148, 106734.

Nelan, M. M., Wachtendorf, T., & Penta, S. (2018). Agility in disaster relief: a social construction approach. Risk, Hazards & Crisis in Public Policy, 9(2), 132-150.

Nodoust, S., Pishvaee, M. S., & Seyedhosseini, S. M. (2023). Vehicle routing problem for humanitarian relief distribution under hybrid uncertainty. Kybernetes, 52(4), 1503-1527.

Sabouhi, F., Bozorgi-Amiri, A., & Vaez, P. (2021). Stochastic optimization for transportation planning in disaster relief under disruption and uncertainty. Kybernetes, 50(9), 2632-2650.

Sentia, P. D., Abdul Shukor, S., Wahab, A. N. A., & Mukhtar, M. (2023). Logistic distribution in humanitarian supply chain management: a thematic literature review and future research. Annals of Operations Research, 1-27.

Simpson, N. C., and Philip G. Hancock. "Fifty years of operational research and emergency response." Journal of the Operational Research Society 60, no. sup1 (2009): S126-S139.

Sirbiladze, G., Kacprzyk, J., Lozano, J. A., Ghvaberidze, B., Midodashvili, B., & Matsaberidze, B. (2022, October). Fuzzy Approach to Planning of Service Centers Location and Goods Transportation Routes in the Disaster Region. In 2022 IEEE 11th International Conference on Intelligent Systems (IS) (pp. 1-5). IEEE.

Szajnfarber, Zoe, and Erica Gralla. "Qualitative methods for engineering systems: Why we need them and how to use them." Systems Engineering 20, no. 6 (2017): 497-511.

Toathom, T., Promsuk, N., & Champrasert, P. (2021, August). Genetic Algorithm with Boosting based on Expected Value for Uncertain Routing. In 2021 International Conference on Science & Contemporary Technologies (ICSCT) (pp. 1-6). IEEE.

Tomasini, R. M., & Wassenhove, L. N. V. (2009). From preparedness to partnerships: Case study research on humanitarian logistics. International Transactions in Operational Research, 16(5), 549–559.

Trunick, P. A. (2005). Logistics when it counts. Logistics Today, 46(2), 38.

U.S. Hurricane Strikes by Decade. (n.d.). Retrieved October 25, 2022, from https://www.nhc.noaa.gov/pastdec.shtml

Vahdani, B., Veysmoradi, D., Noori, F., & Mansour, F. (2018). Two-stage multi-objective location-routing-inventory model for humanitarian logistics network design under uncertainty. International journal of disaster risk reduction, 27, 290-306.

Van der Laan, E. A., De Brito, M. P., Van Fenema, P. C., & Vermaesen, S. C. (2009). Managing information cycles for intra-organisational coordination of humanitarian logistics. International journal of services technology and management, 12(4), 362-390.

Veysmoradi, D., Vahdani, B., Farhadi Sartangi, M., & Mousavi, S. M. (2018). Multi-objective open location-routing model for relief distribution networks with split delivery and multi-mode transportation under uncertainty. Scientia Iranica, 25(6), 3635-3653.

Zhang, J., Liu, Y., Yu, G., & Shen, Z. J. (2021). Robustifying humanitarian relief systems against travel time uncertainty. Naval Research Logistics (NRL), 68(7), 871-885.

Appendix A

1. When responding to disasters, what is the scope of your organization's responsibilities and the authority you have to deploy resources?
2. What are the three most recent events that you have needed to respond to, and their relative magnitudes? Please elaborate on level of resources (personnel, equipment, supplies, capital, etc.) deployed in response to this event.
3. What type of transportation activities were required to achieve your response goals in the events described in the prior questions? Please summarize different types of vehicles and personnel required.
4. What type of transportation plans were developed in advance of this event to achieve your response goals?
5. How often were transportation plans revisited, before and during the event (hourly/daily/weekly)?
6. What types of changes were made to transportation plans (Routes, loads delivered, etc.)?
7. In the course of responding to this event, how did plans need to be modified in light of the situation? For example, were roads blocked by traffic or event related damage?
8. Which response goals were accomplished? Please describe how your transportation plan enabled this outcome.
9. What tools or information increased your capacity to respond to the events? Would you change these in any way?
10. Are there any tools or information which, if you had or were more effective, could have helped achieve your response goals?

11. What constraints restricted your organization's response in terms of overall capacity, delays in deployment, or increased response times?
12. How did you overcome these constraints?
13. Where are the demand points, how many of the points exist, how many shipments were each receiving, etc.?
14. On what timeline are truckload shipments to the demand points happening (24 hours after? 48?) How did uncertainty (especially on road status) impact these shipments which group makes decisions in terms of what demand points needed shipments and the relative priorities among them?
15. Once a decision was made to send a shipment to a demand point, what operational details made that happen (e.g., how were trucks and drivers matched to loads, who “owned” the transportation resources, etc.)
16. Is there anything else you would like to add?