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Domestic disasters and geospatial technology for the Defense Logistics Agency

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MBA PROFESSIONAL REPORT

DOMESTIC DISASTERS AND GEOSPATIAL TECHNOLOGY FOR THE DEFENSE LOGISTICS AGENCY

By: Amanda Nerg and
Kristie Stuckenschneider
December 2014

Advisors: Cameron MacKenzie
Douglas Brinkley

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This report used *Vehicle Routing Problem (VRP) Spreadsheet Solver* and *Esri Maps for Microsoft Office* to determine the optimal route each fuel truck should take to meet every location's demand. *Vehicle Routing Problem Spreadsheet Solver* used GIS technology to identify the location or each demand location and the amount of time taken to travel from one location to another. When the model could not meet the total fuel demand, this report used *Esri Maps for Microsoft Office* to determine the next available truck to supply that location.

This report concludes that GIS technology would significantly benefit DLA. This report also recommends that DLA use ArcGIS, since FEMA has already implemented the program into its disaster response. ArcGIS also provides an organization subscription service in which DLA personnel could collaborate easier with other disaster response agencies.

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DOMESTIC DISASTERS AND GEOSPATIAL TECHNOLOGY FOR THE DEFENSE LOGISTICS AGENCY

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Submitted in partial fulfillment of the requirements for the degree of

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LIST OF ACRONYMS AND ABBREVIATIONS

C2	Command and Control
CRS	Congressional Research Service
CIWG	Continuous Improvement Working Group
COP	Common Operating Picture
DCMA	Defense Contract Management Agency
DDE	THE DLA Distribution Expeditionary
DHS	Department of Homeland Security
DIA	Disability Integration Advisors
DISA	Defense Information System Agency
THE DLA	Defense Logistics Agency
DOD	Department of Defense
DOE	Department of Energy
DRC	Disaster Recovery Centers
DRM	Disaster Recovery Manager
DSCA	Defense Support of Civil Authorities
EOC	Emergency Operations Center
ESF	Emergency Support Functions
FEMA	Federal Emergency Management Agency
FR	First Responder
GAO	Government Accountability Office
GCSS-J	Global Combat Support System-Joint
GFS	Global Forecast System
GIS	Geographic Information System
HA/DR	Humanitarian Aid/Disaster Relief
IAA	Inter-Agency Agreement
ITV	In-Transit Visibility
JLLIS	Joint Lessons Learned Information System
JLOC	Joint Logistics Operation Center
LNO	Liaison Officer
NGO	Non-Governmental Organizations

NIMS	National Incident Management System
NOAA	National Oceanic and Atmospheric Administration
NORTHCOM	U.S. Northern Command
NRCC	National Response Coordination Center
NRF	National Response Framework
RSF	Recovery Support Functions
STEP	Sheltering and Temporary Essential Power
UCA	Undefinitized Contract Action
USACE	U.S. Army Corps of Engineers
VIC	Virtual Information Center
VRP	Vehicle Routing Problem

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I. INTRODUCTION

The Department of Homeland Security (DHS) developed the National Response Framework (NRF) as a guide for federal, state, and local organizations to engage in disaster and emergency situations. The NRF defines five primary mission objectives for disaster situations as prevention, protection, mitigation, response, and recovery (DHS, 2013). This report will focus only on the response objective. Response agencies can access data, or geospatial information, to specify their objectives and constraints in preparation for future disaster relief operations. Organizations must be flexible, adaptable, and scalable to a variety of disaster situations based on unique objective functions and constraints. When it comes to response, priorities are saving lives, protecting property and the environment, stabilizing the situation, and providing basic needs to the affected population. Apte and Heath (2012) have developed a basic disaster response process model, shown in Figure 1. Local and neighboring governments are the first resources used and once exhausted, the state government becomes involved.

