

Challenges To Maintaining Disaster Relief Supply Chains In Island Communities: Disaster Preparedness And Response In Honolulu, Hawai'i

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Abstract

Due to global warming and rising sea levels, Honolulu, Hawai'i—a city on a remote island in the Pacific Ocean—is becoming more vulnerable to climate disasters. This article utilizes a mixed-method approach to investigate the challenges of maintaining disaster relief supply chains in the face of the emerging risks to Honolulu. We conduct eighteen in-depth interviews with key emergency management stakeholders to understand current approaches to supply chain risk management. Based on the research, three main challenges influence disaster preparedness in Hawai'i. First, the physical location of the island and the spatial distribution of risk, assets, and capabilities supporting emergency relief present large, unusual constraints not found in other jurisdictions. Second, the challenges of supply chain management, planning, communications and coordination are exacerbated during disruptions and disaster events. Unlike other states, with neighboring, contiguous jurisdictions, there are severe limitations to mutual aid and assistance from outside sources. Third, our research has also identified cultural challenges associated with social, political, and economic development and change. Stronger institutional collaboration both within the state and beyond its boundaries are key to increased supply chain resilience and effective response and recovery from disasters. We conduct social network analysis focusing on measures of density, degree, betweenness, and centrality to better understand the status and gaps in institutional collaboration. The social network analysis reveals that the current levels of collaboration are relatively low with significant gaps between government agencies and the private sector, as well as limited vertical collaborations with respect to supply chain management between federal, state and local partners. There is a need for stronger leadership with deeper engagement across stakeholders. A pathway forward includes: 1) vulnerability analyses focused on private sector supply chain management and public sector transport hubs, networks, and facilities, 2) exercises and training on emergency supply chain management, and 3) longer-term actions to support sustainability, self-sufficiency, local production, and community resilience. Our research is relevant not just to Hawai'i and other island and isolated communities but also to communities threatened by supply chain disruptions.

1 Introduction

With an increased understanding of climate change and the threats to human security, it is crucial to focus on high-risk locations where the potential harm is greatest. More frequent and intense flooding from rising sea levels and storm surges has increased the risk of delays, disruptions, and damage across the infrastructure systems (Savonis et al. 2008). Recurrent flooding occurs in low-lying areas of Washington, D.C, Maryland, Virginia, New Jersey, San Francisco, and South Florida (Ayyub et al. 2012). Coastal communities have also been struck by major storms such as Hurricane Katrina (2005), Ike (2008), Irene (2011), Sandy (2012), Harvey (2017), Irma (2017) and Ida (2021). The frequency and magnitude of weather hazards are projected to increase with climate change (IPCC, 2021). The damage to critical infrastructure, lifelines and emergency facilities exacerbates emergency response, relief, and recovery operations.

The disaster relief supply chain provides essential goods to support the economy and community when transportation networks and other systems are disrupted and overwhelmed (Day et al. 2012). The need for supply chain resilience becomes even more prominent with the threats of climate change. Disaster relief supply chains could mean the difference between life and death (Day et al., 2012), especially critical for island communities. Because of geographic isolation, they are largely left on their own for resources following disruptive events. Island communities such as Hawai'i are exposed to multiple weather-related events such as hurricanes, tropical storms, heavy rainfall, high winds, as well as other hazards including high tides, king tides, earthquakes, tsunamis, volcanoes, and sea level rise. The risk is exacerbated because of the development, urbanization in coastal areas and areas prone to flooding.

With Hawai'i's susceptibility to coastal hazards, topography, rising sea-levels, remoteness, and heavy dependence (over 90%) on imported goods and fuel (Keener 2013), the disaster relief supply chain is extremely vulnerable and exposed to many possible disruptions. We use mixed methods to investigate the key factors relevant to Hawai'i's disaster relief preparedness for coastal hazards and the island's disaster supply chain resilience. Using information collected from stakeholder interviews and social network analysis, the vulnerabilities and strategies for improving resilience are analyzed. The research contributes to both a broader understanding of disaster resilience and specific actions to increase disaster supply chain resilience.

2 Literature Review

It is beneficial to define disaster relief supply chains in order to specify the scope of this study. Relief has been defined by Wood and colleagues (1995) and Kovács and Spens (2008: 101) as "a foreign intervention into a society to help local citizens." Kovács and Spens (2008) distinguish between two types of humanitarian logistics: continuous aid work and disaster relief. Disaster relief addresses sudden onset catastrophes as opposed to continuous, ongoing aid which arises from poverty and chronic conditions. Many catastrophes result from natural hazards, but some are caused by conflict, industrial accidents, and other man-made threats. For this study, we follow Day et al. (2012: 24) and use the broader definition of disaster put forth by the International Strategy for Disaster (2004: 3) as "A serious disruption of society's function, posing a significant, widespread threat to human life, health, property, or the environment, whether caused by accident, nature or human activity, and whether developing suddenly or as a result of complex, long-term processes."

Disaster relief supply chain management finds its roots in private sector supply chain management. Relief supply chain management can be similar to ordinary supply chain but during a disaster, the goals, means, operations, and measures of success are different. During normal operations, the end goal is based on monetary exchange, profit-seeking, and the selling and purchase of goods and services. With disaster relief, for the most part, the end consumer typically does not pay directly for goods nor are prices set by markets, and recipients of relief supplies may have less opportunity and choice over products than during normal times. Food, water, medicine, and other emergency supplies may be necessary for survival and not allocated through the normal channels and systems for trade and commerce. Disaster relief

actors must efficiently supply impacted communities in order to save lives and reduce harm while under constraints and objective functions that are different from normal operations (da Costa et al. 2012). These humanitarian goals of saving lives and providing emergency supplies during disaster events are outside of traditional logistic services. While disruptions to supply chains can also negatively affect revenue and costs, urgent needs and support for individuals, households, and communities which have lost access to goods and services to maintain survival and health place additional burdens, responsibilities, and requirements on supply chains.

