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LAST-MILE POINTS OF DISTRIBUTION: OPTIMAL DISASTER RELIEF FOR WINDWARD OAHU AND MARINE CORPS BASE HAWAII

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THESIS

LAST-MILE POINTS OF DISTRIBUTION: OPTIMAL DISASTER RELIEF FOR WINDWARD OAHU AND MARINE CORPS BASE HAWAII

by

Tate G. Husemann

June 2022

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13. ABSTRACT (maximum 200 words)

The island of Oahu is the most populous island in the State of Hawaii. If Oahu were to be struck by a natural disaster, its citizens and strategic assets, including military installations located on the island and service members living in Oahu communities, would be vulnerable to disruptions to the island's central supply chain. To support disaster relief, last-mile points of distribution (POD) to act as the handoff points for people seeking food and water are needed. Predetermining POD locations helps planners pre-position supplies before a disaster and get supplies to affected communities quickly afterward. We developed a data set and model to determine optimal POD locations for windward Oahu communities for both resupply and pre-covery situations. We studied idealized, manpower-constrained, and optimistic scenarios to determine which PODs are chosen given different model constraints. Looking across 87 possible PODs for windward Oahu, we found different subsets that serve each scenario studied. Overall, five locations near Marine Corps Base Hawaii and in windward communities are identified as optimal for both resupply and pre-covery, including four schools and one park. Federal and state plans should highlight these locations for future distribution management planning.

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LAST-MILE POINTS OF DISTRIBUTION: OPTIMAL DISASTER RELIEF FOR WINDWARD OAHU AND MARINE CORPS BASE HAWAII

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ABSTRACT

The island of Oahu is the most populous island in the State of Hawaii. If Oahu were to be struck by a natural disaster, its citizens and strategic assets, including military installations located on the island and service members living in Oahu communities, would be vulnerable to disruptions to the island's central supply chain. To support disaster relief, last-mile points of distribution (POD) to act as the handoff points for people seeking food and water are needed. Predetermining POD locations helps planners pre-position supplies before a disaster and get supplies to affected communities quickly afterward. We developed a data set and model to determine optimal POD locations for windward Oahu communities for both resupply and pre-covery situations. We studied idealized, manpower-constrained, and optimistic scenarios to determine which PODs are chosen given different model constraints. Looking across 87 possible PODs for windward Oahu, we found different subsets that serve each scenario studied. Overall, five locations near Marine Corps Base Hawaii and in windward communities are identified as optimal for both resupply and pre-covery, including four schools and one park. Federal and state plans should highlight these locations for future distribution management planning.

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List of Acronyms and Abbreviations

AADT	Annual Average Daily Traffic
BPR	Bureau of Public Roads
CSA	County Staging Area
DLA	Defense Logistics Agency
DOD	Department of Defense
DMP	Distribution Management Plan
DSCA	Defense Support for Civil Authorities
FEMA	Federal Emergency Management Agency
FEMA-DC	Federal Emergency Management Agency Distribution Center
FSA	Federal Staging Area
HFA	Hawaii Food Service Alliance
HIEMA	Hawaii Emergency Management Agency
JSON	Javascript Object Notation
LMRD	Last Mile Relief Distribution
MCBH	Marine Corps Base Hawaii
MPH	Miles per hour
MSCA	Military Support of Civil Authorities
NPS	Naval Postgraduate School
PDC	Pacific Disaster Center

POD	point of distribution
POH	Port of Honolulu
SSA	State Staging Area
USVI	U.S. Virgin Islands
VPH	cehicles per hour

Executive Summary

Hawaii emergency management planning involves the coordination of several interlocking plans required for different phases and activities of disaster response, such as port restoration, debris management, and restoration of critical services. This thesis supports the efforts of the Hawaii Emergency Management Agency (HIEMA), the City and County of Honolulu,the Federal Emergency Management Agency (FEMA), and Marine Corps Base Hawaii (MCBH) to develop a coordinated Distribution Management Plan (DMP) for emergency response. The goal of this thesis is to determine the optimal Points of Distribution (PODs) for ensuring food and water access for windward Oahu communities, including MCBH and military families near the installation.

A POD is a location where food and water are brought to provide an emergency relief point for local communities. In its most basic form, a POD is a container on a truck full of food and water located in a parking lot where communities can go to receive emergency supplies. In more complex arrangements, PODs can serve thousands of meals and people per day and/or provide feeding services before and after disasters. In this work, we identify optimal POD locations for two categories of PODs: resupply and pre-covery. Resupply PODs are standard POD arrangements used by FEMA for emergency response across the entire US. FEMA uses three standard layouts of decreasing size and capacity: Type-1 serving 20,000 meals, Type-2 serving 10,000 meals, and Type-3 serving 5,000 meals. Pre-covery is a new concept developed in Hawaii that involves the prepositioning of containers full of food and water supplies in communities for immediate use without the need for resupply. Pre-covery PODs hold 135,000 meals and only take up the space of a Type-3 resupply POD. However, pre-covery PODs require maintenance and security to ensure they are viable for use in a future disaster, where resupply is easier to coordinate.

We identify optimal resupply and pre-covery POD locations for windward Oahu given three scenarios. Scenario 1 is an idealized situation considering current feeding requirements based on existing data without any manpower or cost constraints. Scenario 2 considers manpower constraints on how many PODs can be feasibly run in windward Oahu. Scenario 3 is an optimistic scenario that is only possible with local community coordination to reduce roadway traffic.

We develop and implement a novel data set and model to determine optimal POD locations that minimize round trip travel time for all communities that might need food. Our data set includes census data for population, road network data for routing and traffic, and identified POD locations from a set of grocery stores, parks, schools, and public lands provided by authoritative sources. For windward communities, we identify 87 possible POD locations that meet necessary traffic and space criteria. We develop a model that takes this data and identifies which of these locations resulting in the shortest travel time for each scenario.

Our results provide insight for emergency planning of resupply and pre-covery point of distributions (PODs). For Scenario 1 (the idealized scenario), we find 63 PODs for resupply and 53 PODs for pre-covery that support optimal traffic routing for windward Oahu communities. However, this scenario will result in large round trip travel times and a significant overage in excess food by opening more PODs than needed.

More realistic results come from Scenario 2 (with manpower and cost constraints). This limits the number of PODs used on Windward Oahu and allows for flexibility throughout the island for PODs given their finite nature. For resupply, we limit the number of PODs to 40, and for pre-covery, we limit the number of PODs to 10. In both situations, the model chooses the maximum number of PODs possible to reduce traffic. Although this scenario reduces overages in excess food, it leads to the worst travel times of all cases.

Results for Scenario 3 (the optimistic scenario) show the benefits of local community coordination. In communities that can coordinate drivers to receive food, the overall traffic will be reduced and the excess of food will also be reduced. For resupply, we identify 58 resupply PODs and 53 pre-covery PODs that lead to optimal traffic routing. This scenario yields the lowest travel times and overages in food. However, this scenario still requires a large amount of manpower to run the the large number of recommended PODs. Balancing manpower constraints and how communities can coordinate emergency supply distribution would ensure efficiency for both communities and first responders.

In cases where pre-covery and resupply makes sense at the same location, the most promising PODs are those found across all scenarios. We find five PODs of the original 87 that meet these criteria. The five locations that are optimal across all scenarios are: Kalaheo Neighborhood Park, St. Anthony School - Kailua, Olomana School, Waimanalo Elem & Inter School, and Kaaawa Elem School. These locations are recommended for both resupply and pre-covery.

Across all scenarios, many of the optimal POD locations are near MCBH, suggesting the importance of the installation in potentially supporting future emergency response. If food were stored or shipped to MCBH for delivery to windward Oahu PODs, this could alleviate traffic over the highways (which might also be blocked by debris) and still feed the majority of windward communities. Importantly, MCBH is also listed as a potential Federal staging area in FEMA plans, but not State or County plans. We recommend developing coordination plans for feeding windward communities via the MCBH airstrip and pier if that is necessary in a future disaster. Specifically, pre-covery may be helpful coordinated through the installation as the front gate of MCBH will also have lots of traffic and possible inundation after a disaster.

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CHAPTER 1:
Introduction

On 23 August 2021, the remnants of Hurricane Linda made landfall in the state of Hawaii bringing heavy rain and minor flooding to the islands of Hawaii, Maui, Molokai, and Oahu. Prior to landfall, the National Weather Service issued its first advisory on 10 August that Hurricane Linda would impact the state of Hawaii (Weather USA 2021). By 14 August, Hurricane Linda had become a Category 4 hurricane with winds upward of 130 miles per hour (Weather USA 2021). In preparation for the storm, the Federal Emergency Management Agency (FEMA) began emergency response for the islands (Leglar 2022a). Similarly, Hawaiian Island residents prepared for the storm by purchasing supplies like food and water to help themselves if they lost access to subsistence supplies. By 20 August, the hurricane had downgraded to a Tropical Storm with winds of 40 miles per hour (Weather USA 2021). While Hurricane Lane became less impactful on approach, the potential of a Category 4 hurricane on the Hawaii Islands brings to bear the importance of a resilient and implementable emergency management plan, especially with respect to coordinating and distributing emergency supplies to vulnerable and impacted communities.

According to Leglar (2022c), Hurricane Linda is only the most recent occurrence where a hurricane was headed toward Hawaii, whereas the average hurricane season in Hawaii typically includes many similar storms. Most storms form East and South of the island chain, gain energy and speed on approach, and then either change course avoiding damages or downgrade to a less impactful storm (Figure 1.1). This means Hawaii experiences many threatening storms, but few impactful ones. For example, in 2018, 24 hurricane warnings were published in Hawaii. Hurricane Lane and Hurricane Hector were within 200 miles of Hawaii (Leglar 2022c). Because the number of threatening storms and likelihood of landfall is only expected to increase into the future, effective emergency management plans are required for the entire state.

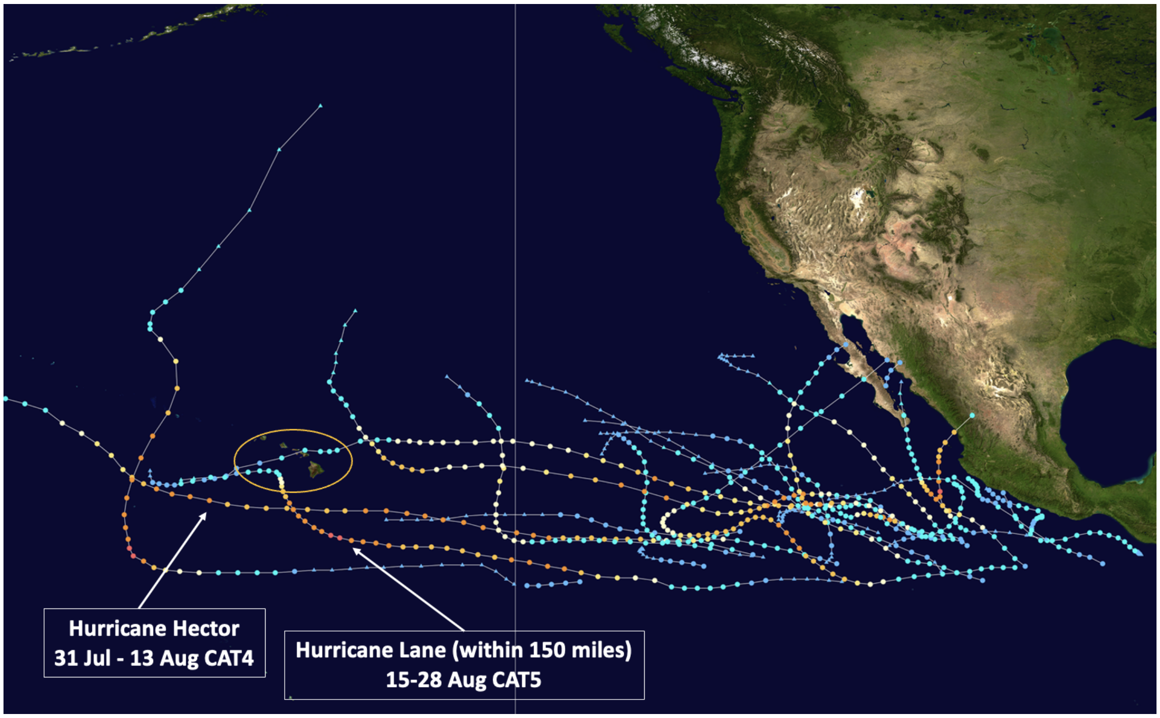

Figure 1.1. 2018 Hurricane Map. Hawaii is along the path of Hurricanes and Tropical storms originating from the West Coast of North and Central America. Despite a large number of threatening storms, few make landfall in the island chain, and tend to lose energy on approach when they do. Still, several named storms have come within striking distance of the islands, including Hurricanes Lane and Hector. Source: Leglar (2022c).

Emergency management planning involves the coordination of several interlocking plans required for different phases and activities of disaster response, such as port restoration, debris management, and restoration of critical services. This thesis supports the efforts of the Hawaii Emergency Management Agency (HIEMA) to develop a coordinated Distribution Management Plan (DMP) that ensures Hawaii residents can access food and water if impacted by a major disaster. This work is sponsored by Marine Corps Base Hawaii (MCBH) and is coordinated with Federal Emergency Management Agency Distribution Center (FEMA-DC), HIEMA, and Honolulu County to develop an executable DMP and determine installation coordination and needs on the Windward side of the island of Oahu during a future disaster.

1.1 Overview of Hawaii

Hawaii has a population of 1,360,301 and consists of nine islands divided into four counties (United States Census Bureau 2010). Oahu is part of Honolulu County, is the most populated island, and includes several key Pacific military installations including MCBH. Kauai County is the farthest west and consists of Niihau Island and Kauai. Moloaki, Lanai, Kahoolwe, and Maui are in Maui County located between Oahu and the island of Hawaii. Hawaii Island, also referred to as the "Big Island," is the farthest east Hawaii County and is the largest island geographically. Using Googlemap's distance feature, the Hawaiian islands are located 2,500 miles from Los Angeles, California, 4,930 miles from Shanghai, China, 5,080 miles from Sidney, Australia, and 5,290 miles from Taguig, Philippines. They act as the most central landmass between the countries bordering the Pacific.

This thesis focuses on Oahu, the population and geographic center of the state. Oahu hosts 953,207 occupants according to United States Census Bureau (2010), 48,000 of which are active duty service members and 20,000 Department of Defense (DOD) civilians (Readiness and Environmental Protection Integration Program 2020). With such a large DOD presence and important geographic location, Oahu is strategically critical for the DOD and national security such that any natural disaster or disruption to island communities will have an immediate impact on Pacific force readiness. Oahu houses the United States Indo-Pacific Command, which is a central hub for U.S. Army, Air Force, and the Naval operations in the region. Four major Military bases occupy Oahu (Figure 1.2), including MCBH located on the eastern windward side in Kaneohe Bay, Pearl Harbor Hickam in south central, Fort Shafter located north of Honolulu, and Schofield Barracks located in the island's center. Any impact to critical infrastructure that limits mobility, energy, water, or food access can have significant and immediate impact on installation operational readiness and force projection.

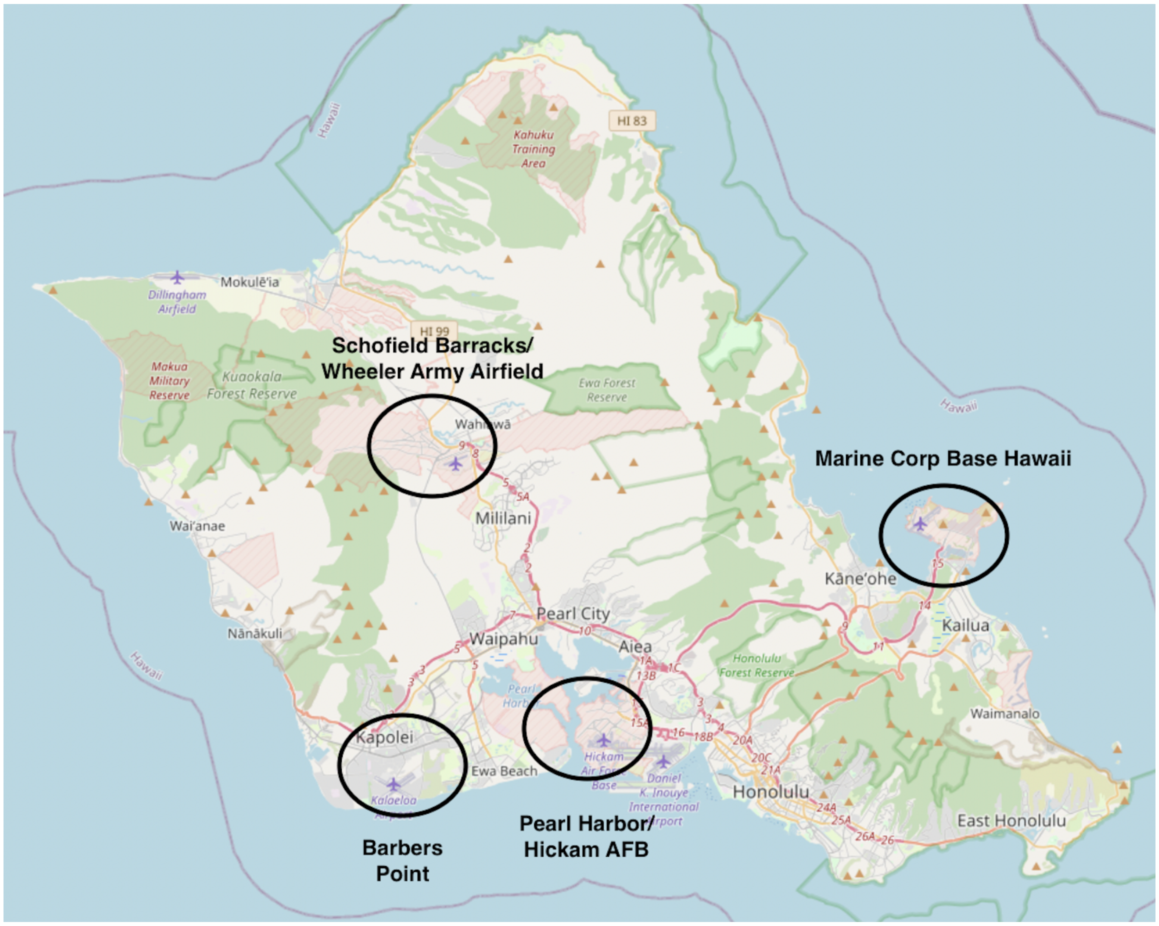

Figure 1.2. Department of Defense Bases on Oahu, Hawaii. Marine Corp Base Hawaii is on the windward side of the island separated from the rest of the island by Koolau Range. Joint Base Pearl Harbor/Hickam is located in the south, and Schofield Barracks is located in central Oahu. Barbers Point is located on the Leeward side of Oahu.

Oahu is also home to the Port of Honolulu (POH), the only commercial port in the island chain with large enough throughput to service the needs of all other islands. All supplies (food, water, etc.) arrive in the state of Hawaii via the POH. From there, supplies meant for other Hawaiian islands are transported by barges run weekly by the company Young Brothers. Moreover, any supplies sent from one island to another will be sent to POH first, offloaded, then put on inter-island barges. making Oahu the hub of all supplies for the state. An impact to the POH will have immediate impact of the entire island chain by preventing the receiving of supplies at the port via containers and the movement of supplies via barge between islands. In the event of a natural disaster, if communities on Oahu are impacted, this can also reduce capacity at the POH. For example, human factors like destroyed houses, family food shortages, etc. come into play for the effectiveness of the port due to manning issues. Therefore, the entire state suffers when critical man-power cannot reach the port due to infrastructure or human factor constraints. See de la Cruz (2011) for an overview of the importance and vulnerability of the POH.

1.2 Hawaii Emergency Planning

The state of Hawaii DMP divides natural disaster preparedness into three priorities for food and water distribution: (1) *"pre-covery,"* (2) state-to-county distribution, and (3) emergency management by the state (Grzybowski 2021b). Pre-covery is the strategic pre-staging and distribution of food and water supplies prior to an event to support immediate needs after a disaster. Pre-covery is meant to support communities until either Hawaii's supply chain is operating as designed or Federal aid is able to fill supply gaps. Converting Hawaii's last mile supply from a port-to-store framework to a hub-and-spoke architecture where FEMA and the state provide supplies to the counties for distribution is their second priority. Here, the counties manage their own on-island supply chains. Lastly, establishing a point of distribution (POD) network for state and federal aid is the third priority and last resort. In this scenario, the state is managing the distribution of supplies to local communities due to an inability for counties to fulfill their own plans. In this scenario, the state in coordination with FEMA are delivering truckloads of supplies to communities following standard POD designs (explained below). The focus of this thesis is to support priority 3 and determine resupply POD locations that may also be good candidates for pre-covery locations as well.

1.2.1 Pre-covery

The state of Hawaii's top priority for disaster response is pre-covery. Pre-covery is the establishment of pre-positioned supplies on the island that can be distributed to the population to provide coverage until critical logistics infrastructure is reestablished or federal aid arrives on the island (Lopez 2021a). One proposed way to achieve this goal is to purchase \$14 million of emergency food rations that have a shelf life of 25 years. Storage of the relief supplies would involve building critical warehousing infrastructure on the island and leasing out warehouse space to local distribution centers. With the purchase and storage of on-island food and water supplies, the goal is to distribute supplies in preparation for disasters, prior to major loss of roads and ports. One way to make this plan feasible is to share the cost with private business partners and rotate stocks over time, minimizing the heavy start up cost every 25 years (Lopez 2021a). As the supplies begin to age, they would sell portions and put the proceeds toward buying fresh rations (Lopez 2021a). Current efforts to fund this plan were denied by the state legislature and has been put on hold (Lopez 2021a), but there are new efforts to procure four pre-covery PODs with the state legislature (Lopez 2021b).

Non-Governmental Organizations are supporting this pre-covery initiative. Specifically, the Hawaii Food Service Alliance (HFA) has begun building pre-covery PODs for the food insecure populations on Oahu. Chad Buck, the CEO of HFA, has personally procured one for the Waipahu community. These PODs contain 135,000 meals and aim to feed the community for 10 days (Buck 2022). The Waipahu POD is located on the leeward side of Oahu but serves as a reference for future PODs throughout Oahu.