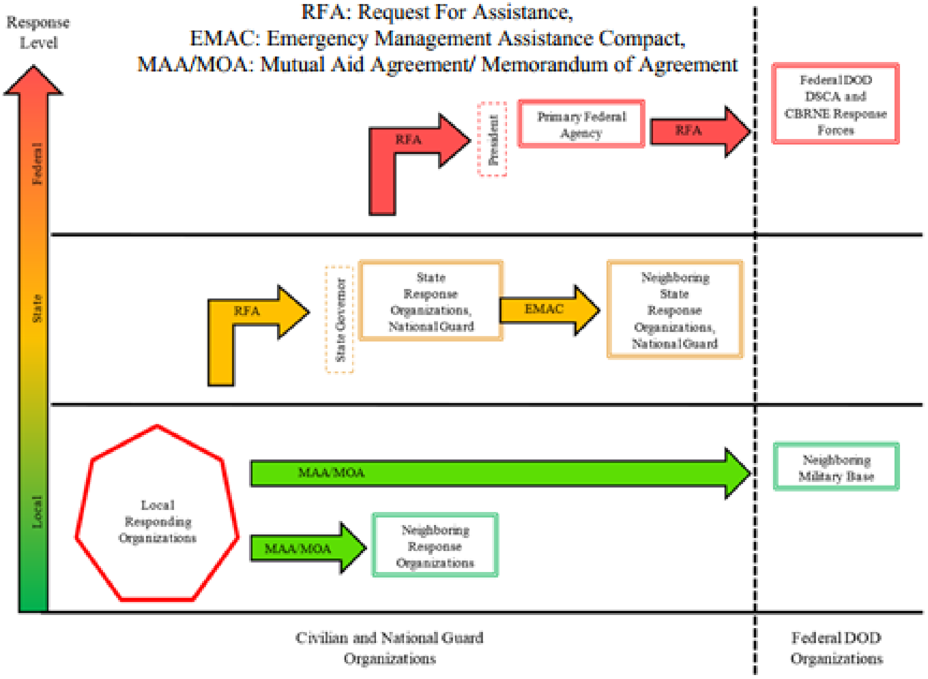

Figure 1. Organizational response process (from Apte & Heath, 2012)

When an incident or event causes multiple failures in infrastructures, disrupting other components, it becomes a complex catastrophe. Complex catastrophes usually call for immediate DOD assistance. Many times disaster situations overwhelm state and local governments and the federal government has assisted in response efforts. When requested, the Defense Logistics Agency (DLA) has provided services and commodities to supplement the Federal Emergency Management Agency (FEMA) for support during declared disasters. Because disaster response is time-sensitive, a geographic information system (GIS) can provide maximum support to actively communicate among the involved agencies, such as FEMA, DLA, USNORTHCOM and local emergency organizations, with current and correct information.

DLA has engaged with FEMA during disaster response operations using the *Defense Support of Civil Authorities* (DSCA) joint publication. DSCA has aligned with the NRF in order to support local and state governments and non-governmental organizations (NGO) using federal resources. DLA has used its expeditionary depots to support FEMA when called upon for assistance. Senior leaders at DLA have discussed the modernization of DLA's domestic response process for many years. The common areas for improvements have been engaging and coordinating with FEMA, overall preparation, in-transit visibility, and stock positioning.

According to the after action reports (AAR), DLA and FEMA did not communicate sufficiently nor did they consolidate information properly during Sandy's response operations. The inter-agency agreement (IAA) between FEMA and DLA states that the DLA will procure supplies for FEMA in response to domestic disasters. The IAA also provides for the deployment of liaison officers (LNO) to assist at the remote locations within the affected area. Agencies would provide LNOs during a disaster to send real-time information to their headquarters. LNOs would gather information to provide needed support instead of sending unnecessary commodities. Within the IAA, DLA has defined its role as support to FEMA, providing materiel for domestic disasters and a necessary outline for the relationship between DLA and FEMA.

DLA has expressed concern over inadequate communication and coordination with other agencies and its internal logistics capabilities, when responding to disasters

(DLA Hurricane Sandy AAR). To mitigate some of these concerns, DLA has implemented the Humanitarian Expeditionary Logistics Project (HELP), a supplemental web-based program, to assist in ordering and tracking commodities during contingency operations. DLA's Global Combat Support System-Joint (GCSS-J) has also developed a web-based "widget" platform allowing users to connect to information that pertains to a disaster or a simple update to a program.