Note that in this paper, we are not considering the entirety of the supply chain, and will not be reviewing nor addressing global systems for production, packaging, processing, and labeling nor all of the transportation and distribution systems and networks that support overall management and operations of supply and demand. Instead, our study focuses on those nodes and links of the supply chain that comprise the disaster relief distribution network. While understanding of the movement of goods comes from private sector operations and the need to procure and ship products, the scope of this study on disaster relief in general focuses more narrowly on what the public sector and its partners can do within a specific high risk environment could do to improve its disaster relief supply chain resilience.

2.1 Disaster relief supply chain resilience

The concept of resilience has been advanced by multiple disciplines, including engineering, ecological and urban systems. This conceptual background provides a useful framework from which supply chain resilience has developed (Pettit et al. 2010: 3). A supply chain's resilience affects disaster relief and humanitarian situations because it constitutes the chain's engineered and managerial strength vis-à-vis shocks. In island communities, this means that the continued supply of necessities to communities during a crisis is partially dependent on supply systems' resiliency.

As initially defined in Holling's (1973) article, resilient systems have two distinct properties. First, they possess the ability to absorb changes. Second, they can return to an equilibrium state after a temporary disturbance. The faster a system returns to normalcy after a disturbance, the greater its resilience (Ponomarov and Holcomb 2009: 125). The concept has been refined to include the "capacity of a system to undergo disturbance and maintain its functions and controls (Carpenter et al. 2001: 765)." Applied to supply chains, the concept of resilience builds on studies of risk and vulnerability. Supply chain managers and stakeholders utilize techniques to ensure supply chain functioning even under disruptive conditions. Increased flexibility, robustness, redundancies, agility, adaptability, and visibility are capabilities by which supply chains can quickly reorganize and continue functionality and increase resilience to hazards and threats (Miao et al., 2013; Pettit et al. 2010: 6).

Ponomarov and Holcomb (2009) provide a definition of supply chain resilience as "the adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function." A similar definition is offered by Ponis and Koronis (2012: 921): "the ability to

proactively plan and design the supply chain network for anticipating unexpected disruptive (negative) events, respond adaptively to disruptions while maintaining control over structure and function and transcending to a post-event robust state of operations, if possible, more favorable than the one before the event, thus gaining competitive advantage.” Both definitions contain three stages: a proactive stage or preparedness for a shock, a reactive stage or a response to a shock when it occurs, and a transition stage or the longer-term recovery from the response state to a new state altogether.

These three stages inherent in the definition of resilience can be adapted and extended to support disaster management. The proactive stage includes hazard mitigation and disaster preparedness. The reactive stage includes emergency response. Finally, the transition stage includes disaster recovery (Ponomarov and Holcomb 2009: 129). On this last note, the question remains whether a supply chain should return to its previous equilibrium state after an initial disruption (Pettit et al. 2010: 4). Given disruptions, the opportunity exists to be seized such that the supply chain is built back better than before (Davidson 2006: 36). Knowing the definition of resilience is necessary for determining measurements and knowing what the resiliency returns to. This study focuses on developing effective long-term planning strategies in the proactive stage to prepare for an efficient reactive stage.

2.2 Governmental limitations and difficulties in disaster relief supply chain management

Since many infrastructures are constructed and maintained by governmental agencies, when disaster relief supply chains are investigated, conversations center on governmental roles and responsibilities (Dayhim et al. 2014; Rampersad et al. 2020; Yuan et al. 2020). Governments, however, face limitations and challenges in coping with disasters. First of all, based on the bureaucratic structure design and implementation, all disaster management relevant responsibilities and powers are distributed throughout various departments. Design and construction responsibilities of highways, for example, fall under the Department of Transportation. Whereas evacuation and transportation of people to safe locations after disasters might be assigned to Emergency Management (EM) relevant agencies (e.g., fire departments, police departments, and local EM offices). Also, the fragmented governmental structure makes information transition difficult between various departments and levels of government. Consequently, responders have difficulties understanding the holistic picture of disaster response (Miao et al., 2013; Schneider 2011; Sylves, 2015). As a result, without regular planning and communication, one common limitation of planning for disasters is people from different organizations often assume other individuals or agencies might take care of specific disaster management functions and roles during disasters.

For instance, Chang and colleagues (2018) found that emergency managers in Oklahoma realize collaboration in disaster planning is imperative, but often assume other EM organizations would collaborate with them to establish a plan to prepare for and respond to all hazards in the jurisdiction. During discussions with EM stakeholders, it was found that they were only required to update their areas of expertise and contact information in the disaster planning processes. To improve this situation, many

EM researchers suggested increasing conversations and cooperation between various governmental departments and organizations during disaster planning processes (Alexander 2002; Bhandari et al. 2014; Comfort 2007; Dynes 1994). Some researchers also suggest organizing more inter-organizations disaster exercises or events to strengthen teamwork between response organizations (Fisher 1998; Lindell and Perry 2007; Moynihan 2009; Sutton and Tierney 2006).

Also, given that many disasters strike small jurisdictions in a short period, it seems some local governments might not be interested in investing in long-term disaster management plans and systems—including the relief supply chain system. As a result, many local governments feel pressure to allocate money to seemingly more urgent needs and issues (for more discussion, see Sylves 2015: 10-13; and Renne et al. 2020: 5-8). It is not just that the long-term disaster plans and systems are not top priorities for the governments. If disasters do not strike a certain area for a while, citizens tend to assume the impacts are mild, and thus they do not expect and prepare for disastrous scenarios. This routinely creates cultural challenges in coping with disasters.