1.2.2 State-to-County Distribution

The second priority for the DMP is to set up a new distribution network where the state and/or FEMA are providing supplies to the counties to support impacted communities. This approach follows the general structure of Federal to Local distribution outlined in the Hawaii DMP (Grzybowski 2021b).

Figure 1.3 provides an overview of how this supply chain will operate. The supplies are received at the Port of Debarkation which can be an airport or a seaport. They are then moved to the Federal Staging Area (FSA). Federal Agencies will move these supplies to the State Staging Area (SSA). The state will then divide the items and distribute the supplies to the County Staging Area (CSA). Once supplies are delivered to the counties, each county can implement its own local distribution plan to deliver emergency supplies.

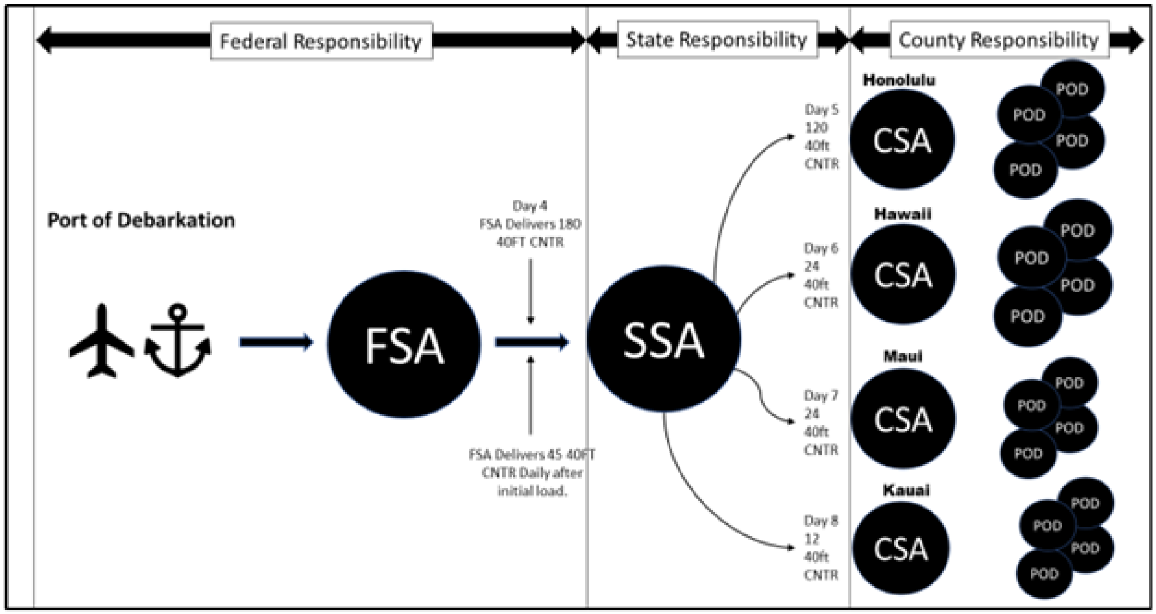

Figure 1.3. Federal Emergency Management Agency Supply Diagram. Supplies flow into Hawaii through the air and sea ports to the FSA, where they are pushed to the SSA. The SSA then distributes to the CSAs on each island. Lastly, the County distributes the relief supplies using its own network or via FEMA PODs. Source: Grzybowski (2021b).

Parts of the emergency supply chain have already been identified in the DMP (Grzybowski 2021b). The primary FSA identified in the DMP is located at Joint Base Pearl Harbor/Hickam. However, if this is not available, FEMA has established additional FSAs on the island of Oahu, such as airfields at Barber's Point Air Field, Wheeler Army Air Field, or MCBH.

The State of Hawaii's primary SSA is located at Aloha Stadium just north of the POH (Grzybowski 2021a). This location is chosen due to its size and ability to support storage and distribution of supplies for the entire state. No other location state-wide was determined to meet HIEMA critera for a SSA. Still, the proposed use of Aloha Stadium is problematic due to plans to demolish the Stadium in 2023 (Freeland 2021).

The portion of the plan that currently lacks specificity and coordination is at the CSAs and local distribution (Rhodes 2022). Each county determines their CSA location and the final leg of the supply chain. Focusing on Oahu, the County of Honolulu has expressed interest in collocating their CSA with the state SSA at Aloha Stadium (Rhodes 2022). While this simplifies the jurisdictional handoff between state and county, it creates additional logistical issues with relying on the County of Honolulu distribution to not interfere with state operations. If supplies meant for Oahu are not moved from the CSA to local populations, there will be no room to receive more containers (Grzybowski 2021a), and the people of Oahu will not have received the rations they require.

As the DMP currently states, all supplies for Hawaii's other counties will be delivered to the SSA at Aloha stadium. The state would then transport the supplies to Young Brothers to barge to the CSAs on other islands (Grzybowski 2021b).

1.2.3 Resupply Points of Distribution

The final priority and the focus of this thesis is to develop PODs for federal aid that are managed by the state. A POD refers to three standard distribution layouts used by FEMA to deliver food and water relief the populations. They are referred to by their relative size — a Type-3 POD, Type-2 POD, and Type-1 POD, based on increasing level of support provided to populations (Figure 1.4). A Type-3 POD is the smallest of the three options. It has the capability to supply 5,000 meals per day and requires a footprint of 150 feet by 300 feet. A Type-2 POD has the capability to supply 10,000 meals per day and requires a footprint of 250 feet by 300 feet. A Type-1 POD is the largest of the three POD options. It has the capability to supply 20,000 meals per day and requires a footprint of 250 feet by 500ft. These POD types allow vehicle and pedestrian traffic to flow while minimizing container space requirements and staffing. Figure 1.4 provides a visual representation of the POD types.

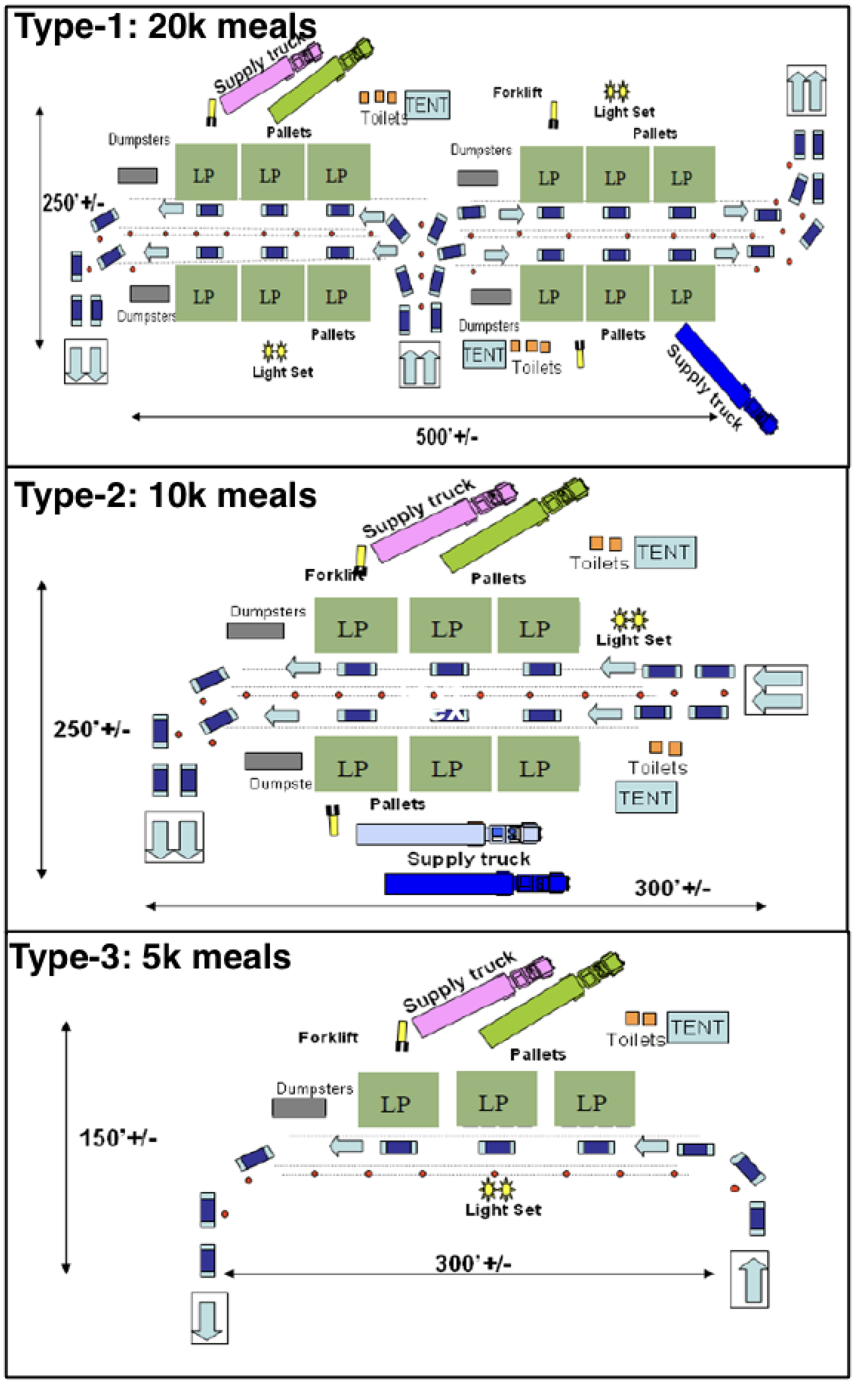

Figure 1.4. FEMA Standard Points of Distribution. Each POD layout has a different size, flow, and capability. All PODs assume populations will come to pick up food via vehicles, rather than deliver food to individual homes. Adapted from FEMA (2021).

If a natural disaster occurs, the DMP requires 180 containers of emergency rations from FEMA or other sources within 96 hours of the disaster. One way to integrate state and county plans is to determine POD locations to move the supplies to for local delivery (Leglar 2022b). However, several Hawaii counties, including Honolulu, have not currently provided HIEMA a list of POD locations (Grzybowski 2021a, 2022). In the case where the state is requested to support, HIEMA needs to determine its own POD locations to distribute food.

Thus, this third priority for the state is to develop its own distribution plan for individual islands if cities and counties cannot effectively distribute emergency supplies. Given the current DMP, 120 containers will be allocated for Oahu (Grzybowski 2021b). These containers must follow the appropriate chain of custody (Grzybowski 2021a). The state and federal agencies have a plan for these containers, but the city and county of Honolulu must inform the state of where they want these containers to go (Grzybowski 2022). This thesis focuses on developing the location for these containers based on population, acceptable terrain, and road networks.

1.2.4 Role of the Military and Marine Corps Base Hawaii

In the event that local distribution networks are impacted — either following county or state plans — the military will likely support disaster response to ensure the large number of military service members and civilian staff on Oahu are cared for. This support is called Defense Support for Civil Authorities (DSCA) and is coordinated with federal and state authorities when provided. MCBH is is a key installation to provide support on Oahu due to its location on the Windward side of the island (Freeland 2021). In particular, MCBH is well-situated and resourced to support nearby communities like Kaneohe Bay and Kailua, especially if key highways connecting windward and leeward portions of the island become blocked or impassable. For reference, the POH and Aloha Stadium are on the leeward side of the island and are only accessible by MCBH and nearby communities via major highway.

MCBH is interested in supporting nearby communities with disaster response also due to the large number of service members and civilians living off-based. MCBH houses roughly 12,000 United States Marines and their families. There is an estimated population of 25,000 Marines and DOD Six thousand Marines are fed thru the Defense Logistics Agency (DLA) supply chain. The remaining 19,000 Marines will be supported by Hawaii in a natural disaster (Freeland 2021). Moreover, some civilians who work on MCBH support critical missions and may need based access during disasters for mission assurance.

One way the military can support the DMP is through the funding and development of PODs that support county and state plans. For example, MCBH can help fund pre-covery storage and distribution of supplies as well as provide manpower to hand out supplies at PODs if coordinated via DSCA. However, without determining POD locations for the windward side of Oahu, it is unclear where or how MCBH can coordinate efforts with local officials.

1.3 Thesis Goals

This thesis focuses on the development of a POD network on Oahu. It establishes a list of potential POD locations among the schools, parks, and grocery stores on the island. We use an optimization model to determine which pre-covery and resupply PODs minimize travel time for the windward population to relief supplies. Identifying POD locations fills a critical gap in the DMP by supporting HIEMA distribution plans if the County of Honolulu is unable to distribute disaster relief. Moreover, identifying POD locations for the windward side of a Oahu helps MCBH determine how it can coordinate disaster relief efforts with local authorities. This thesis provides MCBH with an understanding for optimal pre-covery and resupply POD locations on Windward Oahu as they begin proposing infrastructure developments in their local communities.

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CHAPTER 2:
Literature Review

Last mile logistics for emergency response in Hawaii face a number of unique challenges. There are limited studies on last mile supply distribution for disaster relief. This is additionally complicated because the last mile supply of Hawaii uses a "port-to-store" approach instead of a "hub-and-spoke" approach like the continental United States and other nations. In Hawaii this means the supply chain brings the commodities to the port, and the last mile supply chain distributes them to the stores and purchasers. Fortunately, there is plenty of research in the area of emergency preparedness and last mile supply chain networks that can help shape our research into "port-to-store" last mile relief distribution in Hawaii. When reviewing the relevant literature for this chapter, we focus on research pertaining to Hawaii disaster management, pre-positioned disaster relief models, Last Mile Relief Distribution (LMRD) research, and island disaster relief models.

2.1 Hawaii Disaster Management

Research for disaster management in Hawaii focuses heavily on coordination. Dr. Ross Prizzia from University of Hawaii has written many articles regarding this coordination. According to Prizzia (2004), “Hawaii is adequately prepared in emergency response capability, particularly in the areas of medical services and inter-agency coordination, but coordination with the media reporting on disasters could be improved.” Prizzia (2004) recommends improvements by state and county agencies on “funding for family emergency preparedness, local community response teams, and continuous training of emergency response coordinators in collaboration with the major medical and media organizations.” Prizzia (2006) discusses the coordination with the DOD and the structure provided by Military Support of Civil Authorities (MSCA) on island. Public Administration and Public Policy 138 (2008) discusses the coordinated players in a natural disasters, their assessment on their preparation, and recommendations for increased coordination efforts. These sources show that Hawaii is concerned about the coordinated efforts. However, they do not discuss a plan they are coordinating to support.

An assessment of Honolulu Harbor was conducted previously by de la Cruz (2011), which identifies the impacts of port closure on Oahu and neighboring islands. He also provides options if the POH is not functional. More recently, the Department of Transportation Harbor Division (2021) assessment focuses on restructuring Honolulu Harbor by 2050 to provide more resilience to disaster and capability. These analyses provide ways to make the current distribution structure more resilient and viable, but do not address how to support the population when not functional.

2.2 Prepositioning Models

Work by McCall (2006), Heidtke (2007), and Farlow (2011) provide considerations for pre-positioned relief locations and models for determining their location. They do not assist in understanding last mile distribution.

2.3 Last Mile Logistics Framing in Disaster Relief

This work requires an effective list of quantifiable objectives to understand what government entities expect from a disaster relief model. This was found in a study from India. Specifically, Roy and Lebcir (2021) conducted a study involving 45 interviews with leaders in the government. identifies the objectives that are the concerns of most modeling approaches in a natural disaster. There are eight objectives to LMRD. Roy and Lebcir (2021) include minimization of "response time to deliver relief, coverage of all the affected areas, reduction of distance to deliver relief, satisfaction of demand for relief items, correct allocation of relief items and resources, reduction of relief distribution operations cost, prioritization of service, and securing relief item supplies."

The findings inRoy and Lebcir (2021) are consistent with our conversations with FEMA, Hawaii, and MCBH, who request our efforts focus on (1) coverage of the affected areas in Hawaii, (2) minimizing response times, and (3) satisfying the relief requirements for the population.

2.4 Review of Previous Modeling Approaches

Balcik et al. (2008) developed a model focusing on last mile supply distribution in a hub-and-spoke environment. They assume supplies enter the network and make it to warehouses and distribution centers located near the region of impact. Their main assumptions are that transportation assets and emergency supplies are limited. They also assume that the transportation infrastructure is damaged and relief actors are not coordinating (Balcik et al. 2008). They take a modeling approach that treats the disaster areas as needing many different supplies. Their objective is to minimize cost of transportation in the network with shortages of supplies incurring a cost. Balcik et al. (2008) divide their modeling approach into two phases. Phase 1 takes vehicle, demand locations, and travel time constraints to output a cost per route and demand locations visited by route Balcik et al. (2008). Phase 2 uses the demand at each location, expected supply arrivals over time, and volume of each vehicle to deliver individual routes for each vehicle, and amount of supplies sent to each demand point (Balcik et al. 2008). These phases are laid out in detail in Figure 2.1.

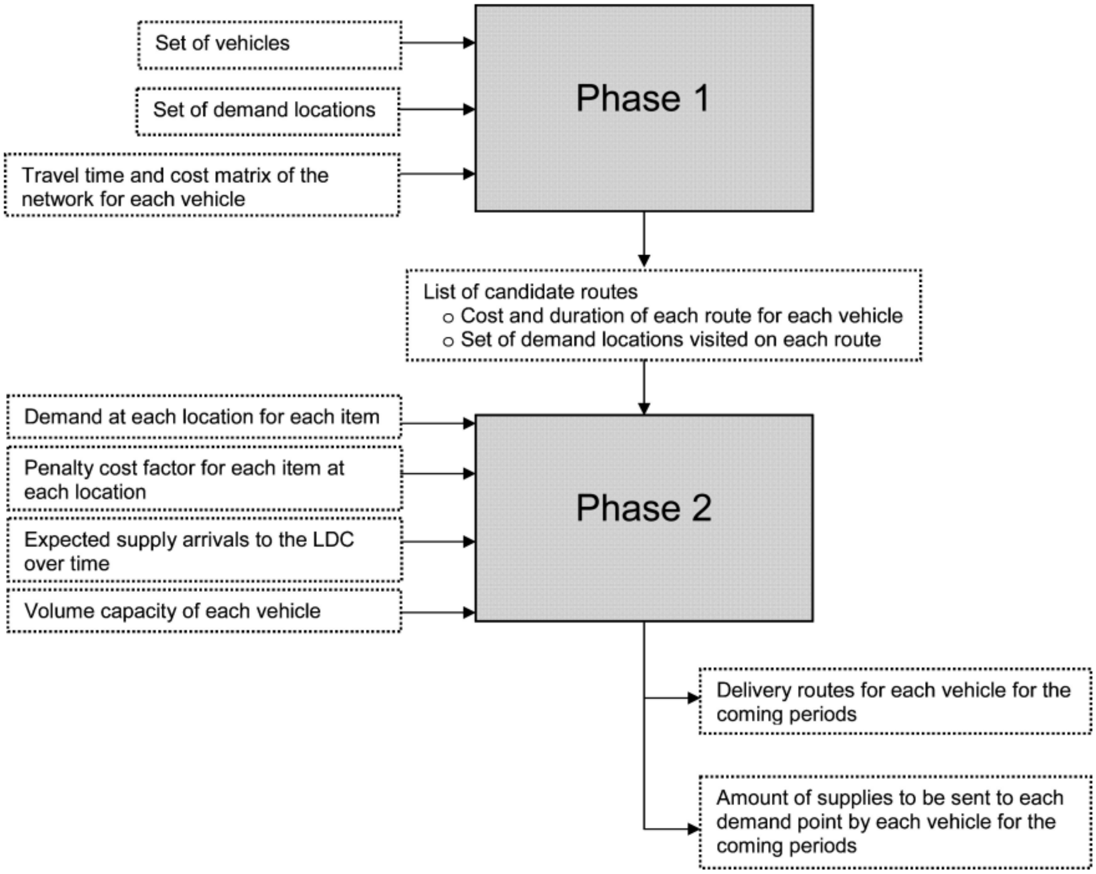

Figure 2.1. Balcik's Two-Phased Model. This figure specifies the inputs and outputs of Balcik's two-phased modeling approach. Source: Balcik et al. (2008).

The model of Balcik et al. (2008) fails to meet our needs for Hawaii. It is designed to look at multiple commodities, while we are looking at just disaster rations. Their model is designed around a "hub-and-spoke" LMRD framework, while Hawaii framework is "port-to-store."

2.4.1 Previous NPS Research

Last mile logistics analysis is an insufficiently studied area of the supply chain. Few articles (scholarly or otherwise) address these challenges. However, former Naval Postgraduate School (NPS) students have looked at this through the lens of the U.S. Virgin Islands (USVI). Recent theses by Good (2019) and Routley (2020) focused on road networks and their impact on the supply chains for the islands of St. Croix, St. Thomas, and St. John. Their work assesses the capacity of the supply chain to support island communities given normal operations, flooding, and worst-case conditions. Good (2019) provides a strong base for modeling. He develops a four-stage traffic model that aims to minimize round-trip times to critical infrastructure like hardware and grocery stores on the islands of St. Croix and St. Thomas.

Modeling efforts of Good (2019) and Routley (2020) have been used as a basis for other research. Jones (2021b)'s thesis focused on the road networks of Newport Naval Station in response to evacuation prior to and following a hurricane. Jones (2021b) uses similar models and methods for determining population routing and drive times. Together, these theses, while not identical in scope or focus, provide a strong basis for how to approach the problem facing Oahu and its windward communities.

2.5 Our Contribution

This thesis addresses Hawaii's gap in LMRD. It expands upon the model created by Good (2019) and Routley (2020) to address the concerns of Hawaii and MCBH regarding disaster relief to Oahu's windward population.

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CHAPTER 3:
Model Formulation

We develop a data set and optimization model to determine optimal POD locations for windward Oahu. This chapter discusses data curation, network construction, model formulation, and implementation.

3.1 Data Curation and Network Construction

For this work, we rely on geospatial data for the island of Oahu. Data used in this thesis includes a broad list of information required to determine optimal POD locations, including roadways, populations, local geography, flood maps, government buildings, parking lots, grocery stores, and local distribution infrastructure. For all data, our primary sources are the Pacific Disaster Center (PDC) and HIEMA, which provide authoritative data on infrastructure and populations for the DOD and local emergency management planners.