However, DLA has expressed concern whether its programs function properly, if the acquired information is accurately managed, and whether the information receives correct and timely distribution. DLA has worried whether the programs have the visibility and coordination among the separate agencies and departments, other governmental agencies, and NGOs that support disaster relief operations. DLA and FEMA have conveyed the need for stronger a relationship, with improvements to the communication, coordination, and overall understanding of the processes during domestic disasters (DLA & FEMA AARs). Both agencies require a more integrated GIS technology and this common interface technology could alleviate their concerns.

Geospatial information is the collection and presentation of real-time data for current situations. The Congressional Research Service (CRS) explained in 2011 that the rate of acquisition and the amount of geospatial information are rapidly increasing, and the ways for using this data vary throughout government offices (Folger, 2011). A GIS combines layers of collected data together. A software corporation, Esri provides commercially available GIS technology and services, cooperating with other major technology leaders to provide users with product compatibility. ArcGIS, one of the many geographic-based systems created by Esri, consolidates detailed geospatial information such as weather patterns, flood areas, and evacuation center and first responder locations.

This combination of data provides users with a greater understanding to perform analyses and to make better informed decisions during disaster response. ArcGIS, an Internet subscription service, allows users to collect and consolidate geospatial information onto one visual map. Using the *hot spots* tool in ArcGIS, an organization can strategically place incident support bases centered on a given set of program requirements, further reducing the man-hours used to input data points.

Hurricane Sandy provided a unique situation for DLA and FEMA. On October 25, 2012, the National Oceanic and Atmospheric Administration (NOAA) considered Sandy a Category 1 hurricane while it moved northwest through the Atlantic. Figure 1 tracks the multiple forecasted paths of the storm. Using the Global Forecast System (GFS) model, NOAA predicted multiple paths, traced in pink, affecting a small portion of the northeast coast in the United States. Only a minority of the predictions had Sandy heading out to sea. However, the official GFS forecast predicted the path indicated by the black line, missing the northeast coast. During the morning of October 29, a combination of high-pressure and a mid-level trough redirected Hurricane Sandy's path towards the northeast coast (FEMA, 2013). NOAA classified Sandy as a post-tropical cyclone as it made landfall that evening. FEMA did not initially respond because Sandy was a post-tropical storm, which is not defined as a complex catastrophe. Figure 2 shows the actual path the storm took from October 26 to October 29. The NOAA predicted this weather pattern as the majority of forecasted paths in the unofficial GFS model.