2.3 Cultural challenges in coping with disasters

Culturally, people develop specific beliefs toward natural disasters (Appleby-Arnold et al. 2021; Benadusi 2014; Mercer et al. 2012). Previous experience may influence risk perceptions and those perceptions can determine how people prepare for and respond to disasters (Oven and Bankoff 2020; Xu et al. 2019; Yong et al. 2017). Those living in disaster-prone areas are more likely to develop memories and cultural knowledge of hazards, which may encourage them to prepare for, respond to, and manage disasters (Warner et al. 2019). Prior experience, however, could serve as a double-edged sword (Dow and Cutter 1998; Plümper et al. 2017). On one hand, people who've experienced damage from disasters may increase their preparedness (Onuma et al. 2017). On the other hand, if repeated, previous disasters did not produce harmful consequences, impacted persons may be less likely to take future disasters seriously or be somewhat complacent about the potential for harm (Onuma et al. 2017). In Honolulu, while hurricane warnings are quite frequent, most of them didn't make direct landfall on the island and only caused minor or no damage in recent years. Dow and Cutter (1998) describe the "cry wolf" syndrome associated with repeated warnings or predictions of dire consequences which did not materialize during hazard events. There are complexities associated with the assessment of risks, trust in official information, and preparedness actions (Dow and Cutter 1998). Furthermore, disaster-prone areas usually invest heavily in protective infrastructure, which may encourage settlement in hazard-prone locations and nurture a false sense of security, preventing people from relocating to safer places or taking preparedness precautions (Kelman et al. 2016; Onuma et al. 2017, Yuzal et al. 2017).

3. Study Area

Due to its remote location in the Pacific Ocean, Hawai'i faces unique disaster relief supply chain challenges. Unlike the continental United States, options for mutual aid and pre-positioning disaster relief

goods in adjacent states are limited. This creates challenges in delivering relief and supporting recovery if impacted by a large weather event. Kim and Bui (2019) studied the impacts of Hurricane Maria on Puerto Rico and applied the lessons learned as to supply chain management to Honolulu's main port for a catastrophic hurricane event.

Within the Hawaiian context, due to the remote location, and the fact that Hawai'i is an archipelago, the harbors play an imperative role in its supply chain. There are ten commercial harbors on six islands of Hawai'i (O'ahu, Molokai, Hawai'i, Kaua'i, Maui, and Lāna'i). Honolulu Harbor on the island of Oahu acts as the hub for inter-island cargo, as well as cargo coming to Hawai'i from the mainland United States (Harbors 2020). The role that Honolulu Harbor plays in receiving goods and supplies from elsewhere cannot be stressed enough. The capacity that Honolulu Harbor has, no other harbor on the Hawaiian Islands can match. Therefore, the functioning of the Honolulu Harbor is essential to the supply chain for Hawai'i.

In addition to having the largest port and main airport, the island of Oahu is the third largest Hawaiian island by area and home to approximately one million people, two-thirds of the population of Hawai'i. Oahu is the center for economic activity, social, educational, health, and services in Hawai'i. It also hosts, on average, over 4.5 million tourists every year (Hawai'i Tourism Authority 2015). The City and County of Honolulu has jurisdiction over the entire island of Oahu, and the state capital is located in Honolulu. Dominated by two large mountain ranges, the island's highways and development are concentrated in low-lying coastal areas, making it particularly vulnerable to flooding, hurricanes, and tsunamis. With projected sea-level flooding risk is expected to worsen. Since 2016, the observed water levels have been 3–6 inches above predicted tidal heights (Knapman, 2017). In late April 2017, levels peaked at more than 9 inches above predicted tides at the Honolulu Harbor tide gauge, resulting in the highest daily mean water level observed over the 112-year record (Knapman, 2017). Rotzoll and Fletcher (2013) project that 0.6 meters of potential sea-level rise would cause substantial coastal flooding and a 1-meter sea-level rise would inundate 10% of a 1-kilometer wide heavily urbanized coastal zone in Honolulu. Furthermore, the rising sea level will provide a higher water base from which storm surges can move further inland, leading to an increased frequency and magnitude of extreme coastal flooding (Beatley 2012) and even more than double the frequency of extreme water-level events in the Tropics (Vitousek et al. 2017).

Given its large population, social and economic activity and high exposure, the City and County of Honolulu has been selected as the case study area. Land is limited and expensive on Oahu, which also limits development of warehouses and storage facilities. Many goods delivered to Honolulu and subsequently the rest of the state operate on a "just in time" basis. In the face of these challenges, the disaster relief supply chain stakeholders must work collaboratively to address these limitations and constraints and improve delivery efficiencies for disaster relief goods to those in need. Our research examines the factors and constraints that influence disaster relief preparedness in the face of coastal hazards and threats. Using detailed interviews, we identify factors and challenges that significantly affect the disaster relief supply chains.

4. Methodology

This research was conducted using a mixed-methods approach. Qualitative, in-depth interviews with stakeholders were conducted and analyzed through a data-driven deductive coding scheme coupled with organizational network analysis. Researchers conducted semi-structured interviews with opportunities for unexpected information to surface with regard to disaster relief supply chain resilience in Hawai'i. (See Appendix A for the Interview Questions).. Participants in this research were identified through preliminary interviews with personnel from the Hawai'i Emergency Management Agency (HIEMA). Through this process, we sought to understand the factors that influence disaster relief supply chain resilience and how supply chains would be impacted by coastal hazards (e.g., sea-level rise, storm surge, hurricane, and tsunami) in Hawai'i. Key questions of the interview included the role of crucial stakeholders; their primary concerns; organizational capacity, and constraints susceptible to unstable environmental conditions; plans and challenges for responding to coastal hazards.

Purposive case sampling and snowball sampling methods (Patton 2002) were utilized to engage key stakeholders with targeted backgrounds, including federal, state, and local agencies, transportation agencies and operators, non-profit organizations, and private sector firms. Through an analysis of the data collected, this research identifies current gaps in disaster relief preparedness leading to possible strategies to cope with coastal hazards, and increase the resilience of disaster relief supply chains.

To use the typical case sampling method (Patton 2002), researchers worked with HIEMA to identify key supply chain stakeholders. At the conclusion of every interview, researchers asked each interviewee to recommend additional interviewees to answer questions to broaden participation in the research. This resulted in a total of 18 interviews with stakeholders from state and local government, non-profit organizations, private companies, academia, suppliers, shipping industry, food industry, energy sector, environmental service, and infrastructure/facility management. Forty-four percent of the interviewees come from government agencies, 22% come from the private sector, and 33% come from non-profit organizations and community groups. Among all government agencies, half comes from the state, and another half comes from local government. Our sample has a diverse representation of various stakeholders involved in supply chain management and operations.