No data set on its own was sufficient to determine POD locations. Instead, data needed to be cleaned and curated for use in our research on Oahu. In general, all data sets followed a similar mix of automated processes and human inputs to clean and organize. The full data cleaning and analysis process flow is shown in Figure 3.1. First, data was accessed via PDC Rapids system and provided directly from HIEMA as geospatial data files. Prior to any data cleaning, all files were converted to Javascript Object Notation (JSON) based geospatial formats, such as GeoJSON, which standardized data coordinate reference systems to EPSG:4326 / WGS84.

Converted files from PDC and HIEMA were loaded into `QGIS` software for initial processing. In this step, we visualized the data to determine what was missing and to perform simple geoprocessing steps that required human inspection to ensure accuracy. Here, data triage was also completed to remove extraneous data sets from our analysis and determine which information we would need to make assumptions about for optimal POD placement. Once, visual inspection and triage was complete, we developed several automated processing methods in `Python` using the `GeoPandas` package to systematically remove information that failed to meet our assumptions and constraints. Here, additional data analysis, merging, and integration was also completed to support optimization models. Once clean, the data was fed into `Pyomo` to determine optimal POD locations. Results were exported back to GeoJSON for storage and presented using the javascript package `Leaflet` via `Folium` integration in Python. This full data and analysis approach generated interactive maps of POD locations that were shared directly with local stakeholders.

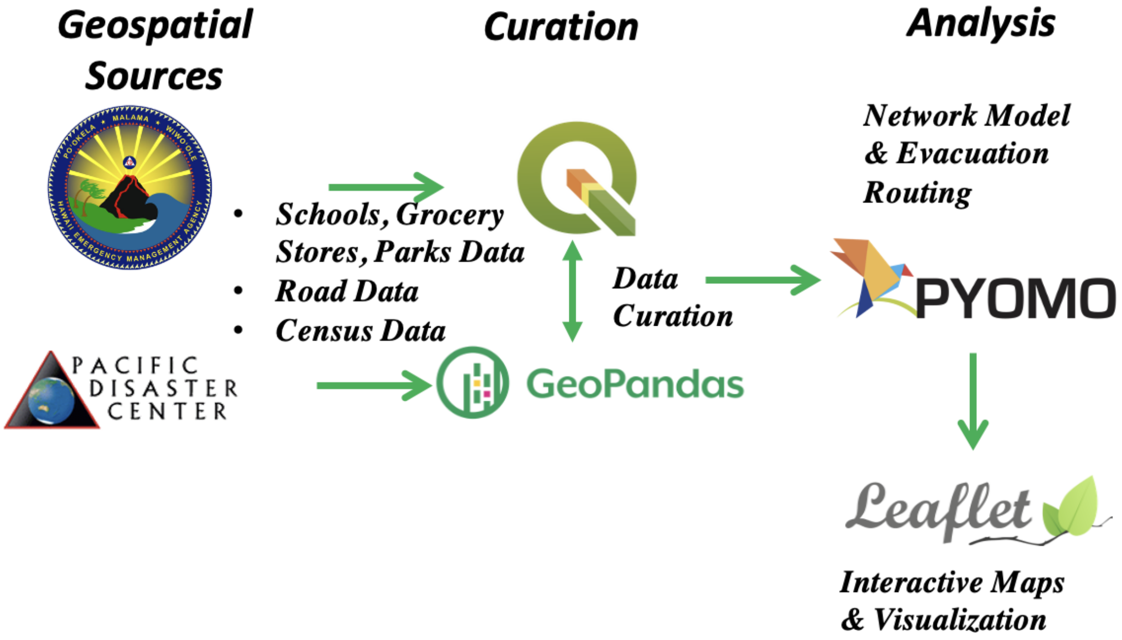

Figure 3.1. Data Processing Flow Chart. Geospatial Sources provided by PDC and HIEMA provide necessary data on schools, roads, parks, grocery stores, and census data. The data are curated though use of `QGIS` and `GeoPandas` the fed into `Pyomo` and `leaflet` for modeling and visualization. Adapted from Jones (2021a).

Using the process in Figure 3.1, the following data curation and network construction steps were completed:

- developing POD location options;
- determining population centers that need food and water supplies;
- identifying road network construction;
- establishing flood inundation zones.

For each of these steps, where possible, we develop an island-wide data set as well as a windward Oahu-specific data set. The analysis completed in this thesis focuses only on windward Oahu. However, island-wide data sets were also prepared to support future analyses for other communities on Oahu.

3.1.1 POD Location Options

Data provided by HIEMA and PDC was used to develop a set of candidate POD locations for the island of Oahu. In general, a POD can be located anywhere with enough space and capability to house a container of supplies and handle traffic flow. Original data sets considered broad types of possible locations, including recreational vessel ports, airports, and hospice centers. To reduce the list of possible POD locations, we implemented criteria provided by HIEMA. Specifically, we focused on identifying grocery stores, schools, and public parks. These locations were chosen because of their proximity to the population centers, the availability of staffing in the event a natural disaster occurs, and community familiarity with the locations. Consolidating these locations resulted in 1575 potential POD options.

Additional criteria was used to reduce the total number of feasible POD locations. Based on the dimensions for Type-3 PODs (FEMA 2021) (the smallest POD option), a minimum of one acre is required for a candidate POD location. We took the initial set of geographical points and removed any options smaller than one acre using visual inspection in `QGIS` and via automated processing in `Python`. We then removed any potential locations that were not within 800 meters of a major road, because these locations would be difficult to reach with a commercial truck and hard to prioritize for debris clearance and recovery after a disaster. Lastly, we visually inspected the remaining locations on a map. If the location did not have a clear option for traffic routing, it was removed. This resulted in 485 possible POD options on Oahu. The resulting POD locations are depicted in Figure 3.2.

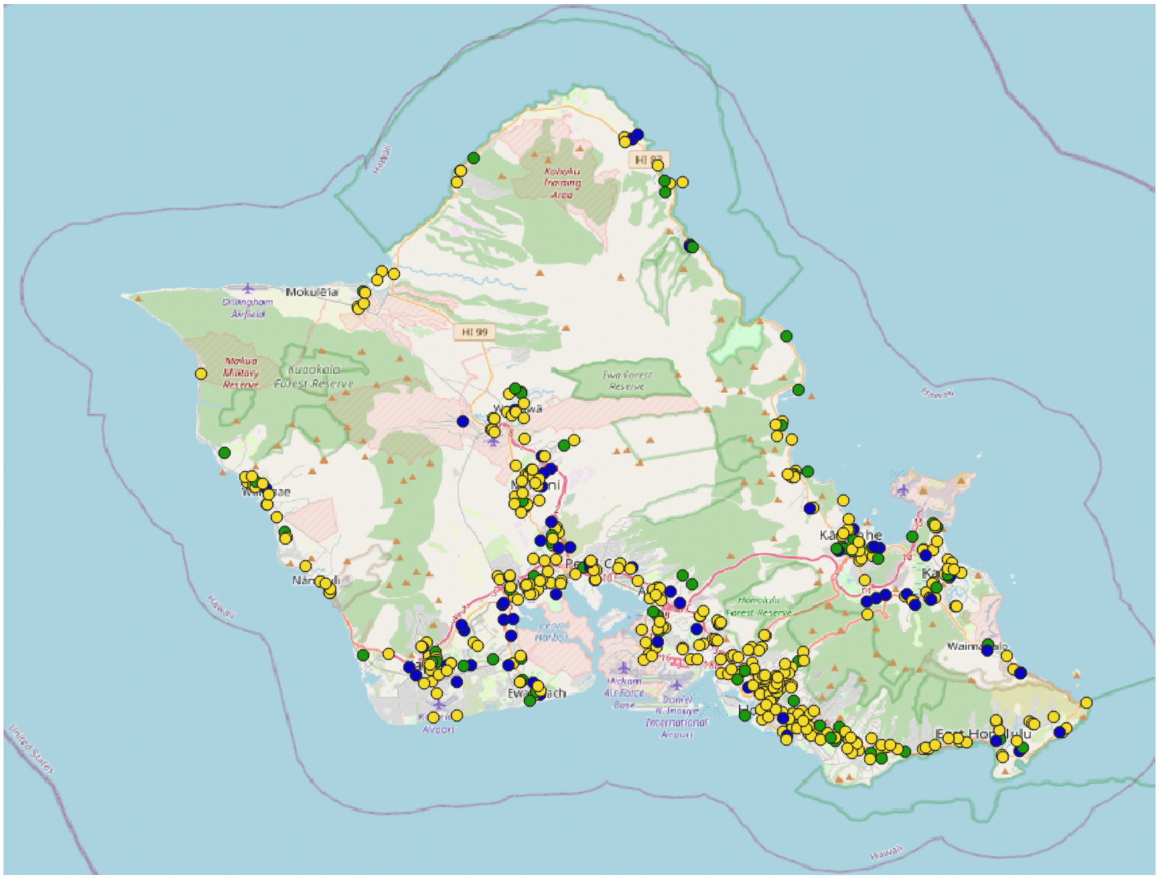

Figure 3.2. POD Options on Oahu. POD options are marked with circles on the map using `QGIS`. Blue circles indicate Type-1 PODs, green indicate Type-2 PODs, and yellow markers indicate Type-3 PODs. POD options include all parks, schools, and grocery stores within 800 meters of a state road that have adequate space for distribution and traffic flow.

Windward POD Options

While possible POD locations are distributed across all communities, only a small number are available on the windward side of the island near MCBH. Specifically, windward PODs can be located along Kamehameha Highway and outside MCBH and separated from the rest of the island by local geography. In total, 87 locations make up our windward POD options, shown in Figure 3.3.

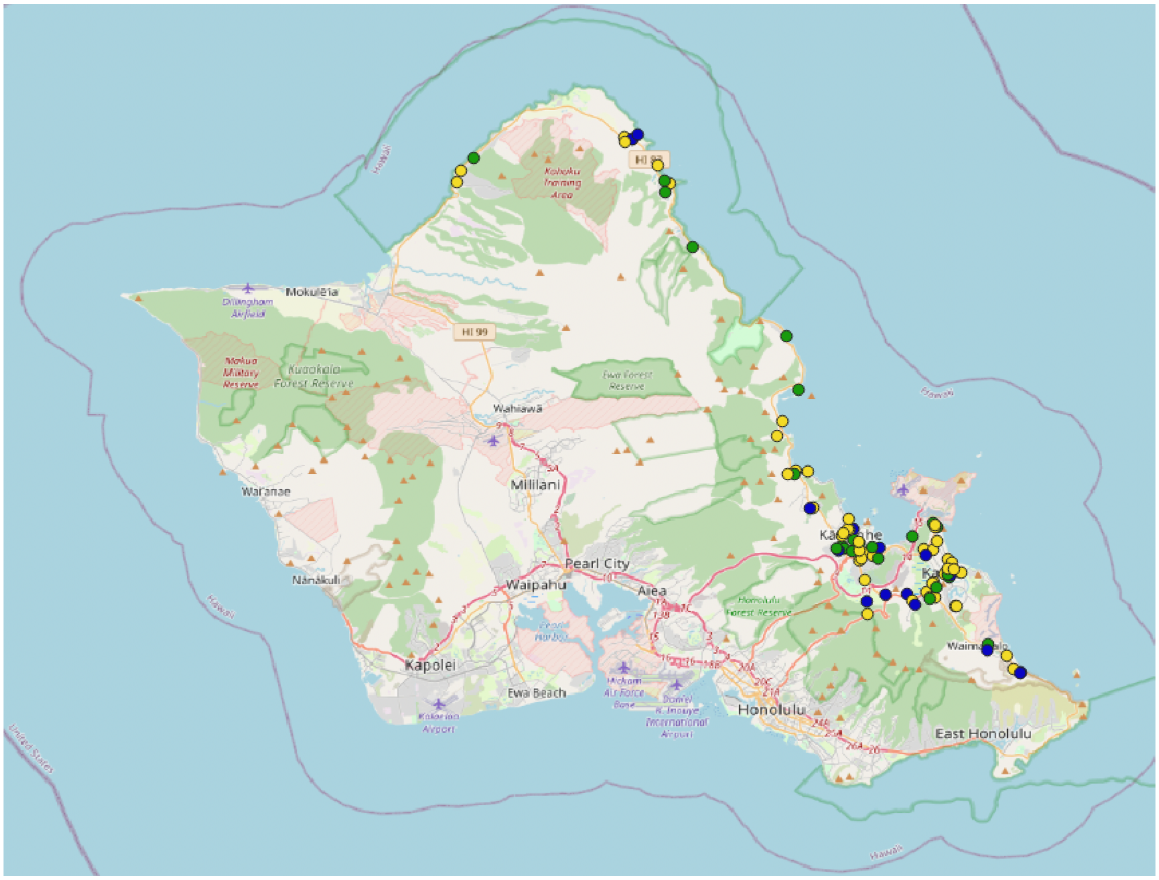

Figure 3.3. Windward Oahu POD Options. PODs on windward Oahu are represented by colored circles. Blue circles indicate Type-1 PODs, green indicate Type-2 PODs, and yellow markers indicate Type-3 PODs. In total, 87 of 485 PODs are determined to be windward PODs.

Pre-covery vs. Resupply

We consider both pre-covery and resupply PODs, referred to as Pre-PODs and Re-PODs. As described in Chapter 1, space requirements for a Pre-POD are the same as the smallest Type-3 Re-POD. The key difference is a single Pre-POD can feed the same population as a Type-1 Re-POD. Hence, all candidate POD locations presented in Figures 3.2 and 3.3 can serve both purposes, yet will have different capacity for serving populations when analyzing optimal POD locations.

3.1.2 Population Centers

Census block data set provided by HIEMA (2021) was modified to generate population centers (points) for our model. Census blocks are polygons representing demographic information including the number of people living in the region and number of households. For our analysis, we require points representing this information for contiguous households that have similar access to roads, rather than polygons that can span large geospatial regions. Thus, census blocks were converted to points resulting in 798 population centers on Oahu. Each point was initially placed at the center of the census block and then visually inspected to relate the population centers on the actual the road network. Resulting points represented census blocks with populations ranging from one person to 10,000 people. To simplify the model, any population center less than 75 people was consolidated on the nearest population center. This reduced our number of population centers from 798 to 653. Then, points that were far from the road network and houses they represent were manually moved to be over their related houses and/or roads. Figure 3.4 presents the final set of population centers for the island of Oahu.

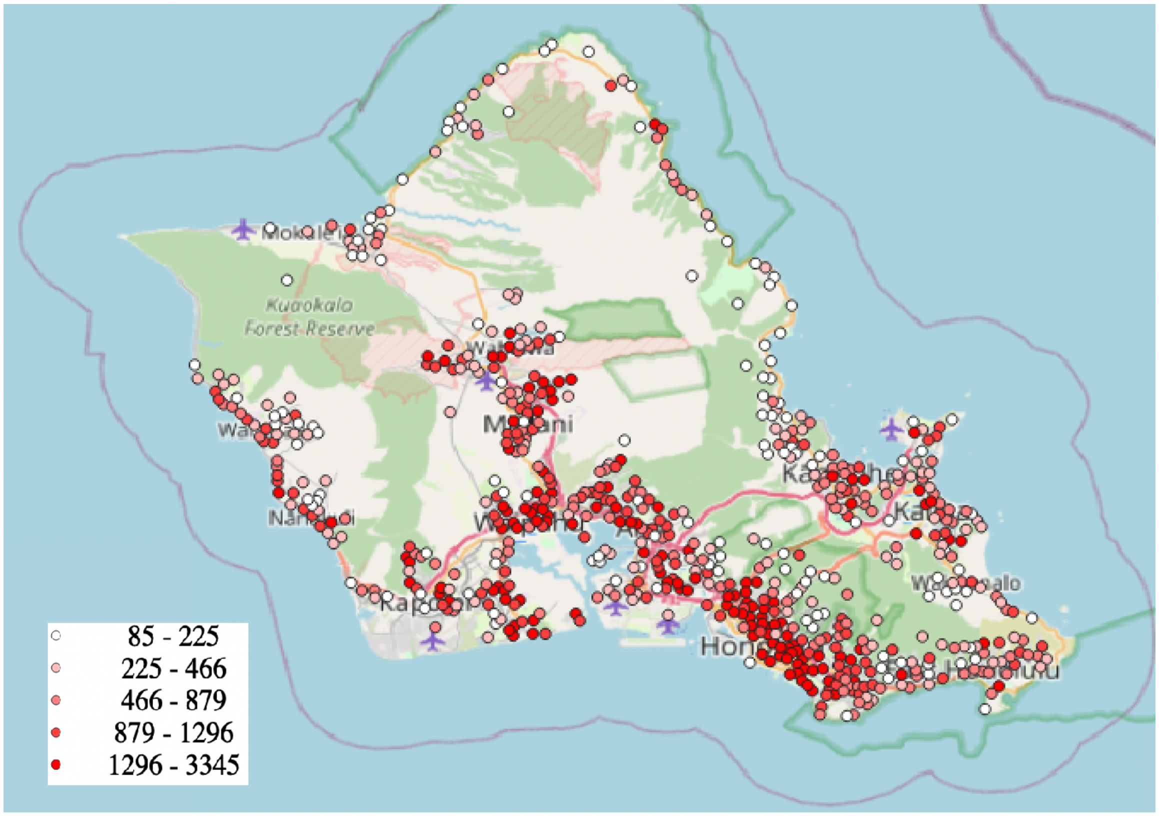

Figure 3.4. Oahu Population Centers. Oahu population centers are marked with circles on a on a sliding scale from white to red. The circles get more red as population in a population center increase. The smallest population centers are white, and the largest population centers are dark red circles. This was accomplished by using `QGIS`, and represent consolidated census blocks on the island. They are distributed throughout the island and are used for determining throughput of potential PODs.

Windward Population Centers

With our focus on windward Oahu, we isolated the population centers along Kamehameha Highway and the communities directly outside MCBH. This brought our population centers in the model from 653 nodes to 187 nodes. The windward population centers are in Figure 3.5.

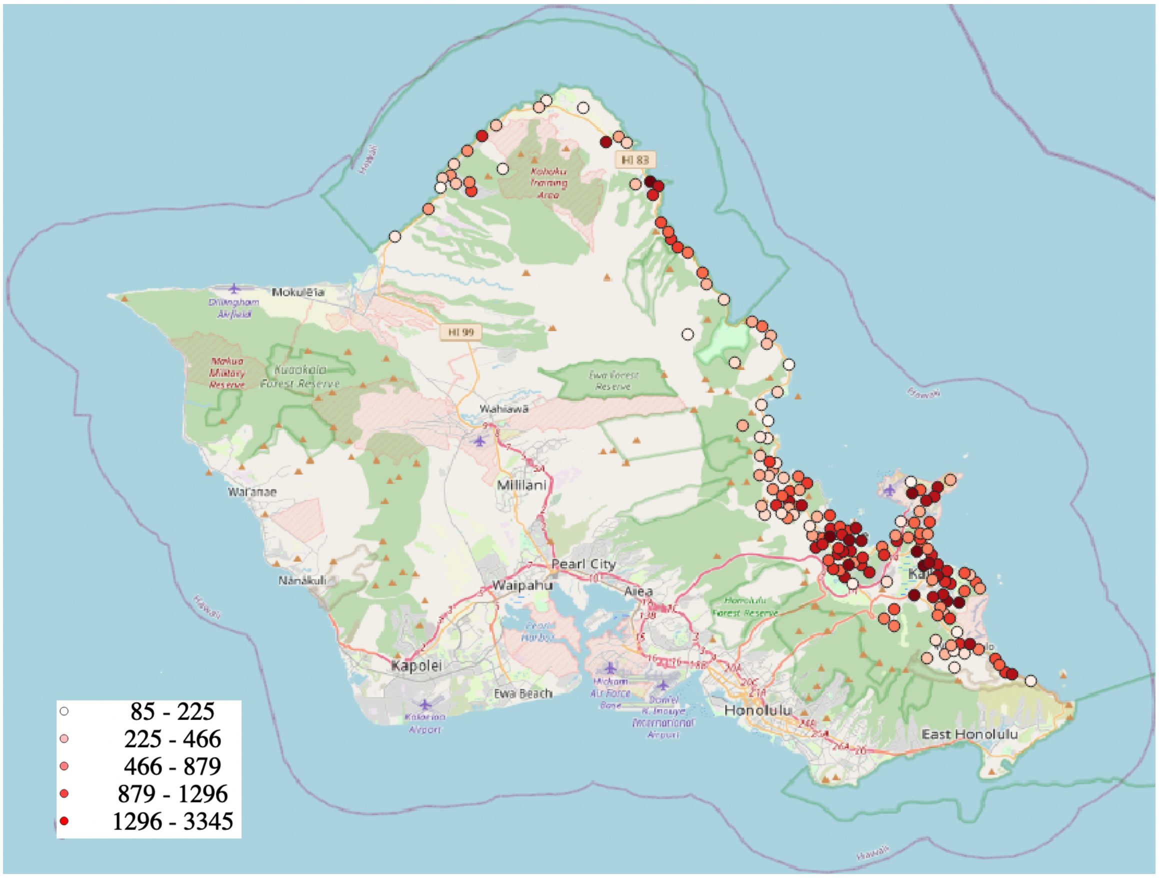

Figure 3.5. Windward Population Centers. The population centers on Windward Oahu are isolated from the rest of Oahu shown in Figure 3.4. Using `QGIS`, we put populations on a color scale between white and red. The smallest populations are white circles, and the largest are dark red.

3.1.3 Road Network

After developing a list of potential POD locations and population centers, we develop the network of roads to connect them. We used state roads data and an Oahu roads data set provided by HIEMA to build this network. The state roads formed the basis of our network. First, we filtered out roads that did not have a minimum daily vehicle throughput rating of 5000 vehicles a day (i.e., enough throughput for a Type-3 POD). Then, we simplified road geometries and generated transshipment nodes representing intersections. From there, we connected all the PODs and population centers to this network using the remaining city and country roads provided by HIEMA. Only the roads necessary to connect these locations to the network were added. The combined and filtered data sets are presented in Figure 3.6.