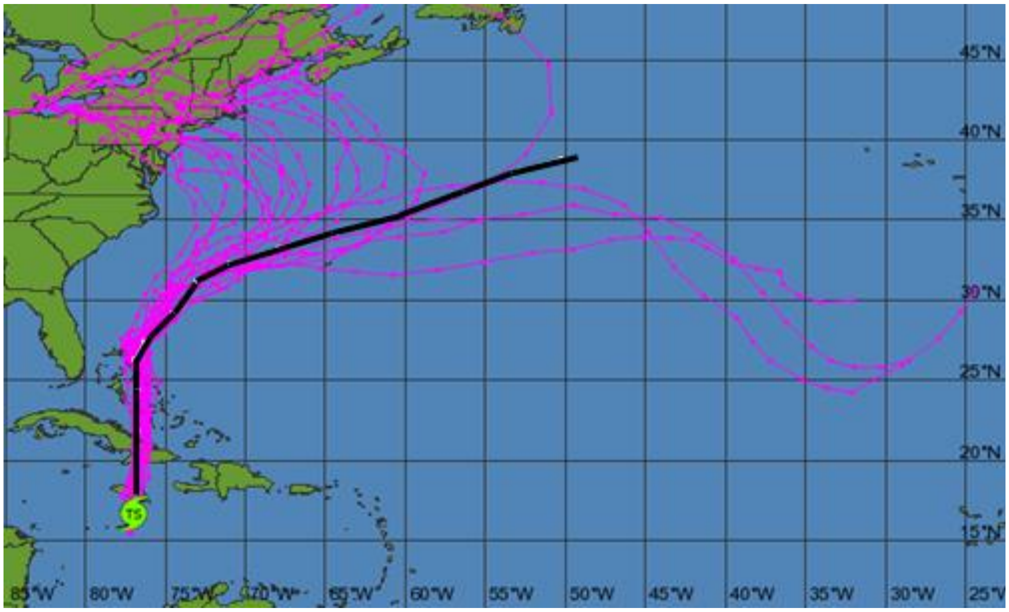

Figure 2. Forecasted paths of Hurricane Sandy (from NOAA, 2012)

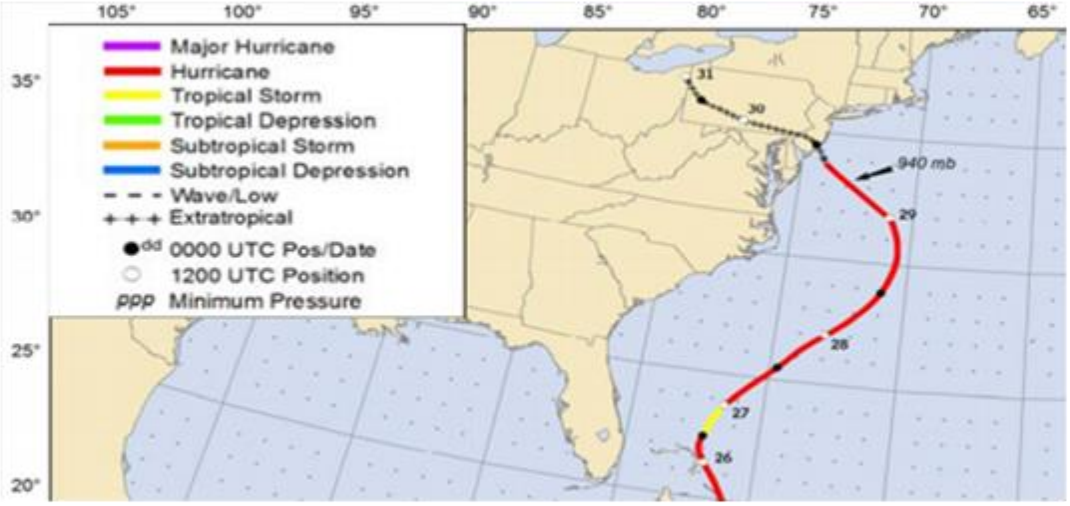

Figure 3. Actual path of Sandy during Oct 26 through 29, 2012 (from NOAA, 2012)

In preparation for Hurricane Sandy, FEMA and DLA established incident support bases in Massachusetts and New Jersey and activated the National Response Coordination Center (NRCC) prior to Sandy's landfall. By creating incident support bases, the AARs reported that the agencies successfully tackled one of the largest disaster responses in its history, distributing over $1.2 billion in housing assistance and over $800 million in debris removal and energy and transportation restoration (FEMA, 2013). Although the agencies deemed this operation successful, Hurricane Sandy exposed four areas for improvement in how the agencies coordinated, which is discussed further in Chapter II.

Optimizing resource requirements improves the accuracy of this geospatial information. If all agencies used a combined structure such as ArcGIS, redundancy in time and resource management may be practically eliminated. Chapter III will discuss the potential benefits and drawbacks to implementing GIS for disaster relief. We recommend using ArcGIS since FEMA has implemented ArcGIS in its program. Also, ArcGIS is commercially available, giving agencies an opportunity to outsource the requirements. This report focuses strictly on DLA's fuel distribution response difficulties during Hurricane Sandy. This report also provides an optimization model, discussed in Chapters IV and V, showing how DLA could benefit from using commercial GIS technology.