Wordings of interview questions were carefully constructed, tested, and revised in advance and paired with follow-up questions to probe for subsequent information. The data collection and analysis were guided by the grounded theory, which aims to understand the small-scale environment and micro-activities where little previous research has occurred (Grbich 2013). The questions and protocol were reviewed and approved by the Internal Review Board of the University of Hawaii prior to conducting interviews and compiling data.

All interviews were transcribed into text for further analysis. Based on the research questions and the response, a coding scheme was developed. To test and validate the coding scheme, two researchers used it to individually analyze a subset of five transcriptions and compared their results for consistency, comparability, and uniformity of results. During this process, the research team discussed and resolved

differences in definitions of categories and coding rules. When sufficient consistency had been achieved, the transcripts were then analyzed using computer software (i.e., QDA Miner Lite and Atlas.ti) to analyze the transcriptions and identify prevalent themes for each of the following focus areas categorized by the data-driven codes (Table 1):

- Existing plans and challenges
 1. Strategies
 2. Challenges
- Major concerns and gaps
 1. Status quo
 2. Causes of challenges
 3. Decision-making constraints
- Key factors and constraints in decision making
 1. Normal and extreme capacity
 2. Scenarios and impact

Table 1-Data-driven Codes

Theme	Codes
1. Existing challenges	Major challenges to transporting resources and materials to those areas impacted by disasters
	1-a Strategies for overcoming difficulties
	1-b Do not implement the current plan
	1-c Do not have back-up plans
2. Major concerns	Major concerns to prepare for disasters
	2- Do not understand the current situations, so cannot plan for disasters
	a 2- Suggest contacting other organizations for further information a-a
	2- The only plan for those possible hazards a-b
	2- Misunderstand the meaning of the all-hazard approach a-c
	2- Lack of Information a-d
	2- Responsibilities are from different departments, so cannot plan for b disasters in a holistic way
	2- Assumptions c
	2-c- Believe another organization will help a
	2-c- Believe situation would not get worse/can be controlled quickly b
	2-c- Believe internal resources/mechanisms are established if the worst c case happens
	2- The worst scenario d
	3. Key factors
3-a Resources (The type, amount, and location of resources if existing)	
3-b Impact (The type and location of vulnerable infrastructure)	
3-c Scenarios (Scenarios that the interviewees are concerned about or planning for)	
3-d Process (Planning process including the data source, method, timeline)	
4. Suggestions	Suggestions on better preparing for disasters in the future

As assumptions about external collaborations were frequently raised as major concerns in the interviews, there is a need to better understand the current status and gaps in stakeholder collaboration. Network analysis was then performed on data from the interviews to analyze the nature and extent of collaboration between institutions and among stakeholders. It is widely acknowledged in the literature that the analysis of the linkages between institutions is as important as the analysis of individual institutions in building local adaptive capacity and resilience (Jaja et al. 2017; Keskitalo 2010; Young and Gasser 2002). Collective resources and collaborations among a wide range of institutions are required during the resilience building process (Jaja et al. 2017). Research has revealed the importance of vertical and horizontal integration of institutions in building climate change adaptive capacity (Davies 2005; Ingold 2014).

Social Network Analysis (SNA) has emerged in recent years as a powerful tool to assess institutional networks and interactions within the network. We use SNA to evaluate the institutional collaboration among different stakeholders involved in disaster relief supply chains. Four commonly applied SNA measures, including network density, average degree, betweenness centrality, and closeness centrality (Bodin and Crona 2009; Jaja et al. 2017; Luthe et al. 2012), are used to evaluate the status quo, potential, strength, and limitations in the current institution collaboration. In particular, network density represents the current status quo of collaborations as a proportion of the maximum number of potential connections in the network (Borgatti 2018). High density, compared to similar-sized networks, is found to strengthen trust, facilitate information sharing, and thus correlate positively with adaptive capacity (Borgatti et al. 2018; Jaja et al. 2017; Olsson et al. 2004). While network density represents the overall status quo and potential collaboration within the network (i.e., network degree), it reflects how collaborative each institution (i.e., node) interacts with others.

The average network degree, which is the average number of connections of all nodes, is calculated to identify the degree to which a single node dominates the connection of the network. Network centrality is a factor that affects adaptive capacity (Jaja et al. 2017). While high centralization may increase the ability for central institutions to prioritize and coordinate activities (Sandström 2009), it may sometimes lead to problems of power, legitimacy, and underrepresentation (Ernstson et al. 2008). Betweenness centrality measures the extent to which an actor locates in the shortest path between two other actors in the network. A higher level of betweenness centrality indicates the actor could act as a bridge between institutions that would otherwise not be in contact to facilitate information, resources sharing, and network integration (Jaja et al. 2017). Finally, closeness centrality, measured by the average graph distance from a given node to all other nodes in the network, helps to identify good “broadcasters” that well connect with others either directly or indirectly. Gephi, an open-source software is used to perform the social network analysis (Bastian et al. 2009).

5. Findings

Based on the interviews we conducted, there are diverse challenges that influence the disaster preparedness in Hawai'i. These challenges include: 1) Geographic challenges, 2) Governmental

challenges, 3) Information availability, and 4) Cultural challenges.

5.1 Geographic Challenges

Due to the geographic limitations, preparing for and responding to natural disasters is difficult on the Hawaiian Islands. Since land and space are confined on the islands, many communities live along the shoreline, and consequently, most access points are historically along the shoreline. Once a natural disaster generates heavy rainfall and extensive weather conditions, water from the Pacific Ocean quickly impacts those communities.

Although emergency managers can utilize disaster warning systems, assign alternative transportation routes, and order mass evacuations in these areas to mitigate disasters, geographic limitations make these EM strategies less effective. As an interviewee who is working for a local community preparedness organization said: “We have one road going around the island, that if that was impacted it would cut off transportation for us.” Not only would the major roads be impacted and thus halt citizens from leaving their communities, even if people could access the roads, they’d have limited places to go. As an emergency manager told us: “Even in some cases [...] with a small evacuation timeline, there’s only so many places to go outside of the inundation area, and it’s all on the same road.”