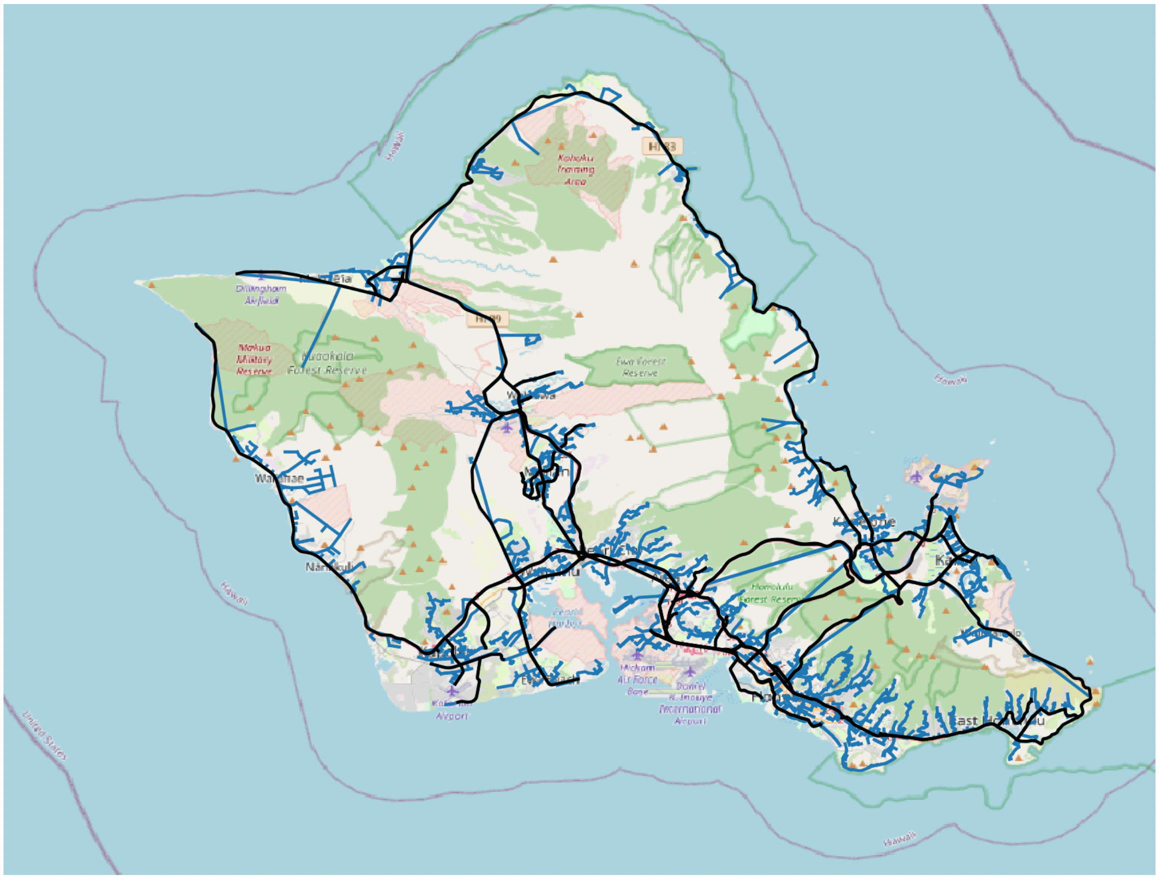

Figure 3.6. Island-wide Road Network Data Set. We develop a simplified road network based on real state roads and local roads data provided by HIEMA and PDC, respectively. The road network marked by black lines includes state/county/city roads that connect all population centers and POD locations together. These roads have a minimum capacity of 5,000 vehicles a day.

Skeletonized Model for Windward Oahu

The detailed data presented in Figure 3.6 was skeletonized into a simplified data set for analysis. To determine travel time and optimal POD locations, some road information is necessary, including road connectivity, capacity, speed limit, length, number of lanes, paving conditions, and direction of traffic. In contrast, other information embedded in road data is not helpful, such as detailed road geometry used for design and road ownership.

Moreover, the geospatial data received was often found to be not connected, such that network construction would be difficult without manual data input. Thus, the road data needed to be integrated, simplified, and modified for analysis. We refer to this process as *skeletonizing*.

Because skeletonizing the data is labor intensive, we only complete this preprocessing for windward Oahu. First, we determined the roads that provide connectivity to windward Oahu and removed all others from our data set. Then, we reduced unnecessary additional road segments that are far from major roads, potential POD locations, and population centers. Then, we removed as many vertices as possible to reduce the number of nodes in the network, leading to straighter roads that are simpler to analyze while retaining necessary data for analysis. Finally, we manually connected potential POD locations and population center points into the skeletonized network. These additional arcs do not represent roads and are assumed to have capacity limited by local roadway travel or POD capacity. This process was completed using QGIS. Our road network for windward Oahu is shown in Figure 3.6, but once skeletonized is seen in Figure 3.7.

Figure 3.7. Skeletonized Road Network. A simpler road network is necessary for our model to run efficiently. This was done by removing any unnecessary vertices in the network to simplify the shape of the roads and remove extraneous variables from our model.

3.2 Model for Determining Optimal Points of Distribution

We develop a model that takes the above data sets and determines optimal POD locations given round-trip travel time by populations to PODs. Our model is an extension of the model developed by Good (2019) and Routley (2020). For simplicity, we present both the previous model this work is based on and model extensions, then describe how the model works as an integrated whole.

3.2.1 Model Formulation from Routley (2020)

The model formulation from Routley (2020) is presented here in its entirety as a basis for our analysis.

Indices and Sets

$i \in N$	nodes (alias j, s, t)
$(i, j) \in A \subseteq N \times N$	arcs
$(s, t) \in D \subseteq N \times N$	set of all origin and destination pairs
$r \in R$	sections for piece-wise linear approximation ($\bar{r}$ = total number of sections)
$Out_i \subset A$	set of all outbound arcs from node i
$In_i \subset A$	set of all inbound arcs to node i

Data [units]

b_{st}	supply rate at node s destined for node t ($b_{st} < 0$ represents demand) [cehicles per hour (VPH)]
u_{ij}	nominal capacity of arc (i, j) [VPH]
s_{ij}	unrestricted speed of arc (i, j) [Miles per hour (MPH)]
d_{ij}	length of arc (i, j) [miles]
$avail_{ij}$	1 if arc (i, j) is available for use, 0 otherwise
q	maximum intended travel window for all origin-destination round trips [hours]

Calculated Data [units]

λ_{ij}	interval width on arc (i, j) for calculating piece wise linear congestion $\lambda_{ij} = 2u_{ij}/\bar{r}$
h_{ijr}	total travel time for all vehicles traversing segment r on arc (i, j) $h_{ijr} = \left(r\lambda_{ij}\right)\left(\frac{d_{ij}}{s_{ij}}\right)\left(1 + 0.15\left(\frac{r\lambda_{ij}}{u_{ij}}\right)^4\right)$
$slope_{ijr}$	slope of segment r for arc (i, j) $slope_{ijr} = \frac{h_{ijr} - h_{ijr-1}}{\lambda_{ij}}$
$intercept_{ijr}$	y intercept of line section r for arc (i, j)

$$intercept_{ijr} = -slope_{ijr}(r\lambda_{ij}) + h_{ijr-1}$$

Decision Variables [units]

Y_{stij}	flow rate of supply originating at node s destined for node t transiting arc (i,j) [VPH]
Y_{ij}	total flow rate transiting arc (i,j) [VPH]
Z_{ij}	travel time on arc (i,j) [vehicle hours]
$Dropped_{st}$	dropped quantity of supply originating at node s destined for node t [vehicles]
$Excess_{st}$	excess quantity of demand originating at node s destined for node t [vehicles]

Formulation

$$\min_{Y,Z,Dropped,Excess} \quad \sum_{(i,j)\in A} Z_{ij} + \sum_{(s,t)\in D, s\neq t} \frac{q}{2}\cdot Dropped_{st} \tag{3.1}$$

$$\text{s.t.} \quad \sum_{(i,j)\in Out_i} Y_{stij} - \sum_{(j,i)\in In_i} Y_{stji} + Dropped_{st} = b_{st} \qquad \forall i\in N, (s,t)\in D, i=s \tag{3.2}$$

$$\sum_{(i,j)\in Out_i} Y_{stij} - \sum_{(j,i)\in In_i} Y_{stji} - Excess_{st} = -b_{st} \qquad \forall i\in N, (s,t)\in D, i=t \tag{3.3}$$

$$\sum_{(i,j)\in Out_i} Y_{stij} - \sum_{(j,i)\in In_i} Y_{stji} = 0 \qquad \forall i\in N, (s,t)\in D, i\neq s, i\neq t \tag{3.4}$$

$$Y_{stij} \leq b_{st} \qquad \forall (s,t)\in D, (i,j)\in A \tag{3.5}$$

$$Y_{ij} = \sum_{s,t\in D} Y_{stij} \qquad \forall (i,j)\in A \tag{3.6}$$

$$Y_{ij} \leq 2u_{ij}avail_{ij} \qquad \forall (i,j)\in A \tag{3.7}$$

$$Z_{ij} \geq intercept_{ijr} + slope_{ijr}\cdot Y_{ij} \qquad \forall (i,j)\in A, \forall r\in R \tag{3.8}$$

$$Excess_{st} = Excess_{ts} \qquad \forall (s,t)\in D \tag{3.9}$$

$$Dropped_{st} = Dropped_{ts} \qquad \forall (s,t)\in D \tag{3.10}$$

$$Y_{stij}, Y_{ij}, Z_{ij}, Dropped_{st}, Excess_{st} \geq 0 \qquad \forall (i,j)\in A, (s,t)\in D \tag{3.11}$$

Discussion

The objective function 3.1 minimizes the cumulative travel time rate (in vehicle-hours) of vehicles traveling from population center s towards a POD t in the network across each arc (i, j) and uses a penalty cost for dropped flow. Travel time rate is used in the objective instead of travel time to ensure the optimal flow path for vehicles is based on the harmonic mean comparisons of similar paths, rather than the arithmetic mean, which is the appropriate way to consider multiple paths constructed of arcs with differing speeds. The penalty is the sum the dropped vehicles ($Dropped_{st}$) multiplied by half of the travel window ($q = 12$ for a full day of POD operations). This penalty forces vehicles to stay home and not receive supplies from any POD if it takes the household longer than the intended POD operations for a round trip.

Round-trip flow is managed across the network using a series of decision variables and constraints. Constraints 3.2,3.3, and 3.4 are used to ensure balance of flow in the network. Constraint 3.2 ensures the number of vehicles leaving a POD for a return trip is equal to the flow rate from any population s to the given POD t. Constraint 3.3 does the same as Constraint 3.2 but balances demand. Constraint 3.4 ensures that any flow across a (i, j) returns across the same arc to its origin. Constraint 3.5 ensures flow to a POD does not exceed the demand. Total flow across an arc is the sum of all commodity flows across the arc due to Constraint 3.6. Constraint 3.7 ensures that total flow on an arc does not exceed twice its design capacity. Constraint 3.9 Excess leaving a population must also be excess returning to the population. Constraint 3.10 is the same as Constraint 3.9 but focuses on dropped demand.

The model minimizes travel time rate using a linear approximation of non-linear roadway congestion. Constraints 3.8 establishes this linear approximation and sets the travel time rate over each road segment to be lower-bounded by a standard function for roadway traffic congestion called the Bureau of Public Roads (BPR) function (Good 2019). The BPR function sets the total travel time over a road near its travel rate if the number of vehicles on the road is less than its design capacity and increases travel time as a quadratic polynomial for each additional vehicle traveling on the road beyond its design capacity. This formulation allows more vehicles to take a road than designed, which might be beneficial and necessary for all populations to reach PODs, yet also captures the sudden onset of congestion when too many vehicles are on a road at the same time. This is accomplished using h_{ijr}, which is a parameterized BPR function broken into r segments. $slope_{ijr}$ and $intercept_{ijr}$ approximates a straight line between segments for the function. Together, Constraints 3.8 ensure that the rate of travel over an arc is lower-bounded by the BPR function.

3.2.2 Model Extensions

Model extensions are necessary to determine optimal POD locations. The Routley (2020) model assumes all destinations (i.e., PODs) are available for travel, rather than determining which of the possible destinations are best. Moreover, the model without extension does not have a lower-bound on the number of vehicles traveling to a destination, allowing some destinations to have few arriving vehicles. This is not useful for determine POD locations as opening a POD, t, with $\sum_{(s,t)\in D} Y_{stij} << 5,000$ wastes limited resources by using manpower and containers at a location few individuals would want to travel to.

The following additional sets, data, and constraints are added to the Routley (2020) model to choose which POD locations to use and set lower bounds on their required vehicle flows.

Indices and Sets

$(i,t) \in Feeders \subseteq A$	feeder arcs from POD i to sink node t

Data [units]

POD_Type_t	largest POD type possible at destination i

Calculated Data [units]

$maxPODFlow_{ij}$	maximum number of vehicles served by a POD of a given type
$minPODFlow_{ij}$	minimum number of vehicles served
MPD	number of meals required per person per day
$Household$	number of people per household
$MaxPODs$	maximum number of PODs on Oahu. = 120.

Decision Variables [units]

POD_{ij}	binary variable = 1 if POD chosen for flow on a $feeder$ arc [0,1]

Formulation

$$\sum_{(i,j)} POD_{ij} \leq MaxPODs \qquad \forall (i,j) \in Feeders \tag{3.12}$$

$$\sum_{(i,j)} MaxPODFlow_{ij} \leq POD_{ij} \frac{POD\_Type_i}{MPD * Household} \qquad \forall i,j \in Feeders \tag{3.13}$$

$$\sum_{(i,j)} MinPODFlow_{ij} POD_{ij} \geq \frac{POD\_Type_i}{MPD * Household} * MinCap \forall i,j \in Feeders \tag{3.14}$$

Discussion:
The additional set, $Feeders$, defines a set of arcs connecting all PODs to a virtual node that is a sink for all vehicle flows. These arcs are virtual and do not represent roads. Instead, they represent whether a POD is open or not and allow for round trips to the sink node. Equation 3.12 ensures that the number of PODs activated does not exceed the number allowed in the model. Equations 3.13 and 3.14 establish indicator constraints on the minimum and maximum flow to a POD if activated.

Figure 3.8 depicts a simplified version of what is occurring in our extended model. The objective of the model is to determine which set of routes minimizes the total travel time in the network. To do this, we first need to connect the populations located on the far left of Figure 3.8 to the transshipment nodes. This is done by developing no cost arcs via QGIS to the nearest transshipment node. These transshipment nodes are points at the end of a road, or an intersection between two roads. Once the populations are connected to their nearest transshipment node, they travel across the arcs, via the road network to the PODs. If the POD is open, they will pass thru the POD to the Super Sink over a no cost arc. If it is not, they will not travel to that POD. By running this model we are able to determine which PODs the populations will pass thru to minimize travel time within the network by a "branch and cut" algorithm.

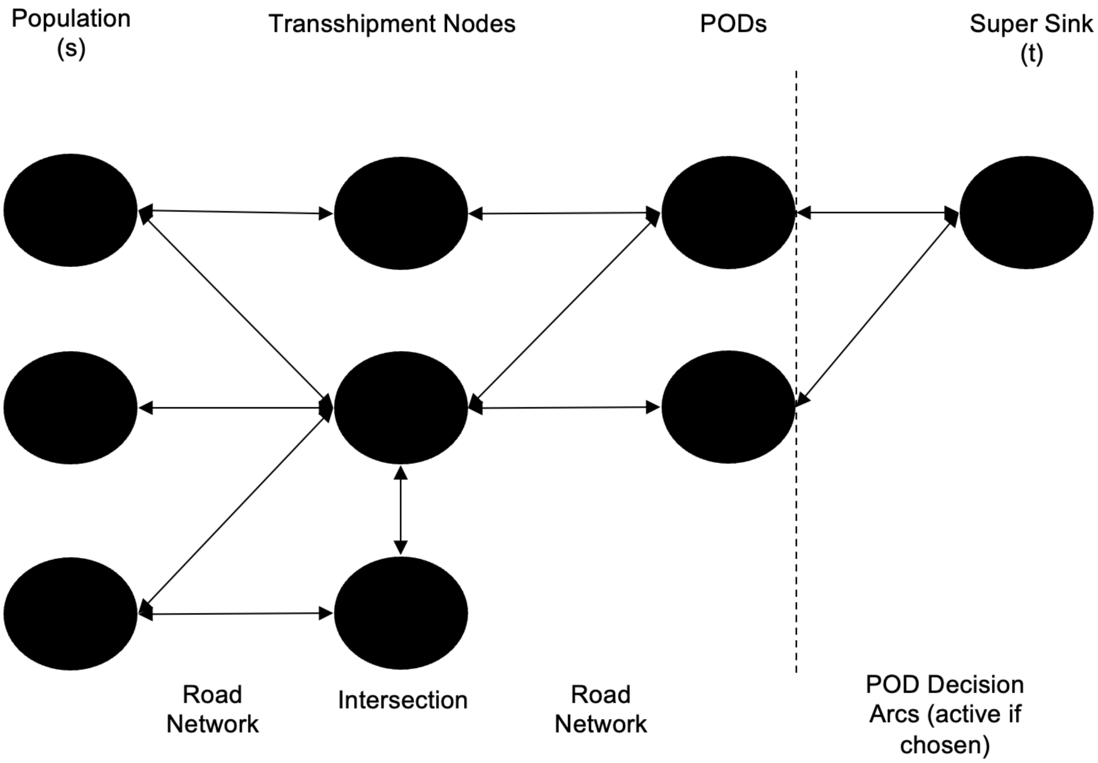

Figure 3.8. Model Network. Populations, Transshipment Nodes, PODs and the Super Sink are represented as nodes within the network. No-cost arcs connecting the populations to the network and the road network are used as the arcs. Demand from the population centers travels along the network through transshipment nodes to the PODs, if their demand is met by the POD, it is fed to the Super Sink then returns to its original population node.

3.3 Example Implementation for Oahu

We implement our optimal POD location model for a small subset of data for Oahu to demonstrate results. Figure 3.9 presents a small portion of the windward Oahu data sets. The network of arcs is denoted by the brown roads, transshipment nodes are the brown dots, the population centers are in green, and the PODs are denoted in red. Notice that the three PODs are connected directly to the closest transshipment node. This connection is made by creating a no cost (virtual) arc to the network. The same process is completed for the two population centers in this network.

Figure 3.9. Example Model Network. Populations are indicated in green, transshipment nodes indicated in brown, PODs are indicated in red. No cost arcs connecting the populations and PODs to the network, and the road network are used as the arcs. Demand from the population centers travel via the network through transshipment nodes to the PODs.

Using our optimal POD location model, we can take this data set and recommend POD locations that minimize round trip travel time. Figure 3.10 presents the results of this analysis. Specifically, we output a map demonstrating the traffic congestion and POD selections for the scenario run. Note, to serve the populations in this small network, only two of the three possible PODs were required (shown in green). Moreover, we list the POD type based on the total traffic flows (shown as the number in each green marker). Table 3.1 presents the details of these selected POD locations. Overall, this small network will require one Type-1 and one Type-3 resupply POD to feed populations in an emergency.

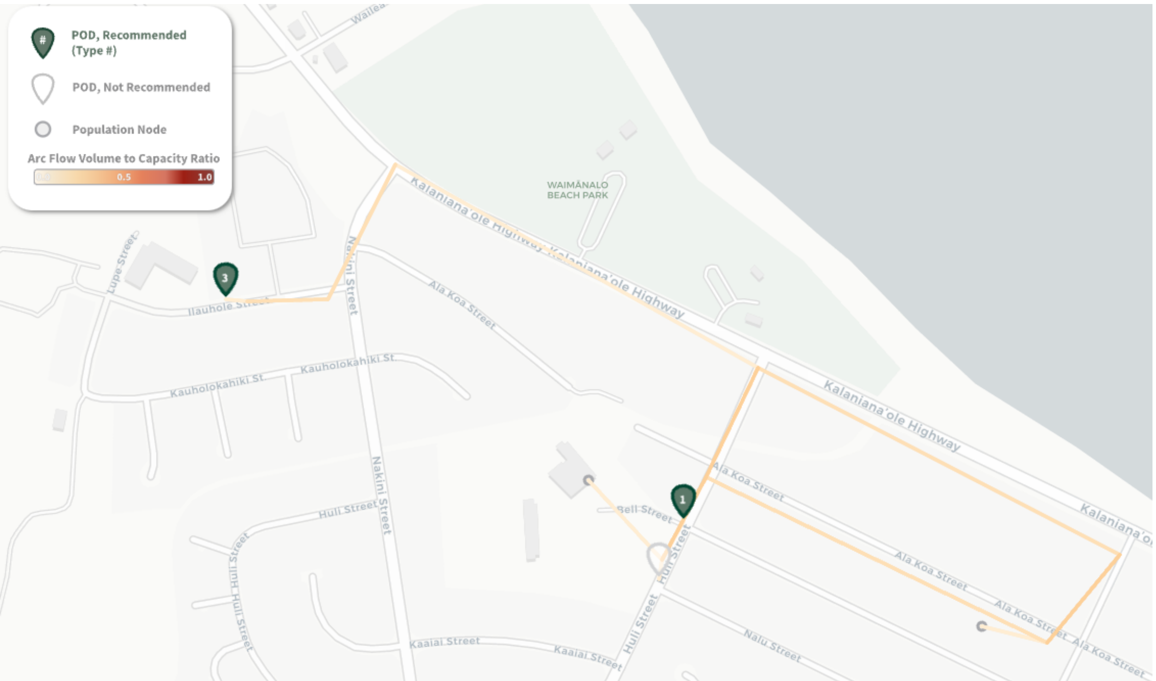

Figure 3.10. Example Model Output. Of the three possible PODs for resupply, our model selects two shown in green with their size requirements shown in which representing POD type. Traffic congestion experienced to reach these PODs is shown as color on the road arcs.