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II. LITERATURE REVIEW

Natural disasters are inevitable. FEMA has had difficulty accurately predicting what resources it needs until it makes an initial assessment. Reviewing lessons learned from previous disasters is one of the best ways to prepare for future disaster operations. Donahue and Tuohy (2006) hypothesized that agencies have repeated mistakes during disaster situations and the authors identified several major categories within lessons learned. The most common repeated categories the authors identified are failed communication, weak planning, resource contracts, and poor public relations (Donahue & Tuohy, 2006).

In a review of multiple journals, articles, and Hurricane Sandy AARs, this report identified the most common challenges during disaster operations as transportation and logistics, coordination and communication, resource management, and the use of geospatial technology. This report separated areas of improvement and recommendations of each AAR into one of these four categories. This chapter discusses the first three categories, and the next chapter analyzes the use of geospatial technology for disaster relief. While this report focuses on improving DLA through the use of GIS technology, FEMA’s and New York City’s ARRs provided more detailed analyses on the response challenges during Sandy.

A. TRANSPORTATION AND LOGISTICS

While pre-positioning supplies and personnel can decrease response time in disaster situations, many challenges arise during preparation. Some of the most challenging factors for disaster relief logistics are the unpredictability of timing and location of demand, short lead times with large and various requirements, and the lack of resources such as personnel, supplies, transportation, and funding (Balcik & Beamon, 2008). The authors created a model to integrate facility locations to provide maximum coverage of disaster response.

Pico and Tan (2012) developed a routing model to help responders send vehicles into a disaster area in order to extract survivors. Using the optimal number of routes and creating an evacuation schedule, Pico and Tan’s (2012) model understood the challenge of time-sensitively in disaster response and attempted to minimize the loss of life in an affected area.

Lean-thinking systems and processes accomplish continuous reduction in waste that prevents forward momentum. Manufacturing and production have used lean-thinking to create wealth, limit waste, continuously improve competition, and offer the proper tools to continue improvements (Womak & Jones, 1996). Incorporating lean-thinking into government agencies could provide faster response times and better training, save lives, and increase transparency. This report discusses the idea of lean-thinking in Chapter VI under further research opportunities.

B. COORDINATION AND COMMUNICATION

The Whole Community is a FEMA program that includes all organizations and coordinates state and local governments during disaster response operations. FEMA determined the need to integrate coordination and communication between federal senior leaders during response and recovery operations. The NRF stresses the importance of senior leader involvement; however it does not outline formal procedures for coordination and communication. Responders also faced challenges accurately communicating responsibilities to those involved. Furthermore, coordinating emergency support functions (ESF) and recovery support functions (RSF) revealed that most agencies had a departmental approach to responding instead of a joint approach, which is what the NRF recommends.

Gibbs and Holloway (2013) also recognized the need to coordinate state and local agencies to develop and enforce evacuation planning and back-up power capacity for healthcare facilities during disaster situations. By establishing protocols, healthcare facilities would be able to communicate through alternative methods in the event of power outages and downed power lines. Gibbs and Holloway (2013) also considered expanding the call capacity of 311 during emergencies and launching public awareness of the proper use of 911 and 311 calling, providing other resources for non-life threatening situations.

The Government Accountability Office (GAO) acknowledged that the federal government has taken action to coordinate efforts; however it has not been completely successful in eliminating information collection redundancies and setting data standards regardless of the collection source (CRS, 2011). GAO recommended that Congress should take more oversight in coordination efforts. However, Carlson (2014) argued that the federal government should not be the primary coordinator during disaster situations. The author further explained that using non-governmental agencies to support disaster response operations allows for faster decision making and expedited results.

Conversely, the Stafford Act (2013) has given the President of the United States the power to direct any federal organization when state and local governments ask for assistance during emergencies. Unfortunately, this act has created communication gaps between senior leaders. Shortly after the events of Hurricane Sandy, Congress also introduced the Disaster Relief Appropriation Act (113th Congress, 2013). This act has attempted to create more transparency and reduce the communication gap through the requirement of outlining agencies' missions within 24 hours if it exceeds $1 million.