Furthermore, implementing these EM strategies relies on well-maintained infrastructure, but updating these busy systems is difficult due to the limited amount of land. As a result, these aged infrastructures generate challenges on EM in Hawai’i. One important harbor, for example, has only one entrance and exit, which could create a bottleneck in extreme conditions. Once disaster supplies come to the harbor, an interviewee who works for a shipping agency (an agency to be the local liaison for vessels and charter the vessels that come to port) said:

That [the harbor] is definitely a bottleneck and that would be a potential issue with dealing with a disaster, because if we only have one entrance and exit for large ships and container ships, it is going to be a lot more difficult to get ships out or to have a continual flow of traffic.

Therefore, emergency managers in Hawai’i, due to their default limitations, need to establish innovative EM strategies to mitigate to, prepare for, respond to, and recover from disasters.

5.2 Governmental Challenges

Another challenge in managing disasters in Hawai’i is inter-organizational cooperation. Infrastructures are maintained and managed by various organizations and levels of government. The harbor, for instance, is managed by the state government, but those roads connecting to the harbor and airport belong to the local government. To control and monitor maritime transportation, however, is the responsibility of the U.S. Coast Guard. Moreover, land transportation is managed by the Department of Transportation (DOTs) at various levels of government. Therefore, an interviewee from a private company described the challenge of resuming their work after disasters:

A lot of time, the Coast Guard dictates the waterways. The Coast Guard is primarily concerned with Marine Traffic, while DOT Harbors and the Department of Emergency Management [DEM] are concerned with the land side and the health and welfare of people. Those two, you know, we need those two to get [give] a thumbs up so we can start working. In the past, it has been the Coast Guard [that] has opened up, but DOT Harbor and DEM haven't opened the road so we can get workers across the bridge to get onto the terminal, or vice-versa.

In this situation, consequently, during the conversations about response and preparedness, some interviewees assume other organizations or departments will help during disasters. A member of a community disaster preparedness team told us: "We do have one health care institution on our side of the island [...] But we kind of operate under that assumption that the government will be able to step in and help. We just don't know how long of isolation that would be." Another interviewee admitted there is no shared disaster preparedness plan between the EM stakeholders in Hawai'i: "They [the Coast Guard] will always do the underwater survey to make sure that the pier is still structurally sound, in the event of an earthquake. They'll inspect the waterway to make sure there is no debris, so the ships don't run into it when they come back in." The Hawai'i Department of Transportation in Harbor area (Harbor division) was repeatedly mentioned during interviews, with several interviewees believing Harbor division would assist some disaster recovery affairs (such as closing adjacent roads around the harbor to prevent further injuries). Coincidentally, after interviewing the Harbor division, we found this department has limited power and capacity to perform such missions.

To better understand relationships between EM stakeholders, the research team conducted network analyses on the empirical data we collected. Conducting social network analysis helps the researchers to study the relationships between nodes, which is widely applied to study disaster response networks (Feng and Cui, 2020). Doing so contributes to our understanding of the status quo and helps identify gaps in stakeholder collaboration. During the interviews, if one agency mentioned working with another agency or said they have direct contact with another agency, we interpret this as having a channel to communicate, share information, and collaborate. There are 22 institutions forming the network, with a network density of 12.6% and an average degree of 1.5, which is relatively low compared to institutional networks of similar size (Jaja et al. 2017). There are four institutions as central bridge nodes that connect most institutions based on betweenness centrality, all of which are government institutions (i.e., one transportation institution and one environmental institution [Figure 2]; and two EM institutions [Figure 3]). Through indirect connection, there are two private shipping and commercial hauler companies that could serve as information broadcasters measured by closeness centrality (Figure 3). Also measured by closeness centrality, the most marginalized sectors in the network are non-profit organizations, community organizations, commercial retailers, construction companies, policy research institutions, and health sectors. It is worth noting the infrastructure sector—despite its importance—has a relatively low centrality in the network (Figure 3). Environmental agencies, on the other hand, show surprising connections and influence because of the existing administrative structure. Table 1 compares the degree centrality, betweenness centrality, and closeness centrality of different levels of institutions. It indicates in

terms of vertical collaboration that state and local institutions have more connection and centrality compared to regional and federal agencies.

Table 2
Centrality measures by federal, regional state, and local agencies

Agencies	Degree		Betweenness centrality		Closeness centrality	
Federal N=3	min	1	min	0.333	min	0
	max	3	max	0.429	max	17.967
	average	2	average	0.381	average	10.556
	SD	1	SD	0.048	SD	9.387
Regional N=8	min	1	min	0.244	min	0
	max	4	max	0.368	max	20
	average	1.875	average	0.311	average	3.225
	SD	1.126	SD	0.037	SD	7.022
State N=4	min	1	min	0.309	min	0
	max	10	max	0.5	max	73.033
	average	5	average	0.431	average	35.117
	SD	3.916	SD	0.088	SD	40.614
Local N=7	min	1	min	0.273	min	0
	max	10	max	0.512	max	104.500
	average	3.571	average	0.365	average	34.295
	SD	3.823	SD	0.086	SD	47.493

The network analysis results echo the findings from interviews establishing the current level of collaboration between stakeholders is relatively low, and there is much to improve. Due to the enormous number of disaster preparedness and response responsibilities, the responsibilities are inextricably spread across many entities. As a result, interviewees lacked a holistic view of the process. The coordination between different sectors (e.g., infrastructure and environment) and between distinct levels (e.g., regional and local) needs to be improved. In particular, the role of the infrastructure sector needs to

be strengthened as its current role in system collaboration is not proportional to its importance in the process. Federal and regional agencies also need to build more connections to strengthen their communication at the local level to minimize misperception and ensure consistency among different sectors. An individual employed with the state transportation agency told the research team that:

Everybody. From our perspective, everybody whether it's road weather it's airports, harbors or for rail. All of those are going to be impacted by these extreme events in the future. Definitely, for us, we are going to start talking about it from the U.S. DOT. What is the federal highway [agency's] perspective? We're looking at our roadways first, but definitely work with the other agencies [such as] the model agencies to ensure that we are on the same page [...] all of it got to be coordinated.