Table 3.1. PODs Selected for Use in Example Model

PODs selected for Use in Example model			
Location Name	POD size	Longitude	Latitude
Head Start Pope	1	-157.69	21.33
Kamehameha Schools- Waimanolo	3	-157.70	21.33

We also study the worst-case travel times for communities to determine who may be underserved by this POD plan. Table 3.2 presents the routes with the longest round trip travel times found in the model results. We look at each route taken, which is an origin-destination pair in our model, such that a single population center can have mulutple routes.

In this small example, the two population centers results in three routes with short travel times (<5 min).

Table 3.2. Longest Round Trip Travel Times for Example Model

Longest Round Trip Travel times for Example Model			
Number	Population Center	Distance (Miles)	Travel Time (Minutes)
1	population2	2.49	4.98
2	population2	1.64	3.44
3	population1	.21	0.50

This table shows the population name, distance traveled to a POD and round trip travel time for that populations route. In the larger runs of this model, it will show only the 20 longest round trip travel times.

CHAPTER 4:
Analysis and Results

We provide recommendations to HIEMA and FEMA on which POD locations should be activated in response to a natural disaster using the methods presented in Chapter 3. The goal is to consider resupply PODs as outlined in the State DMP and the potential use of these locations as pre-covery PODs that warehouse food and water before a disaster. For both Re-PODs and Pre-PODs, we run the optimal POD model for three different scenarios:

> Scenario 1, the idealized scenario given no restriction on manpower and expected food needs per vehicle;
> Scenario 2, a realistic scenario where the maximum number of PODs allowed on windward Oahu is limited to an amount appropriate for the population; and
> Scenario 3, an optimistic scenario, where each vehicle arriving at a POD can collect food for more people.

Each scenario serves a different purpose. Scenario 1 identifies the idealized POD locations for each community given the data sets developed in Chapter 3. This is an idealized scenario because it will likely require more manpower resources than are currently available on the island. Scenario 2 identifies the best POD locations if more realistic limitations are considered for the number of POD locations. Namely, HIEMA and FEMA will likely limit the number of Re-PODs to 40 (i.e., 1/3 of all resupply containers outlined in the DMP) and Pre-PODs to 10 (i.e., a sufficient amount to feed windward Oahu populations for four days). Scenario 3 considers an optimistic coordination scenario where each vehicle can feed more people. This scenario represents a way to reduce congestion and possibly speed up recovery efforts.

Unless otherwise stated, all scenarios use the following data for model parameters and constraints. We limit POD size to their maximum given space restrictions (see Sections 1.2.1 and 1.2.3 for details), we use roadway capacities given Annual Average Daily Traffic (AADT) levels provided in state data sets, minimum traffic flows for opening a POD are set to 250 vehicles, we assume one vehicle per household, and an average family size of 2.5 people (United States Census Bureau 2010). Thus, each vehicle requires five meals on average and a POD will only open if it serve at least 2,500 meals.

We complete analyses for both Re-PODs and Pre-PODs. We compare results across scenarios to determine which PODs are recommended. The common PODs found across all resupply and pre-covery scenarios form the recommended locations where MCBH should request funding to support windward Oahu infrastructure development and HIEMA should incorporate in the future DMP.

4.1 Optimal Resupply POD Locations

We identify ideal Re-PODs locations for windward Oahu given FEMA standard sizes for POD Type-1 (20,000 meals), Type-2 (10,000 meals), and Type-3 (5,000 meals).

4.1.1 Scenario 1: Idealized

We run the optimal POD model for windward Oahu with no limitation on manpower. Here, the optimal POD model selects 63 of the 87 possible POD locations to feed windward Oahu. Figure 4.1 presents the results of this analysis. The green markers indicate PODs that are in use and the number labeling each indicates the POD size. Empty white markers indicate which PODs the model did not select. The full list of PODs selected is presented in Appendix A, Table A.1.

Having no restrictions on manpower favors as many small, distributed PODs as possible. In general, the PODs that are not recommended are clustered near others that are recommended, suggesting optimal POD locations will distribute traffic and reduce travel time as much as possible while not opening unnecessary locations. However, there will still be significant excess food via this plan. Results include one Type-1 POD (20,000 meals), six Type-2 PODs (60,000 meals), and 56 Type-3 PODs (280,000 meals). Given the windward population of 137,115 people, this POD plan would commit an excess of 85,775 meals to serve community needs. While this number is large, it may also provide important food backup in situations where more vehicles arrive than expected at a given POD location.

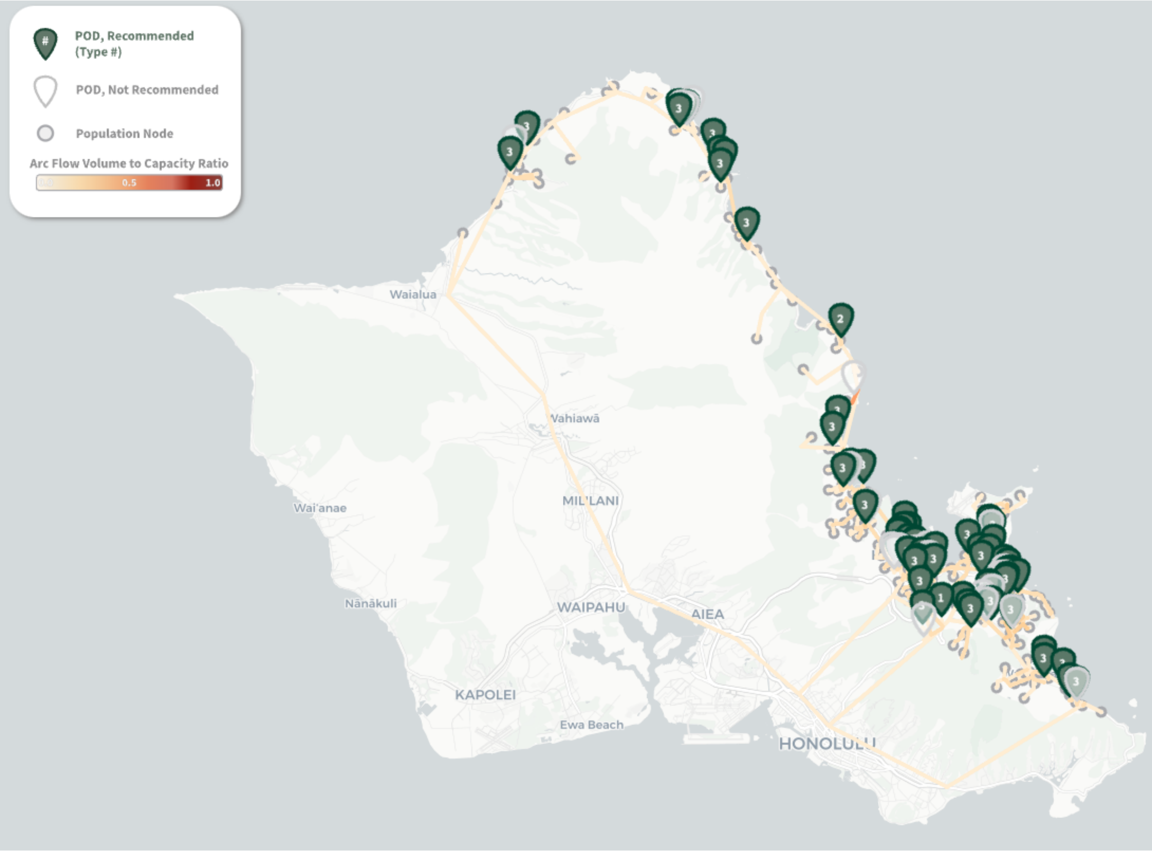

Figure 4.1. Optimal Resupply PODs given an Idealized Scenario. Our model selects 63 of 87 possible POD locations when there are no restrictions on manpower or inundation. PODs selected are shown with green markers with their type indicated by the white number in the center. POD locations that were not selected are indicated by white silhouette markers. The full list of PODs selected is presented in Appendix A, Table A.1. Image created using `Leaflet`.

Of these 63 PODs, 43 are in the two communities directly outside the MCBH front gate. This clustering suggests that MCBH may be an ideal location for an CSA that serves windward communities (assuming the gate and roads to the installation remain operational after a disaster). Moreover, these 43 PODs provide possible locations for MCBH to assist with civilian infrastructure projects outside the installation via federal and community support grants.

We estimate the efficiency of these 63 PODs to feed community members via the round-trip travel time for each population center. Figure 4.2 presents the distribution of round trip travel times across all routes taken. The average round trip travel time for a population center is 15.5 minutes with a standard deviation of 16.8 minutes. The minimum travel time for any vehicle is one minute and the maximum (longest) travel time is 89.7 minutes. Here, we see that the majority of round trips will take less than 20 minutes, yet few round trips will take upwards of 1.5 hours. In general, this means the majority of populations can be served effectively from these 63 locations. However, there are some communities that are isolated from possible PODs locations, such that they will need to travel significantly longer to access food and water.

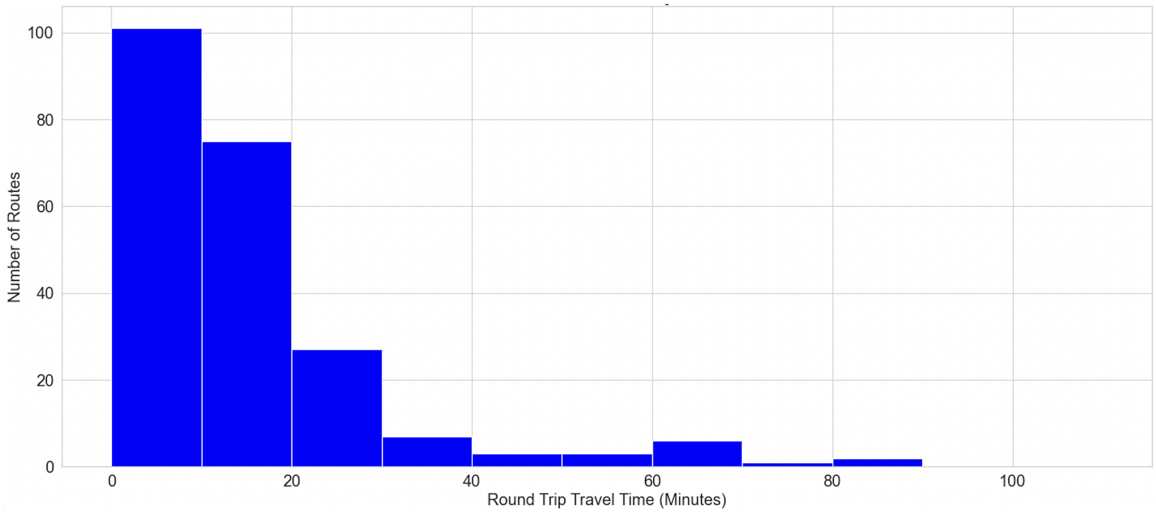

Figure 4.2. Resupply Round Trip Travel Times to PODs given an Idealized Scenario. Each route represents an origin-destination pair between a population center and a POD it is assigned to travel to for food. Here, 165 of the 233 routes populations took to receive relief supplies were under 20 minutes round trip with non-linear traffic congestion. Few routes require significantly longer travel times, with only two over 80 minutes.

We highlight the worst travel times to identify populations centers that will have difficulty receiving food and water. Table 4.1 presents the 20 longest travel times for the idealized scenario. While the round trip travel times are short (< 20minutes) for most populations, some populations are not as well supported. Overall, these population centers are the most under-served by the model. As shown in Table 4.1, 9 of the worst travel times are experienced by population centers population156, population185, population154, population195, and population18, and population160. Whereas some populations experience the longest travel times for a single route, others experience many routes that require long travel times. For example, population156 has a portion of its vehicles experience 89.7 min round trip travel times via a 57.4 mile route, yet the next longest route for the same community is only 49.7 minutes and 30.7 miles. In contrast, population8 uses five routes all with travel time between 67.5 and 58.8 minutes and a distance traveled between 32.4 and 29.7 miles.

Table 4.1. 20 Routes with the Longest Travel Times given an Idealized Resupply Scenario

Rank	Population Center	Distance (Miles)	Travel Time (Minutes)
1	population156	57.4	89.7
2	population85	53.7	83.4
3	population54	47.6	75.9
4	population95	45.0	68.4
5	population8	34.5	67.5
6	population60	33.3	64.3
7	population8	32.4	63.5
8	population8	32.3	63.3
9	population8	31.9	62.2
10	population8	29.7	58.8
11	population60	28.0	55.1
12	population36	34.4	53.7
13	population156	30.7	49.7
14	population60	24.2	48.7
15	population56	29.4	46.3
16	population95	23.0	35.5
17	population132	18.4	35.1
18	population160	19.5	35.0
19	population157	20.9	33.8
20	population51	15.0	32.2

4.1.2 Scenario 2: Manpower-Constrained

Manpower limitations exist in most operations, especially in emergency situations. This limitation is applied to our idealized model by limiting the number of POD locations that can be selected to 40, or one-third the total number of containers of food planned for Oahu during disaster resupply. Figure 4.3 presents the results of this analysis where all forty PODs are required for the optimal solution. The green markers indicate PODs that are in use and the number labeling each indicates the POD size. Empty white markers indicate which PODs the model did not select. The full list of PODs selected is presented in Appendix C, Table A.2.

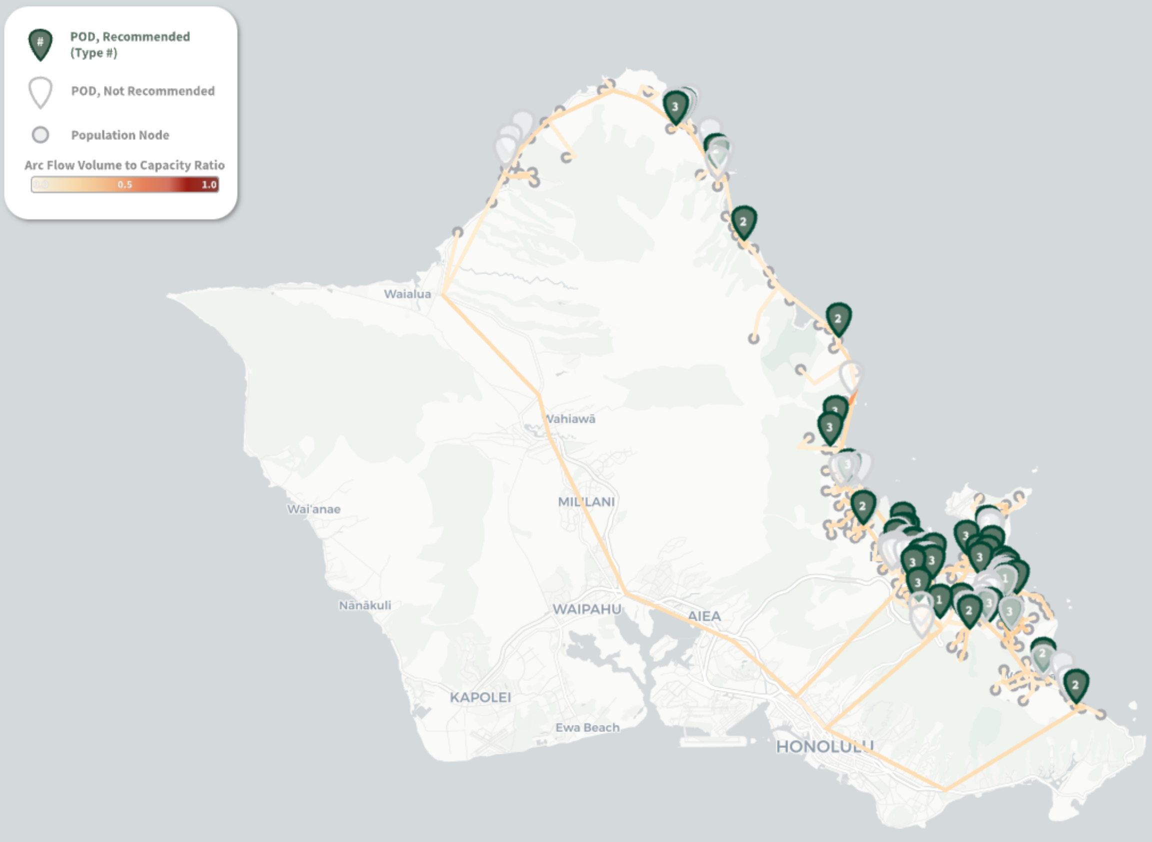

Figure 4.3. Optimal Resupply PODs given a Manpower-Constrained Scenario. This model limited the max number of PODs to 40. The selected PODs are plotted using `QGIS`. PODs selected are under green markers with their type indicated by the number in the center. PODs not chosen are indicated by the white silhouette markers. The full list of PODs chosen is in Appendix A, Table A.2.

In contrast to Scenario 1, this scenario recommends using as many large and centrally located PODs as possible, shown in Figure 4.3. Results select four Type-1 PODs (80,000 meals), 10 Type-2 PODs (100,000 meals), and 29 Type-3 PODs (145,000 meals). Overall, this scenario leads to 50,000 excess meals for the windward population.

Similar to Scenario 1, the majority of POD locations are near MCBH and can be prioritized for pre-positioning of supplies on the installation or funded by federal grants. Here, 29 of the 40 recommended PODs are in the two communities near the MCBH gate.

Travel times experienced when only 40 PODs are available will be significantly longer than the idealized case. As shown in Figure 4.4, the majority of population centers can complete their round trip in less than an 50 minutes, in contrast to less than 20 minutes in the idealized case. Importantly, 11 of the 220 routes taken are longer than 60 minutes, with the longest route taking 191.4 minutes (2 hours and 15 minutes).

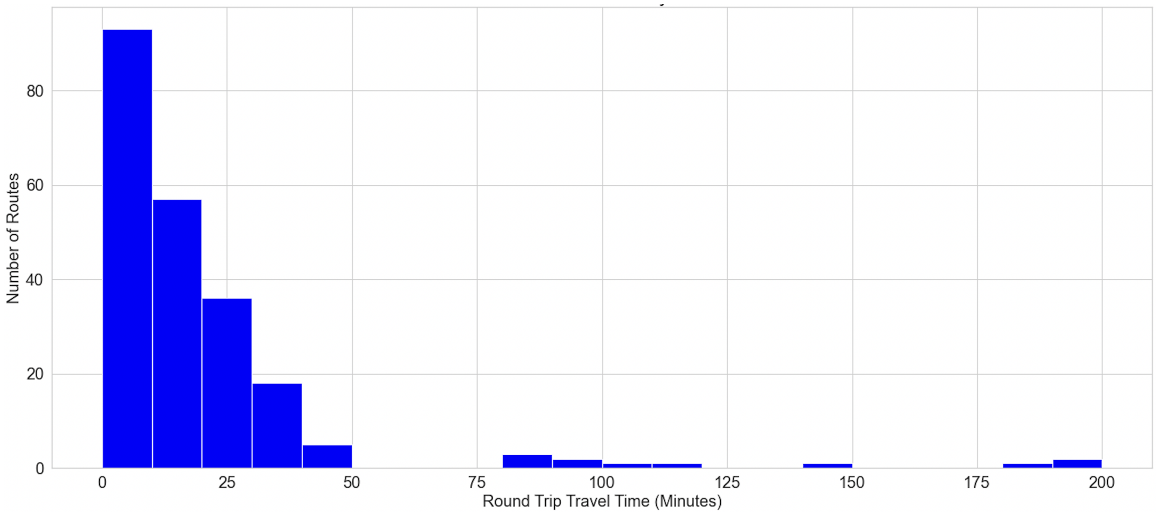

Figure 4.4. Round Trip Travel Time for Routes given a Manpower-Constrained Scenario. This model limited the maximum number of PODs to 40. Here, some communities experience much longer travel times than in the idealized scenario. While the majority of routes are still less than 30 min, 11 routes are greater than 60 minutes to complete.

While traveling over two hours for food and water is not ideal, it may be acceptable in disasters with limited supplies and manpower. In general, Figure 4.2 shows that only few populations will experience long travel times, most notably population71, population160, and population141. Of the 11 routes that take longer than 1 hour, 10 come from these population centers. Note: the multiple entries for a given population center is caused by the model splitting the population centers across multiple PODs and routes in an effort to minimize travel time throughout the network.

Table 4.2. 20 Routes with the Longest Travel Times given a Manpower-Constrained Resupply Scenario

Rank	Population Center	Distance (Miles)	Travel Time (Minutes)
1	population71	128.8	191.4
2	population71	123.0	190.4
3	population71	118.5	184.1
4	population160	94.7	149.8
5	population160	73.3	117.7
6	population141	65.5	105.5
7	population141	60.7	98.8
8	population159	61.4	93.6
9	population141	51.2	84.09
10	population141	50.9	83.9
11	population141	50.2	83.1
12	population72	23.4	43.4
13	population9	24.7	42.9
14	population151	24.7	41.8
15	population9	23.4	40.9
16	population83	25.8	40.2
17	population83	22.9	35.7
18	population72	18.2	35.6
19	population153	20.7	35.4
20	population69	22.7	34.4

4.1.3 Scenario 3: Optimistic Food Collection

As stated above, we expect each vehicle arriving at a PODs receiving five meals to feed 2.5 people on average. We study an optimistic case if we assume vehicles arriving at PODs receive 8 meals, such that each vehicle can feed four people. This assumption assumes that families in nearby houses can coordinate to reduce the number of vehicles on the roads and arriving and PODs.

Results for this optimistic coordination scenario reduces the total number of PODs selected from 63 to 58. The POD distribution depicted in Figure 4.5. Here, one Type-1 (20,000 meals), one Type-2 (10,000 meals), and 56 Type-3 (280,000 meals) PODs were chosen, for a total supply of 310,000 meals. Surprisingly, this scenario generates the lowest overage in food supply of 35,770 meals. Thus, from a feeding perspective, this scenario is the most efficient.

This scenario also has the shortest travel times and reduces the overall worst-case travel times for communities (see Figure 4.6). When the number of people per car is increased to four from 2.5, the average round trip travel time drops from 18.66 minutes to 12.25 minutes. The standard deviation for a given route drops to 10.5 minutes. As seen in Figure 4.6, all populations complete their round trip in less than 50 minutes with 112 population centers completing the trip in less than 10 minutes.