5.3 Information Availability

Existing information and previous research do not appear to be sufficient for the stakeholders to understand the current situation. There is similarly a lack of information and research to support accurate estimation and planning for the potential hazards. A national non-profit humanitarian organization's regional officer told the research team:

We have generalized versions like with Florida or other places, but here we don't really have enough data to quantify like: how much rain causes a landslide in some of our mountainous terrain? And at what different wind speed does it start to impact certain types of housing? There are some generalized versions of that, but a lot of the products that I've seen just aren't tailored towards Hawai'i.

As a result, an official from a state infrastructure agency estimates there are only limited things they can do to prevent a specific natural hazard (sea-level rising), saying: "We really didn't move forward on any of the improvements that were necessary for the shoreline erosion portion mainly because we didn't know which portions of roads will stay and which one we have to move."

The general lack of data collection to understand local situations and conduct research to prepare for disasters in Hawai'i also connects two discussions in Hawai'i: 1) costs versus benefits, and 2) citizens' expectations.

5.3.1 Costs versus Benefits

Since Hawai'i's population is relatively small and land on the islands is limited (compared to other states in the U.S.) and the fact that previous disasters have not severely impacted the state in recent years, EM appears not to be an urgent priority for the local governments. An interviewee from the Hawai'i Pilots Organization told us:

Some of those kind of things [ways to mitigate impacts and prevent damages from earthquakes] are alleviated by some modification of the engineering and design, but obviously that adds to the cost, which is always the case, especially if it is a state project or a county project. They [state and county officials] are going to weigh the cost of if it is really worth doing all of this extra stuff. There's always that balance

[...] to some degree of addressing those kinds of potential disasters but the public and taxpayers have to judge what is worth the investment versus the likelihood of something happening?

The costs versus benefits discussion are associated with the citizens' expectations for the government administration and the use of public budgets.

5.3.2 Citizens' Expectations

Citizens in Hawai'i are collectively exposed to interruptions resulting from hazards, but they are not passionate about building resilience in the local communities. An interviewee from an energy agency described this mindset as:

There is a low tolerance of people here to have any outages. If you talk to people on the mainland, they are used to maybe in winter having their power go out for a couple of days. In the summer, they are having brownouts or stuff like that. We have become accustomed to a high-reliability standard. But that is not the same thing as resilient power, so we see there is a need to bridge this gap between reliability under blue sky to resiliency under grey sky.

Due to the fact that previous disasters have not generated huge impacts and losses, during normal time residents may be unable to link the resilience of infrastructure systems to the increased threat from disasters. This disconnection is further discussed in the next section on cultural challenges in Hawai'i.

5.4 Cultural Challenges

As we mentioned above, the geographic challenges create hurdles for disaster managers in Hawai'i. These geographic limitations also challenge private sectors and citizens. More specifically, all stores in Hawai'i do not have storage or distribution centers on islands. Thus they develop a "just in time" business model to accommodate the needs. The "just in time" model means an on-demand economy, because the sellers cannot afford the high costs of land to keep warehouses and store goods. An interviewee described the "just in time" model as:

Another issue is the 'just in time' delivery model of operating a business [...] there is a huge cost to storing excess fuel that is not being used. The industry tries to pair them down to exactly what they need between shipments or between production runs or to meet expected demand on the electricity side [...] they don't want to store excess capacity or inventory because it is costly. And so, everything is very tight there is not much slack in the system [...] when you have a complex event where there is multiple disruptions and there is a cascading effect and it takes them out of their normal planning realm that they can address with their normal planning tools that they have. Those are the kind of vulnerabilities in the 'just in time' inventory system that really put us as a state in a vulnerable position.

On one hand, this business model obviously creates difficulties in planning for and responding to disasters and thus makes the Hawaiian Islands vulnerable to disasters, because all materials rely on shipments from the mainland through the Honolulu Harbor, which is aged and suffers design flaws often resulting in gridlock. An interviewer described the harbor operations during disasters as:

Assuming the ports are operational [during a disaster], we would be heading out to the ports and picking up and taking out whatever containers are there and getting it out. Once upon a time people talked about 'Hey, let's unload emergency supplies first' or the most valuable items for emergencies first, but there's no way to tell what's in the containers. There's really no way to pick containers from a ship to unload. Right now, the thought is at least the ports will just unload everything they can, and guys will come down and pick up stuff and hope that the company is in the condition to accept this stuff.

On the other hand, because previous disasters have not created considerable damage, many residents believe those consequences generated from disasters can be controlled quickly. As a result, people are often unprepared for disasters in Hawai'i. A Hawai'i Harbor pilot explains why local residents frequently have inadequate resources, and thus many rush to supermarkets just before or during disasters:

You hear people say things like 'We have enough food on the island to survive about 10 days' or 'We have enough gasoline in the tank to survive a week.' I am telling you, everything you have ever heard about that stuff, it is way less [...] It takes, honestly, just one day to throw things so out of kilter on the schedule with the barges, that it gets kind of panicky.

These three challenges make traditional EM strategies less effective in Hawai'i. For example, one of the traditional EM strategies—establish back-up plans and stock additional resources—appears unpopular in Hawai'i. An interviewee who works for a shipping company's vessel planning center said:

Basically, all of your big-box stores like you mentioned Walmart or Costco, all those kinds of guys they don't have a warehouse or a distribution center here on [the] island. Basically, it goes from ship to yard, to store back to yard, back to ship. So obviously, if there's a disruption and we're late, then there's a disruption in the supply chain. I think most of the retailers probably have less than a week of supply on their shelves. I mean, they do keep a smaller warehouse at the various stores, but I don't think it's enough to keep [the] supply chain going for weeks.

A local government emergency manager discussed their back-up plans: "We don't have a good sense of alternatives if our supply chain fails. Like what does that look like if smaller ships need to go through other ports? What does that timeline become? We don't have a sense of the throughput, like how quickly stuff gets here."

An interviewee from a private company, however, says the missing details mentioned previously (planning for and using those smaller ships) are critical for disaster response:

If there is a disaster that happens, and we are bringing goods to Honolulu Harbor, if any of the roads going to [the] North shore are compromised, how are we going to supply those people on that side of the island with their goods and services? You have to put it on a boat. But we don't have ferries, we have tugboats, we have some water taxis, but it is not in the amount that would be required to bring goods over to that side.

Another traditional EM strategy—establishing alternative infrastructure systems also seems difficult to implement in Hawai'i. A local emergency manager, for instance, explained why Pearl Harbor could not replace the Honolulu Harbor during disasters:

Some people talk about the alternate port to Honolulu Harbor if a disaster strikes—Pearl Harbor. But this is only about 5 miles away from Honolulu Harbor. Also Pearl Harbor is a military harbor, not a logistics harbor. The likelihood that a hurricane or tsunami will hit just on Honolulu Harbor and not the other [infrastructure] is small.

6. Conclusions And Future Work

Small islands are generally more vulnerable to coastal hazards, and their disaster relief supply chains are less prepared for disasters. In Hawai'i, due to the lack of severe hazards in recent years, there is generally a lack of disaster awareness and complacency and widespread belief that plausible worst scenarios may not happen, that disaster events would not get worse, and that hazard situations can be controlled quickly. These optimistic views have resulted in limited development of back-up plans, building warehouses, stockpiling or storage of emergency supplies. The geographic conditions make it difficult to devise alternative infrastructure improvements. For example, the current back-up harbor, Pearl Harbor, is only 5 miles away from the main Honolulu harbor. An extreme event such as a large hurricane or tsunami is might disrupt both facilities. Elevating important buildings and facilities in low-lying areas is also of limited value because roads connecting these facilities would need to be raised as well. Many communities could be stranded by extreme events as there is only one road in and out, which would imperil emergency services as well as the delivery of disaster relief supplies. Stakeholders, in general, also believe that internal resources and mechanisms are already well-established in the event of a large-scale threat, which is not the case. Linkages between large institutions and community organization or non-profit organization groups need to be strengthened to ensure prompt distribution of relief supplies to the communities and the most in need. There is also a collaboration gap between public and private sectors, which the stakeholders are aware of and trying to bridge.

The challenges identified above make it difficult for island communities to apply traditional EM strategies to improve their relief supply chain. Based on these challenges found in interviews, further strategies to improve emergency management of supply chains in Hawai'i include the following: 1) conducting further risk and vulnerability analyses of local supply chains likely to be disrupted by hazard events, 2) developing and delivering more training and exercises to facilitate increased capabilities, coordination, and communication among disaster relief organizations, and 3) increasing long-term response and relief capabilities, self-sufficiency, and community resilience.

6.1 Conducting further risk and vulnerability analyses

Several interviewees suggest we conduct further analyses to identify those vulnerable populations and areas with the emphasis on the resilience of critical nodes like the harbor and the efficiency of local

distribution networks from the port/airport to vulnerable communities. An official from the DOT-Harbors Division describes the vulnerability analyses needed in Hawai'i:

Just testing different scenarios, so if there was a cat. 5 Hurricane what would be the impacts of each harbor. Like can it survive the storm, what would be the supporting facilities that might be at risk, and so forth [...] The pier itself is really resilient but everything else connecting to it is gonna be a challenge [...] even if the harbor can survive, the roadways that need to deliver relief supplies, and that needs to be intact.

To address these concerns, more quantitative assessment of the potential impacts of different hazards scenarios on disaster relief supply chain would be very helpful to identify the bottleneck and to reposition resources accordingly. For example, it would be useful to estimate the current demand and supply for disaster relief with consideration of private partners' capacities for different hazard scenarios, especially hurricanes. This will help to identify the potential capacity gaps. It would also be prudent to identify distribution centers such as grocery stores within the local communities to pre-position essential supplies during the hurricane seasons. An optimization model that helps to select the most suitable warehouses and pre-position back-up supplies would help to expedite the distribution process should any hazard scenario happen. Additionally, it would be beneficial to study the physical upgrade requirements for these distribution centers in order to increase their resilience, for example, through off-grid renewable energy systems and diversified drinkable water supplies.

6.2 Develop and deliver more training and exercises to support disaster supply chain resilience

The network analysis findings emphasize the importance of strengthening the role of certain agencies as the central bridge and information broadcasters in system coordination to reduce fragmentation and foster integration. As shown by the betweenness centrality, government agencies are by nature the most suitable leading or coordinating agencies compared to others. However, to better involve the currently marginalized groups such as non-profit organizations, community organizations, and private companies, it is important to bring out the private partners' potential as information broadcasters, given they have already established the connections. It is also worth noting that more in-depth engagement with the private enterprises is critical and needs to be strengthened, given their important role as actors in the response and recovery process. Finally, the collaboration between different sectors and different levels must be strengthened to minimize misperception, reduce duplicated efforts, and ensure consistency in actions and policies.

Since EM stakeholders in Hawai'i might benefit from further understanding of the holistic disaster plans and better communication between departments, organizations, and private sectors, some interviewees also mention the importance of organizing more disaster exercises and training to facilitate inter-organizational cooperation. As Chang and Trainor (2018) mentioned, establishing pre-disaster trusts and relationships is imperative to successful disaster response. The Hawai'i government should consider

organizing more inter-organizational training or exercise. An interviewee from the State Energy Office, for instance, suggests:

I think having a good common operating picture, where there is information sharing between industry and government in blue skies so that everybody knows what their capacities are and what their vulnerabilities are. When it comes to the actual event, we have a better shared understanding of what it is going to take to get it up and running again.

We believe this can improve disaster preparedness and response in Hawai'i.

6.3 Increasing long-term community resilience

Finally, for communities, many interviewees suggest providing public education programs for citizens to raise their awareness of possible hazards and how to protect their lives. As an interviewee working on the North Shore Preparedness Committee says:

People here just need to be better prepared individually, that is the key. I was here during [Hurricane] Iwa, and we were out of electricity for 10 days out here. At the time I was the manager of my dad's clinic and we couldn't get a generator out here, so in the future there should be a generator there that can be used. In terms of our future plan, we just need to be able to implement it. Getting Red Cross volunteers trained, getting evacuation signs up, focusing on places like Pupukea that should have supplies positioned.

An emergency manager from the Hawai'i Emergency Management Agency explains the future plan regarding coastal hazards response as:

What has to be improved is our [local communities'] ability to be self-sufficient. Counties have to look at their population and determine the pod's contents, power, toilets, staff, equipment, resupply, security. Having laid down spaces for goods. As well as having a way to manage debris from the hinterlands of the islands, finding ways to protect the ports from flooding.