Table 4.3 shows the 20 longest round trip times given the optimistic scenario. Here, all populations are able to access food supplies within a one hour time frame. Also, few populations are split between multiple POD locations to access food, simplifying emergency coordination. Specifically, only population51 and population52 are split between multiple PODs, where other possible routes can access food 17 min faster than their worst-case route. Overall, this scenario shows how coordination of vehicles and POD access results in much better travel times than the idealized and the manpower-constrained scenarios.

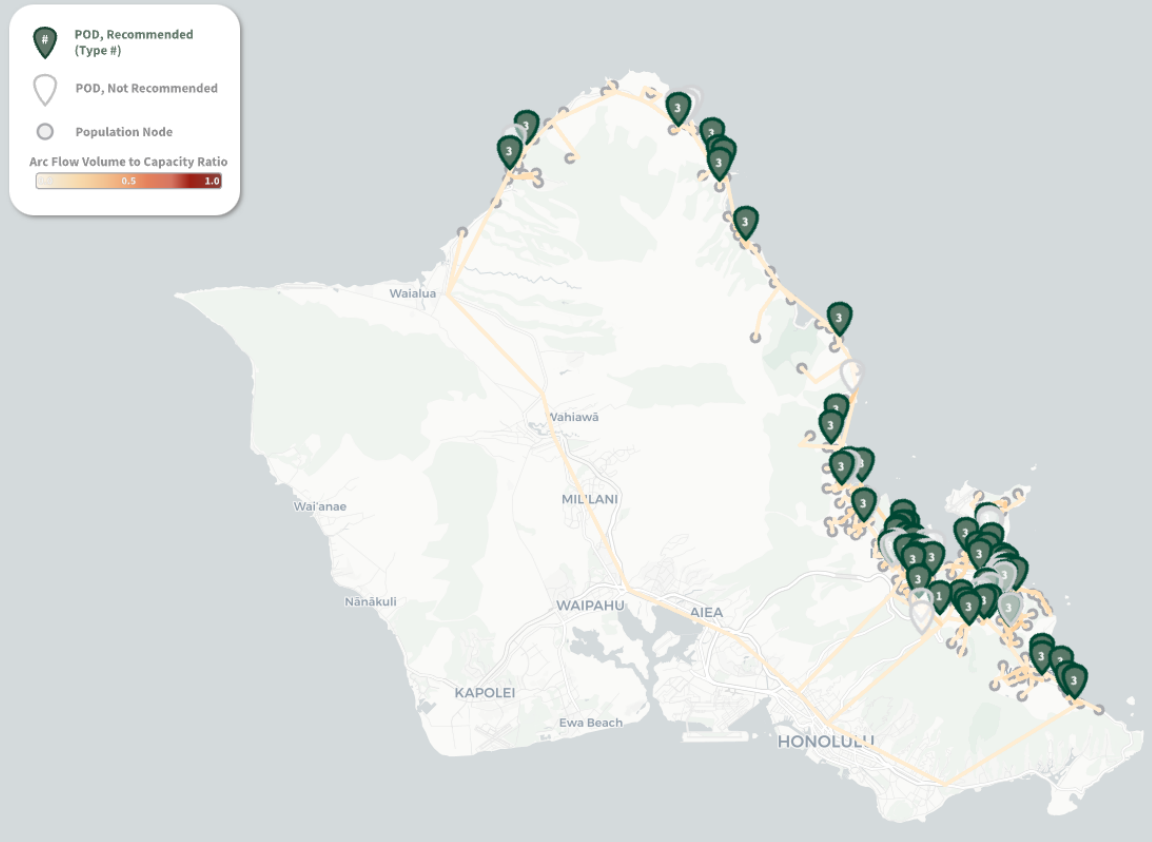

Figure 4.5. Optimal POD Locations for Optimistic Scenario. This resupply model increases the number of people served by a single car per car from 2.5 to four people. Here, 58 of 87 PODs are selected. They are shown with green markers with their type indicated by the number in the center. PODs not chosen are indicated by the white silhouette markers. The full list of PODs is presented in Appendix A, Table A.3.

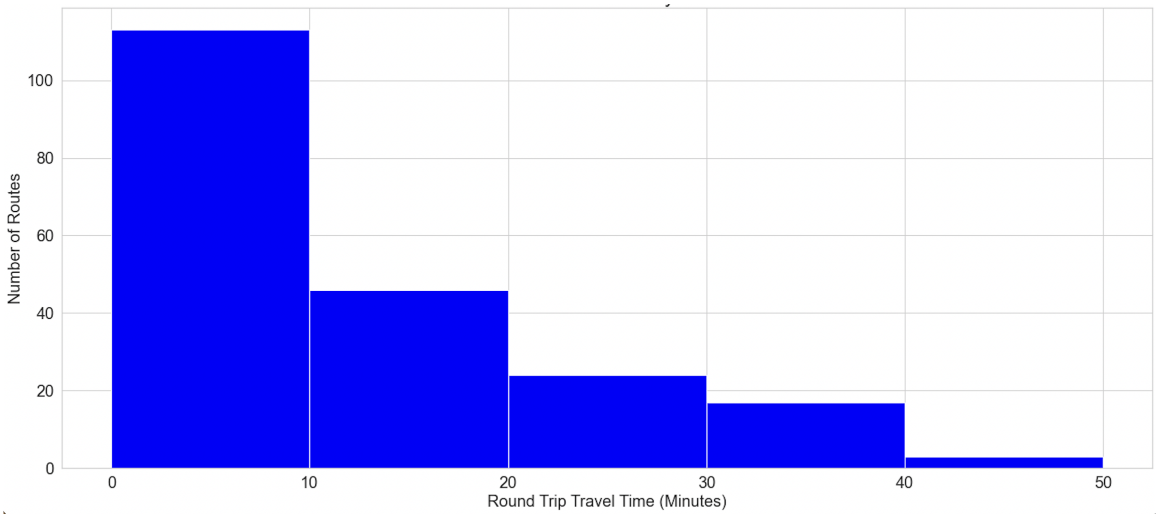

Figure 4.6. Round Trip Travel Time for Routes given an Optimistic Scenario. This model is optimistic to allow fewer cars to feed the same number of people. Here, all communities are able to access PODs and return home within a 50 min time frame.

Table 4.3. 20 Routes with the Longest Travel Times given an Optimistic Resupply Scenario

Rank	Population Center	Distance (Miles)	Travel Time (Minutes)
1	population52	28.3	46.8
2	population51	21.3	45.7
3	population157	26.1	42.6
4	population155	19.4	38.1
5	population51	17.3	37.1
6	population149	22.6	35.4
7	population116	17.4	35.4
8	population119	19.5	35.0
9	population52	20.5	34.1
10	population66	17.8	33.8
11	population114	19.7	33.2
12	population53	19.6	31.5
13	population109	19.2	31.4
14	population37	13.0	31.3
15	population151	17.5	31.1
16	population51	14.8	31.0
17	population111	17.5	30.8
18	population67	15.8	30.6
19	population137	19.5	30.4
20	population160	16.7	30.0

4.2 Optimal Pre-covery POD Locations

As stated in Chapter 1, the Hawaii DMP plans for the possible need to operate resupply PODs, but prefers to use pre-covery for emergency preparation. Pre-covery PODs are different from FEMA standard PODs in space requirements and feeding capacity. Specifically, Pre-PODs only require the space of a Type-3 POD but can provide the food rations similar to a Type-1 POD for a four-day period. Practically speaking, this means any POD location used for resupply can be used for pre-covery in terms of space. However, the infrastructure required, maintenance, and management of stock are additional factors that are not considered for resupply are important for pre-covery. Thus, resupply and pre-covery POD may be the same location, but will likely be different given their capabilities and requirements. Also, it will take time to plan and fund pre-covery PODs and it is important to plan for resupply first, as a near-term disaster will may require FEMA PODs.

We run our optimal POD location model for pre-covery. We assume each location used for resupply can become a pre-covery POD (87 locations). Each pre-covery POD is assumed to have a total food capacity of 135,000 meals (Buck 2022), which is assumed to support 20,000 people for the pre-covery period of four days identified in the DMP. Unless otherwise stated, all other parameters and scenario data are the same, including the same minimum vehicle flows to open a POD. For the purposes of this work, we only consider travel time to PODs and do not consider additional pre-covery factors (e.g., maintenance, security).

4.2.1 Scenario 1: Idealized

The idealized scenario for pre-covery allows the model to choose any or all windward Oahu POD locations that minimize the round trip travel times to access food. Figure 4.7 presents the results using our optimal POD location model given this scenario. Here, the model recommends 53 POD locations, which is equivalent to 7.155 M if each container is at full capacity. However, far fewer meals are required. Using the same break points as resupply POD types, the number of vehicles arriving at each Pre-POD corresponds to four Type-1 (80,000 meals), twelve Type-2 (120,000 meals), and forty Type-3 PODs (200,000 meals) for a total number of meals to closer to 400,000 per day or 1.6 M meals for the four day pre-covery period. Considering a 2-meal requirement per person, the total number of meals for pre-covery is estimated as 1.097 M meals. Accordingly, the idealized scenario results in an overage of $\tilde{5}$03,000 meals.

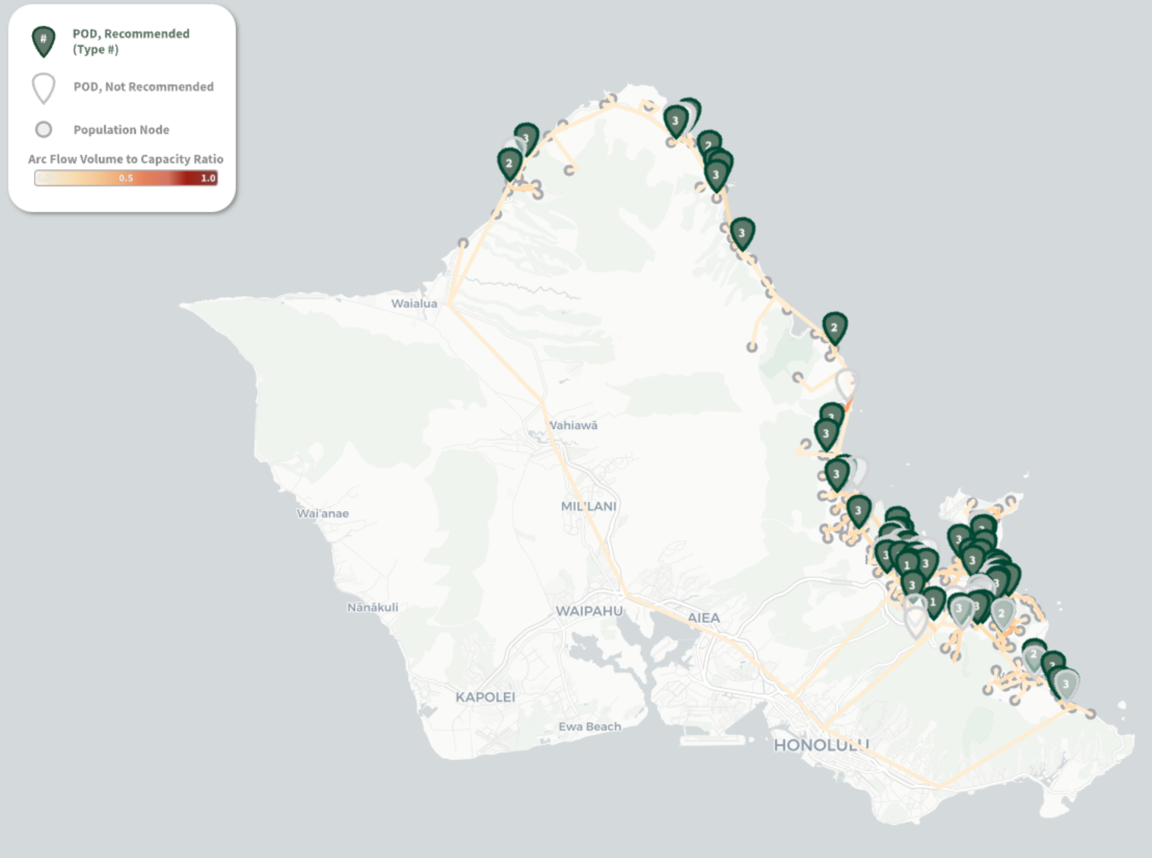

Figure 4.7. Optimal POD Locations for Pre-covery given an Idealized Scenario. This pre-covery model is not constrained by number of PODs and maintains the same feeding rate per vehicle and minimum POD size as resupply. The 53 selected PODs are plotted using `Leaflet`. PODs selected are labeled with green markers with their type indicated by the number in the center. PODs not chosen are indicated by the white silhouette markers. Full list of PODs provided in Appendix B, Table A.4.

The distribution of round trip travel times is presents in Figure 4.8. We find the majority of routes taken to be less than 60 minutes round-trip with an average travel time is 15.97 minutes with a standard deviation of 16.97 minutes. All 206 routes take less than two hours to complete. Still, there are nine routes that take longer than one hour (60 minutes). Surprisingly, only two populations have more than one route greater than one hour. Overall, Population centers population29, population96, population146, and population52 will have the most difficulty reaching pre-covery PODs using this distribution plan.

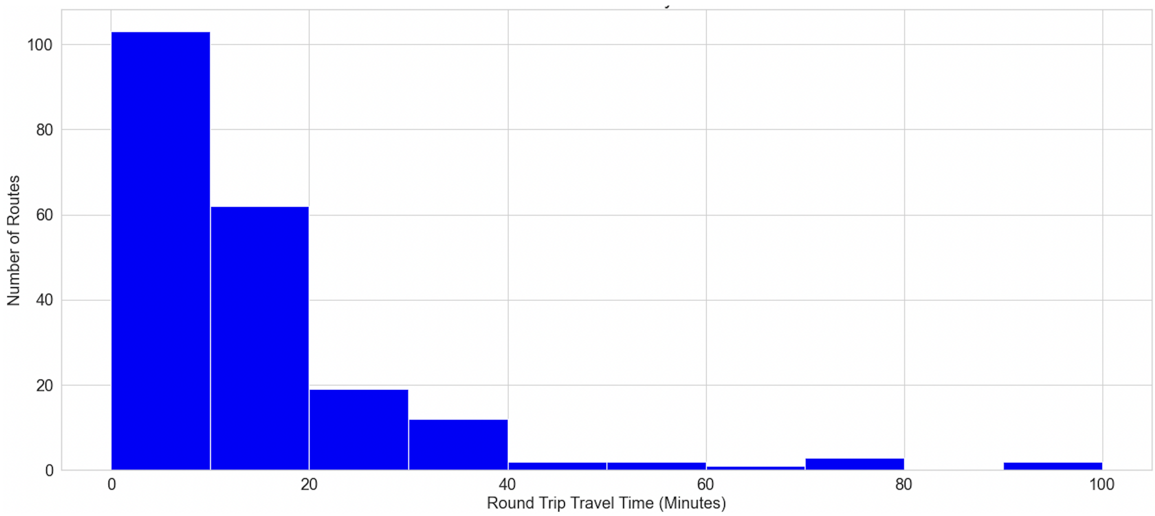

Figure 4.8. Pre-covery Round Trip Travel Times given an Idealized Scenario. The idealized pre-covery model has 206 routes. All routes are under two hours (120 minutes) and only nine routes take longer than one hour (60 minutes).

Table 4.4. 20 Routes with the Longest Travel Times given an Idealized Precovery Scenario

Rank	Population Center	Distance (Miles)	Travel Time (Minutes)
1	population155	60.9	95.9
2	population159	61.5	92.8
3	population115	50.5	77.6
4	population113	50.5	77.3
5	population29	46.2	70.4
6	population29	45.6	69.4
7	population112	41.0	63.6
8	population96	40.2	62.9
9	population96	39.5	61.4
10	population150	33.7	55.7
11	population142	34.8	54.0
12	population146	29.6	53.5
13	population52	30.0	49.4
14	population145	27.1	46.5
15	population146	24.2	42.4
16	population151	23.5	39.9
17	population153	22.5	39.4
18	population8	16.9	38.6
19	population52	21.4	35.4
20	population144	16.2	34.1

4.2.2 Scenario 2: Manpower-Constrained

Similar to the resupply scenarios, manpower and costs are an important constraint for deciding POD locations. Manpower is even more important for pre-covery PODs that have more strict requirements than resupply PODs. To reflect the goal of reducing manpower and cost constraints, we run our optimal POD location model where the number of pre-covery

PODs is limited to 10.

Figure 4.9 presents the optimal locations for these 10 PODs. Similar to other scenarios, the majority of these PODs are located in the communities outside of MCBH and provide a possible location for installation support. All PODs in this model will have vehicles arriving on the scale of Type-1 resupply PODs and should be fully stocked. This results in 1.35 M meals required for windward communities and an excess of $\tilde{2}$53,000 meals. This overage in feeding is roughly half of the overage given the idealized scenario.

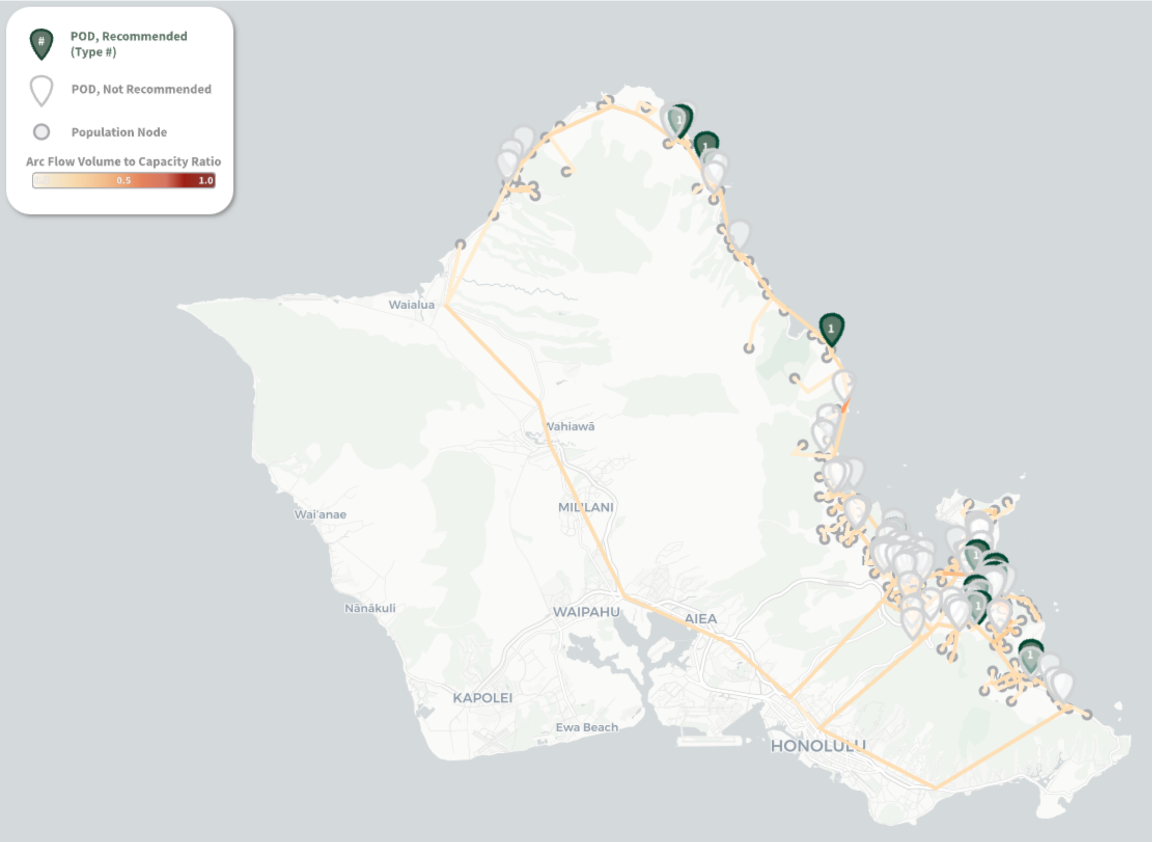

Figure 4.9. Optimal Pre-covery PODs given a Manpower-Constrained Scenario. This model limited the max number of pre-covery PODs to ten. The selected PODs are plotted using `Leaflet`. The 10 PODs selected are under green markers with their type indicated by the number in the center. PODs not chosen are indicated by the white silhouette markers. Full list of PODs chosen is in Appendix B, Table A.5.

Figure 4.10 presents the round trip travel times for routes given the manpower-constrained scenario. In this scenario, the average round trip travel time for this scenario is 19 minutes with a standard deviation of 15.4. Six of the 20 longest round trip travel times are greater than one hour (60 minutes), and only one is over 70 minutes. Table 4.5 shows the 20 longest round trip travel times. Of note, note one population center has two or more of the 20 worst round trip times.

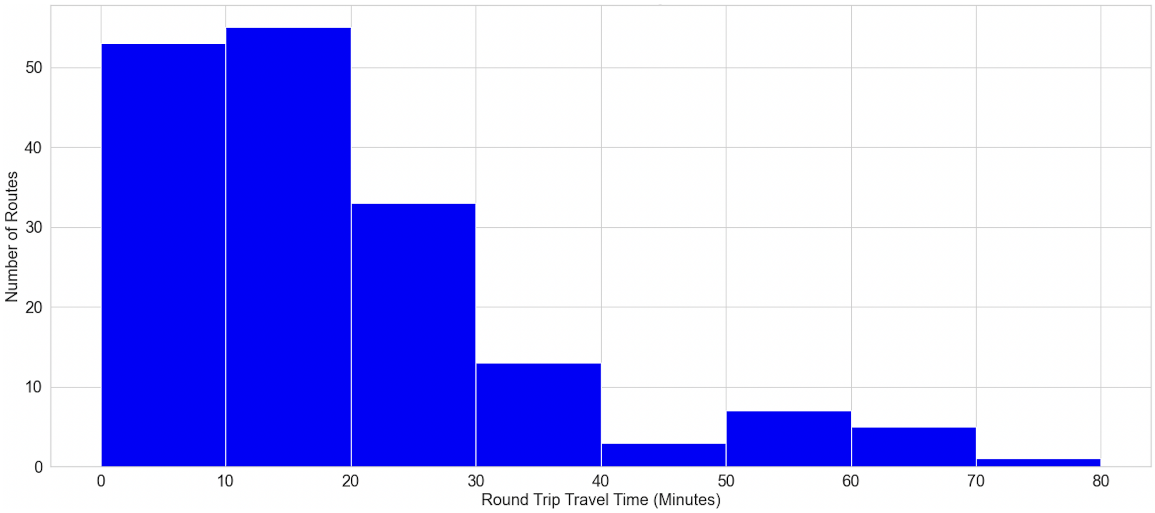

Figure 4.10. Pre-covery Round Trip Travel Time for Routes given a Manpower-Constrained Scenario. All round trip travel times for the routes in this model are under 70 minutes.

Table 4.5. 20 Routes with the Longest Travel Times given a Manpower-Constrained Pre-covery Scenario

Rank	Population Center	Distance (Miles)	Travel Time (Minutes)
1	population92	46.3	71.5
2	population133	44.1	68.0
3	population82	43.5	66.2
4	population96	43.1	65.5
5	population136	40.3	61.7
6	population25	39.7	61.2
7	population148	37.8	59.3
8	population135	37.7	57.2
9	population160	34.9	57.2
10	population108	37.0	55.9
11	population55	36.0	55.2
12	population85	35.0	52.7
13	population68	33.4	52.3
14	population71	26.1	42.4
15	population156	25.9	41.9
16	population132	22.3	41.0
17	population123	21.7	38.2
18	population155	22.16	38.1
19	population115	22.74	36.1
20	population95	23.1	35.8

4.2.3 Scenario 3: Optimistic Food Collection

We also study the optimistic feeding scenario for pre-covery PODs by increasing the amount of people fed by a single vehicle from 2.5 to 4, or meals collected from 5 to 8. Results for this scenario are presented in Figure 4.11. Here, 53 PODs were selected corresponding to daily traffic and feeding similar to the following resupply PODs: two Type-1 (20,000 meals), seven Type-2 (70,000 meals), and 44 Type-3 (220,000 meals). This results in a total food requirement of 1.214 M meals with an excess of 1̃17,000 meals. Similar to the resupply results, this optimistic scenario feeds windward Oahu with the lowest overage of food among pre-covery scenarios.

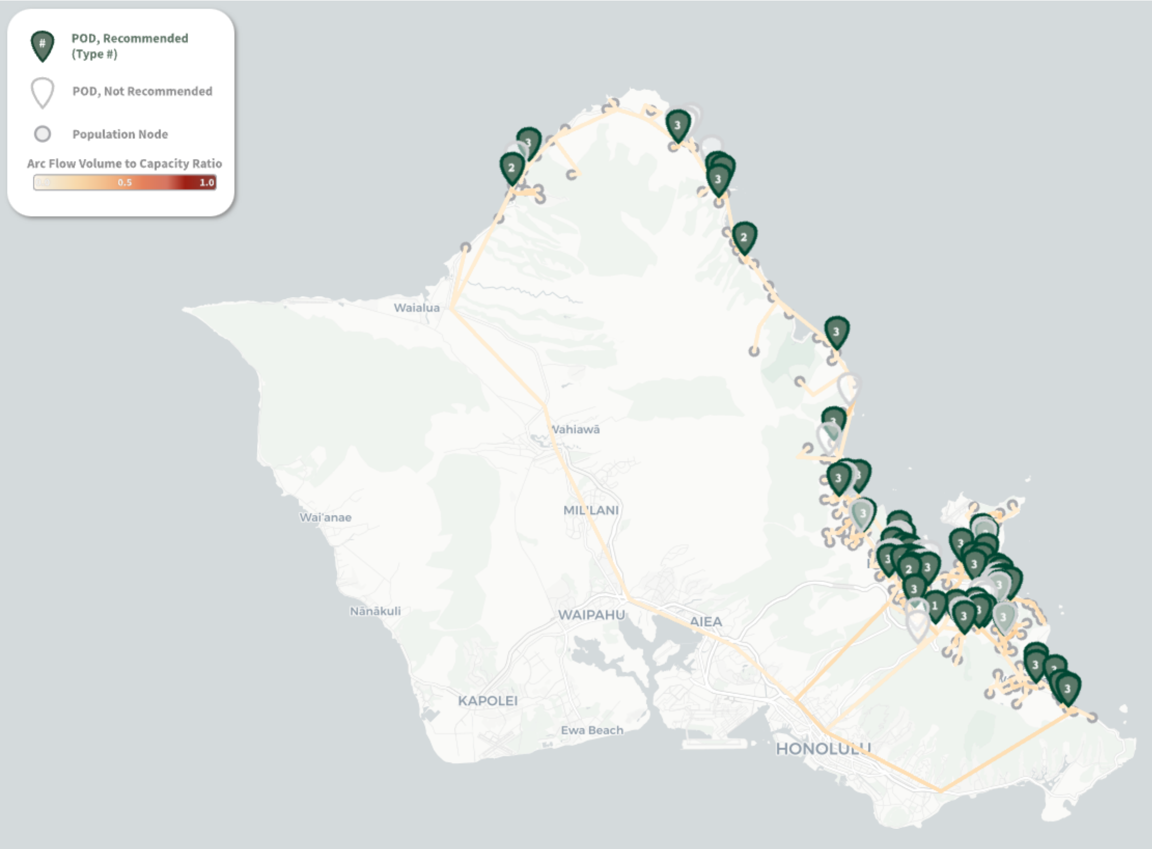

Figure 4.11. Optimal POD Locations given an Optimistic Pre-covery Scenario. This pre-covery model increases the food collected per vehicle from 5 to 8 meals. Here, 53 PODs are selected. They are shown with green markers with their type indicated by the number in the center. PODs not chosen are indicated by the white silhouette markers. The full list of PODs is presented in Appendix B, Table A.6.

Figure 4.12 presents the distribution of round trip travel times for the optimistic scenario. This scenario has an lowest travel times of all scenarios studied with an average travel time of 7.6 minutes and a standard deviation of 6.5 minutes. All routes taken will be less than 31 minutes.

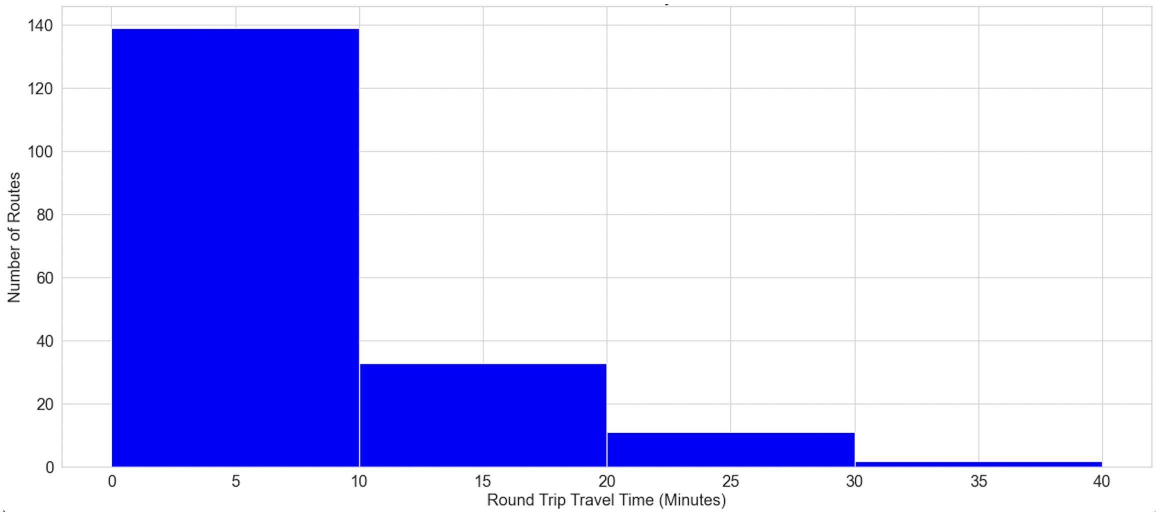

Figure 4.12. Round Trip Travel Time for Routes given an Optimistic Pre-covery Scenario. This model is optimistic to allow fewer cars to feed the same number of people. Here, all communities are able to access PODs and return home within a 40 min time frame.

Table 4.6 shows the 20 longest travel times for the optimistic pre-covery scenario. The longest route in this model belongs to population119 at 31 minutes. Overall, this distribution of PODs will produce the least traffic of all scenarios.

Table 4.6. 20 Routes with the Longest Travel Times given an Optimistic Pre-covery Scenario

Number	Population Center	Distance (Miles)	Travel Time (Minutes)
1	population119	16.8	31.0
2	population160	16.7	30.0
3	population151	14.2	27.2
4	population77	15.0	26.6
5	population9	14.7	25.9
6	population12	14.3	25.0
7	population123	13.3	22.6
8	population51	10.0	21.6
9	population52	12.8	21.4
10	population112	13.1	21.0
11	population153	10.5	20.9
12	population145	9.7	20.8
13	population8	9.5	20.5
14	population113	12.6	19.7
15	population37	8.1	19.4
16	population124	11.9	19.1
17	population37	7.9	19.0
18	population51	8.4	18.7
19	population155	9.2	18.7
20	population149	11.0	17.7

4.3 Comparison of Resupply and Pre-covery Results

We compare results across resupply and pre-covery scenarios. The goal is to determine the POD locations that are common among each scenario. These PODs constitute ideal locations for emergency planning by MCBH and integration in the HIEMA DMPs.

4.3.1 Comparison of Resupply Results

Across the idealized, manpower-constrained, and optimistic resupply scenarios, 63, 40, and 48 PODs were selected, respectively. All PODs selected for these scenarios are presented in Appendix A.

We find significant overlap in PODs chosen across resupply scenarios. Comparing idealized and manpower-constrained scenarios, we find nearly every single POD chosen is in both solutions. Specifically, 39 PODs from the manpower-constrained scenario are also in the idealized scenario. The full list of 39 PODs found across these scenarios is presented in Appendix C, Table A.7. Of the 57 PODs selected by the optimistic scenario with idealized and manpower-constrained, we still find 37 PODs across all solutions. The full list of PODs across the three resupply scenarios is presented in Appendix C, Table A.8.

4.3.2 Comparison of Pre-covery Results

Across the idealized, manpower-constrained, and optimistic pre-covery scenarios, 53, 10, and 53 PODs were selected, respectively. All PODs selected for these scenarios are presented in Appendix B.

Comparing idealized and manpower-constrained scenarios, eight PODs are common between them. The full list of these eight PODs is presented in Appendix C, Table A.9. While the number of PODs selected in the optimistic scenario is the same as idealized, their locations are different. As a result, when considering optimistic scenario with idealized and manpower-constrained, only six common PODs are found. These six PODs are found in Appendix C, Table A.10.

4.3.3 Points of Distribution Across All Scenarios

We compare the resupply and pre-covery PODs to make recommendations to Hawaii and MCBH about which PODs to seek federal and DOD grants to source on Windward Oahu. Locations that are both optimal pre-covery and resupply PODs can provide food for communities before and after a disaster and simplify emergency res;onse. Specifically, dual-use locations can act as pre-covery PODs first, then switch to become a resupply POD if emergencies persist, simplifying the coordination of food access.

We find only five PODs that appear in all six scenarios. Figure 4.13 presents the locations and Table 4.7 lists their information. These PODs are listed in proximity to MCBH.

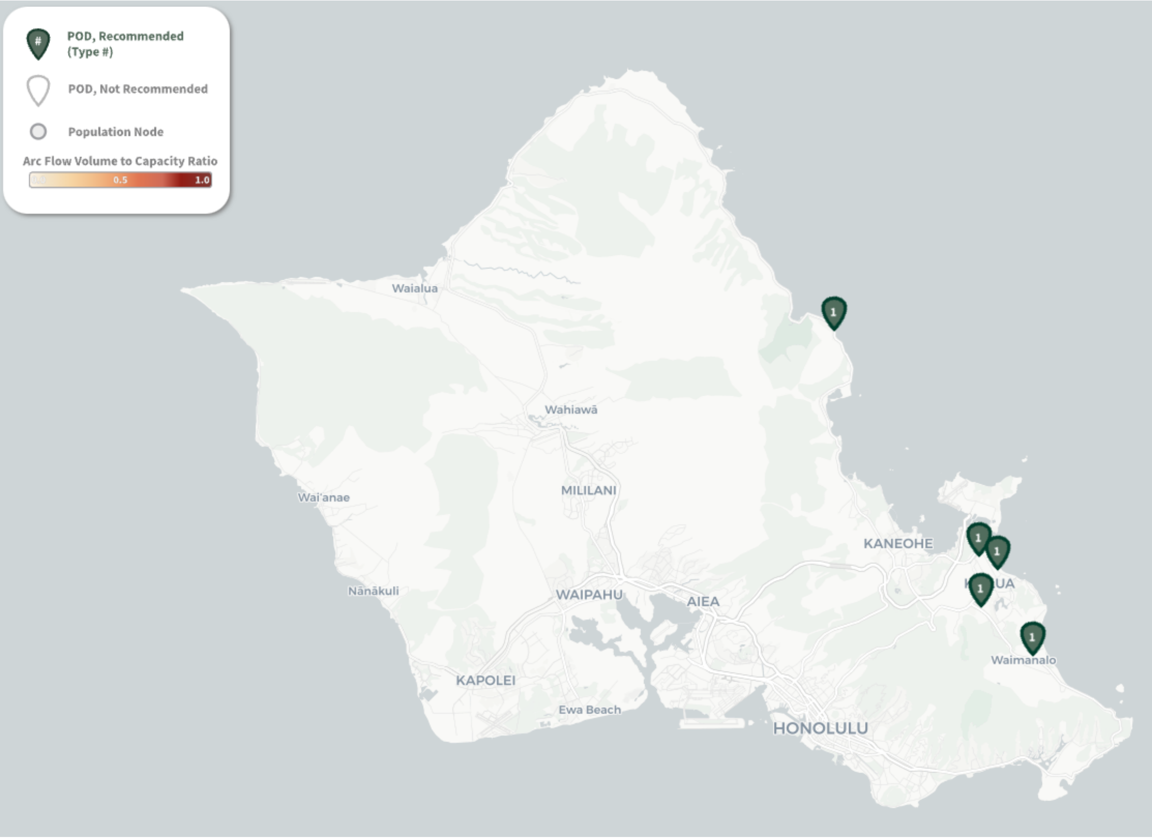

Figure 4.13. Optimal POD Locations Across All Scenarios. The five PODs shown in this figure were found in all scenarios analyzed in this thesis. Thus, given idealized, manpower-constrainted, or optimistic scenarios, these locations reduce travel time. Moreover, they are recommended for both resupply and pre-covery. Four of the five locations listed are in close proximity to MCBH. POD details are presented in Table 4.7.

Table 4.7. PODs across All Six Scenarios

Location Name	POD size	Longitude	Latitude
Kalaheo Neighborhood Park	3	-157.75	21.40
St. Anthony School - Kailua	3	-157.73	21.40
Olomana School	3	-157.74	21.37
Waimanalo Elem & Inter School	2	-157.71	21.34
Kaaawa Elem School	2	-157.84	21.54

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CHAPTER 5:
Conclusion

This thesis concludes with a summary of results, along with recommendation for additional research into LMRD on Oahu.

5.1 Summary

This thesis focuses on three main areas: (1) we constructed data sets for populations, POD options, and road networks throughout windward Oahu; (2) we developed a traffic model with the aim to minimize round trip travel time for windward populations to a POD; and (3) this data was used to determine which POD locations provide the most promise to emergency planers across ideal, manpower constrained, and optimistic coordination scenarios.

Results from each scenario provide useful data for emergency planning of resupply and pre-covery PODs. Results for the idealized Scenario 1 are based on normal feeding requirements given FEMAs and HIEMA expectations, yet ignore manpower constraints. If there is the need or interest for significant excess food to be delivered to communities, then choosing this scenario is helpful guidance for emergency response.

More realistic results come from Scenario 2 with manpower and cost constraints. This limits the number of PODs used on Windward Oahu and allows for flexibility throughout the island for PODs given their finite nature. While this scenario can create feasible resupply and pre-covery plans, it also experiences the greatest traffic and round trip travel times.

The optimistic Scenario 3 is helpful because it shows the benefits of local community coordination. In communities that can coordinate drivers to receive food, the overall traffic will be reduced and the excess of food will also be reduced. However, this scenario still requires a large amount of manpower to run the PODs. Balancing how many PODs can be opened due to manpower constraints and how communities can coordinate emergency supply distribution would ensure efficiency for both communities and first responders.

Many of the optimal POD locations are near MCBH, suggesting the importance of the installation in potentially supporting future emergency response. If food were stored or shipped to MCBH for delivery to windward Oahu PODs, this could alleivate traffic over the highways (which might also be blocked by debris) and still feed the majority of windward communities. Importantly, MCBH is also listed as a potential FSA in FEMA plans, but not State or County plans. We recommend developing coordination plans for feeding windward communities via the MCBH airstrip and pier if that is necessary in a future disaster. Specifically, pre-covery may be helpful coordinated through the installation as the front gate of MCBH will also have lots of traffic and possible inundation after a disaster.

Where pre-covery and resupply makes sense at the same location, the most promising PODs are those found across all scenarios. We find five PODs of the original 87 that meet these criteria. The list of these PODs in order of proximity to MCBH is presented in Chapter 4, Table 4.7.

5.2 Future Research

There are several limitations in this study that provide a basis for future research. First, this research should be expanded from windward Oahu to focus on the entire island. This expansion will inform the state's POD location decisions by including all traffic, population, and POD location factors throughout the island. This will create more accurate and informed POD decisions and possibly change the optimal locations for windward Oahu.

Similarly, this analysis can be expanded from food and water relief to include medical supplies or fuel distribution. This extension in scope is necessary for an holistic view of relief needs for the population.

The POD options should be expanded and refined. Currently the model only looks at grocery stores, parks, and schools as potential locations for a POD. This selection of locations should be expanded to include shelters, food banks, and other areas specified by Hawaii or the City and County of Honolulu. Moreover, constraints special to pre-covery PODs including maintenance and security of long-term food storage should be included in POD recommendations.

Finally, the model can be improved for accurance and local relevance. The current model minimizes round trip travel time, but does not consider additional traffic factors like queuing at PODs. Including these dynamics will provide more accurate travel times than those listed here and may recommend different locations. Moreover, additional travel modes, such as by walking or foot, or delivery modes (e.g., delivery of food directly to homes vs. PODs) would be helpful to consider in the future.

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APPENDIX A:
Resupply Points of Distribution

Table A.1. Ideal Recovery POD List

Location Name	POD size	Longitude	Latitude
SW Aikahi Oahu 2208	2	-157.75	21.42
Foodland Kaneohe #8 - Oahu	3	-157.80	21.40
Foodland Pupukea #27 - Oahu	3	-158.06	21.65
Foodland Laie #32 - Oahu	3	-157.92	21.65
Sunset Beach Neighborhood Park	2	-158.05	21.66
Malaekahana State Recreation Area	3	-157.93	21.66
Kahaluu Regional Park 1	3	-157.84	21.46
Waiahole/Waikane Nature Preserve	3	-157.84	21.49
Kaneohe District Park 1	2	-157.81	21.41
Kaneohe Community and Senior Cente	3	-157.79	21.41
Keaalau Neighborhood Park	2	-157.76	21.42
Hawaii Pacific University	1	-157.78	21.38
Windward School for Adults	3	-157.75	21.41
CALVARY EPISCOPAL PRESCHOOL	3	-157.79	21.40
KAILUA BAPTIST CHRISTIAN PRESCHOOL	3	-157.75	21.39
KAILUA METHODIST PRESCHOOL	3	-157.75	21.39

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Table A.1 – continued from previous page

Location Name	POD size	Longitude	Latitude
PALI VIEW BAPTIST PRESCHOOL	3	-157.79	21.39
Head Start Pope	1	-157.69	21.33
Kamehameha Schools - Kahuku	3	-157.95	21.68
Kamehameha Schools - Waimanalo	3	-157.69	21.33
Le Jardin Academy	1	-157.76	21.38
Trinity Christian School	3	-157.76	21.38
Hauula Elem School	2	-157.90	21.61
Kaaawa Elem School	2	-157.84	21.55
Kahuku High & Inter School	1	-157.95	21.68
Laie Elem School	2	-157.92	21.65
Malama Honua - PCS	3	-157.70	21.34
Olomana School	3	-157.74	21.38
Waimanalo Elem & Inter School	2	-157.71	21.35
SW Kailua Oahu 1087	2	-157.73	21.39
SW Kaneohe Oahu 0207	1	-157.80	21.42
Target Kailua #2697	1	-157.73	21.39
Laenani Neighborhood Park	3	-157.83	21.46
Kaneohe Civic Center Neigh. Park	2	-157.79	21.41
Kaneohe Bayview Neighborhood Park	1	-157.78	21.41
Kalaheo Neighborhood Park	3	-157.76	21.41
Kapunahala Neighborhood Park	2	-157.80	21.41
Heeia Neighborhood Park	3	-157.81	21.42

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Table A.1 – continued from previous page

Location Name	POD size	Longitude	Latitude
Kawai Nui Neighborhood Park	1	-157.76	21.40
Aikahi Community Park	2	-157.75	21.43
Kaneohe Community Park	2	-157.80	21.41
Kaluapuhi Neighborhood Park	2	-157.79	21.40
Kailua District Park	1	-157.73	21.39
Kaelepulu Mini Park	3	-157.73	21.39
Maunawili Valley Neighborhood Park	1	-157.76	21.37
Keolu Hills Neighborhood Park	3	-157.73	21.37
Waimanalo District Park	1	-157.71	21.34
Brigham Young University - Hawaii	2	-157.92	21.64
Golf Academy of America	1	-157.79	21.37
LITTLE LEARNERS PRESCHOOL, LLC	3	-157.74	21.40
ST. ANN'S EARLY LEARNING CENTER	3	-157.80	21.42
St. Ann's Model School	3	-157.81	21.42
St. Anthony School - Kailua	3	-157.74	21.40
Ahuimanu Elem School	1	-157.83	21.44
Aikahi Elem School	3	-157.75	21.42
Heeia Elem School	3	-157.81	21.41
Kahaluu Elem School	3	-157.85	21.45
Kahuku Elem School	3	-157.95	21.67
Kailua Inter School	3	-157.74	21.40
Kainalu Elem School	3	-157.75	21.41
King Inter School	3	-157.81	21.43

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Table A.1 – continued from previous page

Location Name	POD size	Longitude	Latitude
Parker Elem School	3	-157.80	21.41
Waiahole Elem School	3	-157.85	21.48

These 63 PODs for the first set to compare against for our resupply models.