Therefore, increasing local communities' and citizens' abilities to "bounce back" from disasters and be able to sustain for days before the disaster relief resources arrive is important to successfully prepare for and respond to disasters in Hawai'i. Additionally, it is necessary to provide tourists with basic knowledge on how to respond and seek assistance during hazards. Again, the role of private sectors and community organizations should be underlined to bridge the gaps in vertical collaboration. For example, training and information can be distributed by the private partners with most local connections or organized by tourism industry partners. Information about the individual and household preparedness capacity can also be collected with the help from community partners to identify what resources are needed to ensure the community's self-sufficiency.

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The authors have no relevant financial or non-financial interests to disclose.

Author Contributions

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AUTHOR CONTRIBUTIONS

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Figures

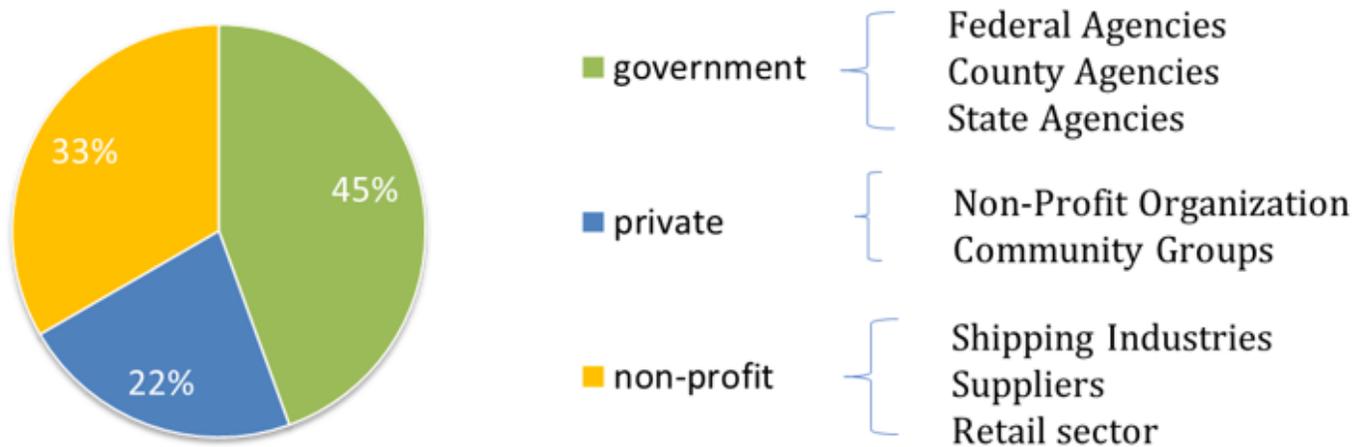
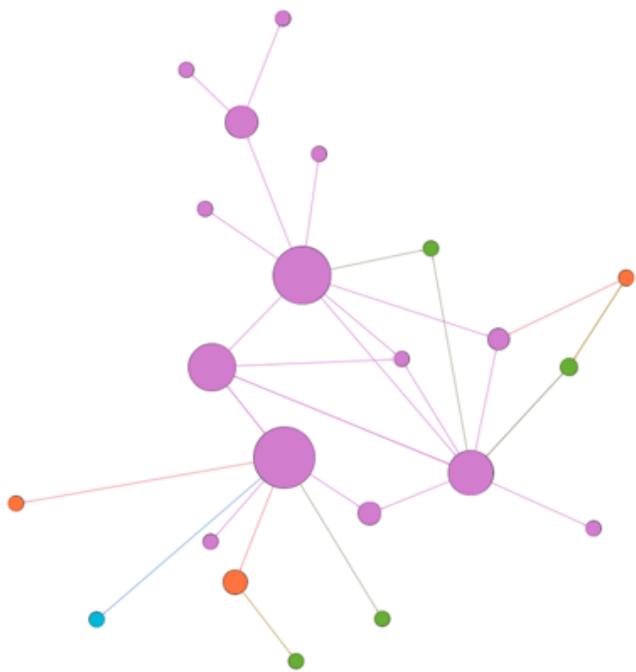
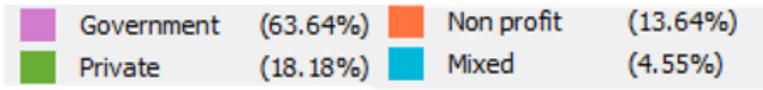
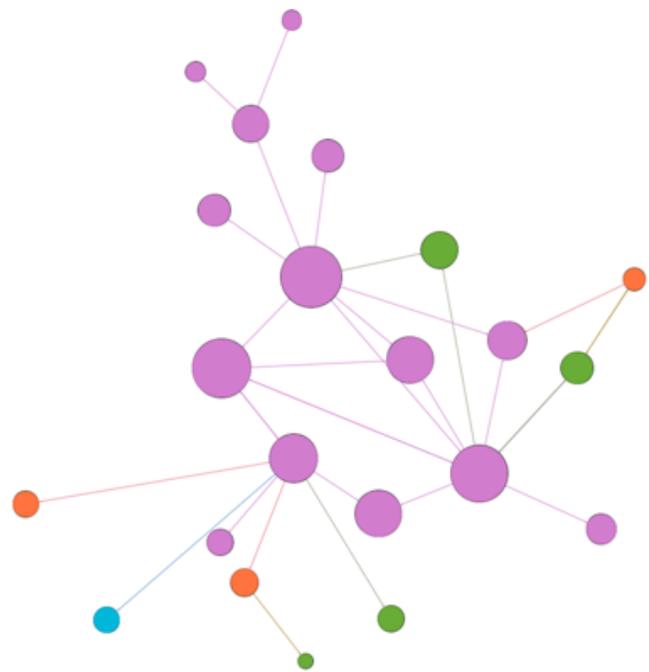


Figure 1

Interviewee background



a) Betweenness Centrality



a) Closeness Centrality

Figure 2

Centrality measures by institutional types