Table A.2. Manpower Constrained POD List

Location Name	POD size	Longitude	Latitude
Foodland Kaneohe #8 - Oahu	3	-157.80	21.40
Kahaluu Regional Park 1	3	-157.84	21.46
Waiahole/Waikane Nature Preserve	3	-157.85	21.49
Kaneohe Community and Senior Cente	3	-157.79	21.41
Keaalau Neighborhood Park	2	-157.76	21.42
Hawaii Pacific University	1	-157.78	21.38
Windward School for Adults	3	-157.76	21.41
CALVARY EPISCOPAL PRESCHOOL	3	-157.80	21.40
PALI VIEW BAPTIST PRESCHOOL	3	-157.80	21.39
Le Jardin Academy	1	-157.77	21.38
Hauula Elem School	2	-157.91	21.61
Kaaawa Elem School	2	-157.85	21.55
Kahuku High & Inter School	1	-157.95	21.68
Laie Elem School	2	-157.93	21.65
Olomana School	3	-157.75	21.38

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Table A.2 – continued from previous page

Location Name	POD size	Longitude	Latitude
Waimanalo Elem & Inter School	2	-157.71	21.35
SW Kaneohe Oahu 0207	1	-157.80	21.42
Target Kailua #2697	1	-157.74	21.39
Kaneohe Civic Center Neigh. Park	2	-157.80	21.41
Kaneohe Bayview Neighborhood Park	1	-157.79	21.41
Kalaheo Neighborhood Park	3	-157.75	21.41
Heeia Neighborhood Park	3	-157.81	21.42
Kawai Nui Neighborhood Park	1	-157.76	21.40
Aikahi Community Park	2	-157.75	21.43
Kaluapuhi Neighborhood Park	2	-157.79	21.40
Kaelepulu Mini Park	3	-157.73	21.39
Maunawili Valley Neighborhood Park	1	-157.76	21.37
Keolu Hills Neighborhood Park	3	-157.74	21.37
LITTLE LEARNERS PRESCHOOL, LLC	3	-157.74	21.40
ST. ANN'S EARLY LEARNING CENTER	3	-157.81	21.42
St. Ann's Model School	3	-157.81	21.42
St. Anthony School - Kailua	3	-157.74	21.40
Ahuimanu Elem School	1	-157.83	21.44
Kahuku Elem School	3	-157.95	21.67
Kailua Inter School	3	-157.74	21.40
Kainalu Elem School	3	-157.75	21.41

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Table A.2 – continued from previous page

Location Name	POD size	Longitude	Latitude
King Inter School	3	-157.81	21.43
Parker Elem School	3	-157.80	21.41
Pope Elem School	1	-157.69	21.33
Waiahole Elem School	3	-157.85	21.48

These 40 PODs were selected when family size was set to 2.5 people, one car, and only 40 PODs could be selected for use on windward Oahu.

Table A.3. Optimistic Feeding Scenario POD List

Location Name	POD size	Longitude	Latitude
Foodland Kaneohe #8 - Oahu	3	-157.80	21.40
Foodland Pupukea #27 - Oahu	3	-158.06	21.65
Foodland Laie #32 - Oahu	3	-157.92	21.65
Sunset Beach Neighborhood Park	2	-158.05	21.66
Malaekahana State Recreation Area	3	-157.93	21.66
Kahaluu Regional Park 1	3	-157.84	21.46
Waiahole/Waikane Nature Preserve	3	-157.85	21.49
Kaneohe Community and Senior Cente	3	-157.79	21.41
Keaalau Neighborhood Park	2	-157.76	21.42
Hawaii Pacific University	1	-157.78	21.38
Windward School for Adults	3	-157.76	21.41
CALVARY EPISCOPAL PRESCHOOL	3	-157.80	21.40

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Table A.3 – continued from previous page

Location Name	POD size	Longitude	Latitude
KAILUA METHODIST PRESCHOOL	3	-157.75	21.39
PALI VIEW BAPTIST PRESCHOOL	3	-157.80	21.39
Head Start Pope	1	-157.69	21.33
Kamehameha Schools - Waimanalo	3	-157.70	21.33
Le Jardin Academy	1	-157.77	21.38
Trinity Christian School	3	-157.76	21.38
Hauula Elem School	2	-157.91	21.61
Kaaawa Elem School	2	-157.85	21.55
Laie Elem School	2	-157.93	21.65
Malama Honua - PCS	3	-157.70	21.34
Olomana School	3	-157.75	21.38
Waimanalo Elem & Inter School	2	-157.71	21.35
SW Kaneohe Oahu 0207	1	-157.80	21.42
Target Kailua #2697	1	-157.74	21.39
Laenani Neighborhood Park	3	-157.83	21.46
Kaneohe Civic Center Neigh. Park	2	-157.80	21.41
Kalaheo Neighborhood Park	3	-157.75	21.41
Kapunahala Neighborhood Park	2	-157.80	21.41
Heeia Neighborhood Park	3	-157.81	21.42
Kawai Nui Neighborhood Park	1	-157.76	21.40
Aikahi Community Park	2	-157.75	21.43
Kaneohe Community Park	2	-157.80	21.41

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Table A.3 – continued from previous page

Location Name	POD size	Longitude	Latitude
Maunawili Neighborhood Park	2	-157.75	21.38
Kaluapuhi Neighborhood Park	2	-157.79	21.40
Kailua District Park	1	-157.74	21.39
Kaelepulu Mini Park	3	-157.73	21.39
Maunawili Valley Neighborhood Park	1	-157.76	21.37
Keolu Hills Neighborhood Park	3	-157.74	21.37
Waimanalo District Park	1	-157.72	21.34
Brigham Young University - Hawaii	2	-157.93	21.64
LITTLE LEARNERS PRESCHOOL, LLC	3	-157.74	21.40
ST. ANN'S EARLY LEARNING CENTER	3	-157.81	21.42
St. Ann's Model School	3	-157.81	21.42
St. Anthony School - Kailua	3	-157.74	21.40
St. Mark Lutheran School	3	-157.80	21.41
Ahuimanu Elem School	1	-157.83	21.44
Hakipuu Learning Center - PCS	2	-157.81	21.41
Heeia Elem School	3	-157.81	21.42
Kahaluu Elem School	3	-157.85	21.46
Kahuku Elem School	3	-157.95	21.67
Kailua Inter School	3	-157.74	21.40
Kainalu Elem School	3	-157.75	21.41
King Inter School	3	-157.81	21.43
Parker Elem School	3	-157.80	21.41

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Table A.3 – continued from previous page

Location Name	POD size	Longitude	Latitude
Pope Elem School	1	-157.69	21.33
Waiahole Elem School	3	-157.85	21.48

57 PODs were selected by the model when we did not limit the number of PODs allowed, left the number of cars per househould at one, and increased the family size from 2.5 to four people.

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APPENDIX B:
Pre-covery Points of Distribution

Table A.4. Ideal Pre-covery POD Locations

Location Name	POD size	Longitude	Latitude
SW Aikahi Oahu 2208	2	-157.74	21.42
Foodland Kaneohe #8 - Oahu	3	-157.73	21.40
Foodland Pupukea #27 - Oahu	3	-158.06	21.64
Foodland Laie #32 - Oahu	3	-157.92	21.64
Sunset Beach Neighborhood Park	2	-158.05	21.66
Malaekahana State Recreation Area	3	-157.93	21.65
Kahaluu Regional Park 1	3	-157.84	21.45
Waiahole/Waikane Nature Preserve	3	-157.84	21.49
Kaneohe Community and Senior Cente	3	-157.79	21.40
Keaalau Neighborhood Park	2	-157.76	21.41
Hawaii Pacific University	1	-157.78	21.37
Windward School for Adults	3	-157.75	21.40
CALVARY EPISCOPAL PRESCHOOL	3	-157.79	21.40
KAILUA BAPTIST CHRISTIAN PRESCHOOL	3	-157.75	21.38
PALI VIEW BAPTIST PRESCHOOL	3	-157.79	21.38
Head Start Pope	1	-157.69	21.32

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Table A.4 – continued from previous page

Location Name	POD size	Longitude	Latitude
Kamehameha Schools - Waimanalo	3	-157.69	21.33
Trinity Christian School	3	-157.76	21.37
Hauula Elem School	2	-157.90	21.60
Kaaawa Elem School	2	-157.84	21.54
Laie Elem School	2	-157.92	21.64
Malama Honua - PCS	3	-157.70	21.33
Olomana School	3	-157.74	21.37
Waimanalo Elem & Inter School	2	-157.71	21.34
SW Kailua Oahu 1087	2	-157.73	21.39
SW Kaneohe Oahu 0207	1	-157.80	21.42
Target Kailua #2697	1	-157.73	21.39
Kahuku Golf Course	1	-157.94	21.67
Kaneohe Civic Center Neigh. Park	2	-157.79	21.41
Kalaheo Neighborhood Park	3	-157.75	21.40
Kapunahala Neighborhood Park	2	-157.80	21.40
Heeia Neighborhood Park	3	-157.80	21.41
Kawai Nui Neighborhood Park	1	-157.75	21.40
Maunawili Neighborhood Park	2	-157.75	21.37
Kaluapuhi Neighborhood Park	2	-157.78	21.40
Kailua District Park	1	-157.73	21.39
Kaelepulu Mini Park	3	-157.73	21.39
Keolu Hills Neighborhood Park	3	-157.73	21.37

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Table A.4 – continued from previous page

Location Name	POD size	Longitude	Latitude
Windward Community College	1	-157.81	21.40
Brigham Young University - Hawaii	2	-157.92	21.64
KAMA' AINA KIDS-AIKAHI	3	-157.74	21.42
LITTLE LEARNERS PRESCHOOL, LLC	3	-157.74	21.40
ST. ANN'S EARLY LEARNING CENTER	3	-157.80	21.42
St. Ann's Model School	3	-157.80	21.42
St. Anthony School - Kailua	3	-157.73	21.400
Ahuimanu Elem School	1	-157.83	21.43
Kahaluu Elem School	3	-157.84	21.45
Kahuku Elem School	3	-157.95	21.67
Kailua Inter School	3	-157.73	21.39
Kainalu Elem School	3	-157.74	21.41
King Inter School	3	-157.80	21.42
Parker Elem School	3	-157.79	21.41
Waiahole Elem School	3	-157.85	21.48

53 PODs were selected when running the ideal pre-covery POD model. This model allowed for the selection of any or all POD options on windwad Oahu,one car per family, and a family size of 2.5 people.

Table A.5. Limited to 10 Pre-covery POD List

Location Name	POD size	Longitude	Latitude
Malaekahana State Recreation Area	3	-157.93	21.66
KAILUA METHODIST PRESCHOOL	3	-157.75	21.39
PUNANA LEO O' KO'OLAULOA	3	-157.95	21.68
Kaaawa Elem School	2	-157.85	21.55
Olomana School	3	-157.75	21.38
Waimanalo Elem & Inter School	2	-157.71	21.35
Kalaheo Neighborhood Park	3	-157.75	21.41
Kailua District Park	1	-157.74	21.39
ST. ANN'S EARLY LEARNING CENTER	3	-157.81	21.42
St. Anthony School - Kailua	3	-157.74	21.40

10 PODs were selected when the ideal model was limited to selecting no more than ten PODs.

Table A.6. Four People per Vehicle Pre-covery POD List

Location Name	POD size	Longitude	Latitude
Foodland Kaneohe #8 - Oahu	3	-157.80	21.40
Foodland Pupukea #27 - Oahu	3	-158.06	21.65
Foodland Laie #32 - Oahu	3	-157.92	21.65

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Table A.6 – continued from previous page

Location Name	POD size	Longitude	Latitude
Sunset Beach Neighborhood Park	2	-158.05	21.66
Malaekahana State Recreation Area	3	-157.93	21.66
Kahaluu Regional Park 1	3	-157.84	21.46
Waiahole/Waikane Nature Preserve	3	-157.85	21.49
Kaneohe Community and Senior Cente	3	-157.79	21.41
Keaalau Neighborhood Park	2	-157.76	21.42
Hawaii Pacific University	1	-157.78	21.38
Windward School for Adults	3	-157.76	21.41
CALVARY EPISCOPAL PRESCHOOL	3	-157.80	21.40
KAILUA METHODIST PRESCHOOL	3	-157.75	21.39
PALI VIEW BAPTIST PRESCHOOL	3	-157.80	21.39
Head Start Pope	1	-157.69	21.33
Kamehameha Schools - Waimanalo	3	-157.70	21.33
Le Jardin Academy	1	-157.77	21.38
Trinity Christian School	3	-157.76	21.38
Hauula Elem School	2	-157.91	21.61
Kaaawa Elem School	2	-157.85	21.55
Laie Elem School	2	-157.93	21.65
Malama Honua - PCS	3	-157.70	21.34
Olomana School	3	-157.75	21.38
Waimanalo Elem & Inter School	2	-157.71	21.35

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Table A.6 – continued from previous page

Location Name	POD size	Longitude	Latitude
SW Kaneohe Oahu 0207	1	-157.80	21.42
Target Kailua #2697	1	-157.74	21.39
Laenani Neighborhood Park	3	-157.83	21.46
Kaneohe Civic Center Neigh. Park	2	-157.80	21.41
Kalaheo Neighborhood Park	3	-157.75	21.41
Kapunahala Neighborhood Park	2	-157.80	21.41
Heeia Neighborhood Park	3	-157.81	21.42
Kawai Nui Neighborhood Park	1	-157.76	21.40
Aikahi Community Park	2	-157.75	21.43
Kaneohe Community Park	2	-157.80	21.41
Maunawili Neighborhood Park	2	-157.75	21.38
Kaluapuhi Neighborhood Park	2	-157.79	21.40
Kailua District Park	1	-157.74	21.39
Kaelepulu Mini Park	3	-157.73	21.39
Maunawili Valley Neighborhood Park	1	-157.76	21.37
Keolu Hills Neighborhood Park	3	-157.74	21.37
Waimanalo District Park	1	-157.72	21.34
Brigham Young University - Hawaii	2	-157.93	21.64
LITTLE LEARNERS PRESCHOOL, LLC	3	-157.74	21.40
ST. ANN'S EARLY LEARNING CENTER	3	-157.81	21.42

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Table A.6 – continued from previous page

Location Name	POD size	Longitude	Latitude
St. Ann's Model School	3	-157.81	21.42
St. Anthony School - Kailua	3	-157.74	21.40
St. Mark Lutheran School	3	-157.80	21.41
Ahuimanu Elem School	1	-157.83	21.44
Hakipuu Learning Center - PCS	2	-157.81	21.41
Heeia Elem School	3	-157.81	21.42
Kahaluu Elem School	3	-157.85	21.46
Kahuku Elem School	3	-157.95	21.67
Kailua Inter School	3	-157.74	21.40
Kainalu Elem School	3	-157.75	21.41
King Inter School	3	-157.81	21.43
Parker Elem School	3	-157.80	21.41
Pope Elem School	1	-157.69	21.33
Waiahole Elem School	3	-157.85	21.48

58 PODs were selected when the ideal pre-covery model was used but the family size was increased from 2.5 to 4 people.

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APPENDIX C:
Scenario Comparison Points of Distribution

C.0.1 Resupply Results Comparison

Table A.7. Points of Distribution Common across Ideal and Manpower Constrained Scenarios

Location Name	POD size	Longitude	Latitude
Foodland Kaneohe #8 - Oahu	3	-157.79	21.40
Kahaluu Regional Park 1	3	-157.84	21.45
Waiahole/Waikane Nature Preserve	3	-157.84	21.49
Kaneohe Community and Senior Center	3	-157.79	21.40
Keaalau Neighborhood Park	2	-157.76	21.41
Hawaii Pacific University	1	-157.78	21.37
Windward School for Adults	3	-157.75	21.40
CALVARY EPISCOPAL PRESCHOOL	3	-157.79	21.40
PALI VIEW BAPTIST PRESCHOOL	3	-157.79	21.38
Le Jardin Academy	1	-157.76	21.37
Hauula Elem School	2	-157.90	21.60
Kaaawa Elem School	2	-157.84	21.54
Kahuku High & Inter School	1	-157.94	21.67
Laie Elem School	2	-157.92	21.64
Olomana School	3	-157.74	21.37
Waimanalo Elem & Inter School	2	-157.71	21.34

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Table A.7 – continued from previous page

Location Name	POD size	Longitude	Latitude
SW Kaneohe Oahu 0207	1	-157.80	21.42
Target Kailua #2697	1	-157.73	21.39
Kaneohe Civic Center Neigh. Park	2	-157.79	21.41
Kaneohe Bayview Neighborhood Park	1	-157.78	21.40
Kalaheo Neighborhood Park	3	-157.75	21.40
Heeia Neighborhood Park	3	-157.80	21.41
Kawai Nui Neighborhood Park	1	-157.75	21.40
Aikahi Community Park	2	-157.75	21.42
Kaluapuhi Neighborhood Park	2	-157.78	21.40
Kaelepulu Mini Park	3	-157.73	21.39
Maunawili Valley Neighborhood Park	1	-157.76	21.37
Keolu Hills Neighborhood Park	3	-157.73	21.37
LITTLE LEARNERS PRESCHOOL, LLC	3	-157.74	21.40
ST. ANN'S EARLY LEARNING CENTER	3	-157.80	21.42
St. Ann's Model School	3	-157.80	21.42
St. Anthony School - Kailua	3	-157.73	21.40
Ahuimanu Elem School	1	-157.83	21.43
Kahuku Elem School	3	-157.79	21.67
Kailua Inter School	3	-157.73	21.39
Kainalu Elem School	3	-157.74	21.41
King Inter School	3	-157.80	21.42
Parker Elem School	3	-157.79	21.41

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Table A.7 – continued from previous page

Location Name	POD size	Longitude	Latitude
Waiahole Elem School	3	-157.85	21.48

These 39 PODs are are in both the unconstrained and constrained resupply models

Table A.8. Points of Distribution Common across Ideal, Manpower Constrained, and Optimistic Scenarios

Location Name	POD size	Longitude	Latitude
Foodland Kaneohe #8 - Oahu	3	-157.79	21.40
Kahaluu Regional Park 1	3	-157.84	21.45
Waiahole/Waikane Nature Preserve	3	-157.84	21.49
Kaneohe Community and Senior Center	3	-157.79	21.40
Keaalau Neighborhood Park	2	-157.76	21.41
Hawaii Pacific University	1	-157.78	21.37
Windward School for Adults	3	-157.75	21.40
CALVARY EPISCOPAL PRESCHOOL	3	-157.79	21.40
PALI VIEW BAPTIST PRESCHOOL	3	-157.79	21.38
Le Jardin Academy	1	-157.76	21.37
Hauula Elem School	2	-157.90	21.60
Kaaawa Elem School	2	-157.84	21.54
Laie Elem School	2	-157.92	21.64
Olomana School	3	-157.74	21.37

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Table A.8 – continued from previous page

Location Name	POD size	Longitude	Latitude
Waimanalo Elem & Inter School	2	-157.71	21.34
SW Kaneohe Oahu 0207	1	-157.80	21.42
Target Kailua #2697	1	-157.73	21.39
Kaneohe Civic Center Neigh. Park	2	-157.79	21.41
Kalaheo Neighborhood Park	3	-157.75	21.40
Heeia Neighborhood Park	3	-157.80	21.41
Kawai Nui Neighborhood Park	1	-157.75	21.40
Aikahi Community Park	2	-157.75	21.42
Kaluapuhi Neighborhood Park	2	-157.78	21.40
Kaelepulu Mini Park	3	-157.73	21.39
Maunawili Valley Neighborhood Park	1	-157.76	21.37
Keolu Hills Neighborhood Park	3	-157.73	21.37
LITTLE LEARNERS PRESCHOOL, LLC	3	-157.74	21.40
ST. ANN'S EARLY LEARNING CENTER	3	-157.80	21.42
St. Ann's Model School	3	-157.80	21.42
St. Anthony School - Kailua	3	-157.73	21.40
Ahuimanu Elem School	1	-157.83	21.43
Kahuku Elem School	3	-157.95	21.67
Kailua Inter School	3	-157.73	21.39
Kainalu Elem School	3	-157.74	21.41
King Inter School	3	-157.80	21.42
Parker Elem School	3	-157.79	21.41

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Table A.8 – continued from previous page

Location Name	POD size	Longitude	Latitude
Waiahole Elem School	3	-157.85	21.48

This chart shows the 37 POD options that overlap between the unconstrained, constrained, and four people per vehicle models.

C.0.2 Pre-covery Results Comparison

Table A.9. Common Pre-covery Points of Distribution for Unconstrained and Constrained to 10 PODs

Location Name	POD size	Longitude	Latitude
Malaekahana State Recreation Area	3	-157.93	21.66
Kaaawa Elem School	2	-157.85	21.55
Olomana School	3	-157.75	21.38
Waimanalo Elem & Inter School	2	-157.71	21.35
Kalaheo Neighborhood Park	3	-157.75	21.41
Kailua District Park	1	-157.74	21.39
ST. ANN'S EARLY LEARNING CENTER	3	-157.81	21.42
St. Anthony School - Kailua	3	-157.74	21.40

The eight locations above along with their POD size and latitude/longitudes form the intersection set between the unconstrained pre-covery model and the pre-covery model that limits POD selection to ten PODs on Windward Oahu.

Table A.10. Intersection of Unconstrained, Constrained, and Four People per Vehicle Pre-covery Models

Location Name	POD size	Longitude	Latitude
Kaaawa Elem School	2	-157.85	21.55
Olomana School	3	-157.75	21.38
Waimanalo Elem & Inter School	2	-157.71	21.35
Kalaheo Neighborhood Park	3	-157.75	21.41
Kailua District Park	1	-157.74	21.39
St. Anthony School - Kailua	3	-157.74	21.40

These six locations above along show the intersection of our model running four people per car with the intersection provided in Table **??**.

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