FEMA also has identified the need to refine the mission assignment process based on the current process flow. Roughly 40 percent of personnel assignments for Hurricane Sandy took more than one day to process (FEMA, 2013). In a way to alleviate delays, many response agencies acted on verbal mission assignments before receiving written notice. Additionally, the lack of transparency between agencies has increased uncoordinated mission assignments. The *Incident Management Handbook* has outlined three organizational concepts for disaster operations. During Hurricane Sandy, FEMA used a combined organization structure, implementing both a functional and geographic approach, to respond in initial actions. Although the combined structure helped with local response efforts, it created tension between program staff and division supervisors. Program staff did not want to decentralize their authority, and division supervisors wanted to manage those response programs at a local level. Hurricane Sandy also created tension between field and regional staff, both parties disagreeing when to transition authority to disaster recovery managers (DRM). Field personnel also claimed that regional staff could not route mission assignments and resource requests in a timely manner (FEMA, 2013).

Staff tensions were possibly the trigger for FEMA to seek a new way in decision-making for future disaster response. During the aftermath of Hurricane Sandy, the planning components in the different agencies functioned independently of each other, limiting the support of decision-making. Rather than analyzing survivor outcomes, FEMA measured what was done and how quickly it was performed. Challenges to collect and analyze outcome-based information arose because of this measurement. FEMA also did not document whether it addresses capability gaps during nonemergency planning stages prior to Sandy's landfall. Likewise, it did not report plans used during response that delayed post-incident evaluation and assessment. These problems have pointed to a lack of formal procedures to record disaster response improvements and resolving any highlighted problems.

During the aftermath of Hurricane Sandy, multiple agencies reported different requirements that added to confusion in the execution phase. The overload of requirements has made it difficult to identify the responsible authority, what requests should be fulfilled, and which should be acquired first. DLA has recognized this problem and has recommended closer relationships with disaster response organizations (DLA Hurricane Sandy AAR).

C. RESOURCE AND PERSONNEL MANAGEMENT

Oloruntoba and Gray (2006) explained that funding and resources are often subject to political influence. NGOs have competed for donations during emergencies because donors tend to be more sympathetic. Using a business supply chain model, Oloruntoba and Gray (2006) analyzed a typical humanitarian aid supply chain. Although donors prefer to see their funding used on tangible items, the integration of internal capabilities and organization processes, through improved information technology, can increase the supply chain flexibility (Oloruntoba & Gray, 2006). The report stresses the need for a more integrated GIS that multiple agencies can use during disaster response. While Oloruntoba and Gray focused more on a business supply chain, this report applies the authors’ conclusion in support for funding an integrated GIS requirement, which could improve agencies’ capabilities and processes.

Prior to Hurricane Sandy, FEMA sought to improve and diversify its disaster workforce structure. It redeveloped the disaster assistance employee program into a reservist program and partnered with the corporation from national and community service to create the FEMA Corps program (FEMA, 2013). During Sandy, FEMA relied on these programs to complete the largest and most diversified personnel deployment in its history. However, FEMA nearly drained its personnel resources during these deployments. Most personnel reported confusion with the process and expectations. Only five percent of the staff was a part of the reservist program, which forced FEMA to deploy permanent staff members.

Although deployment confusion created multiple challenges, FEMA maintained a survivor-centric approach throughout response operations. FEMA has recognized the importance of initial interactions with survivors and the agency has devoted resources to communicate and interact with the impacted population. FEMA created a sheltering and temporary essential power (STEP) program to simplify support for those whom Hurricane Sandy affected the most. Services under the STEP program provided survivors the opportunity to remain in their own homes. During Hurricane Sandy, FEMA designed disaster recovery centers (DRCs) to provide information about disaster assistance programs and how survivors could register for it. Unfortunately, survivors did not receive consistent service. Call center limitations also affected the initial response to survivors. Staffing and technology challenges could not fully meet information requests, forwarding callers to an automated message requesting them to visit the FEMA website.

Gibbs and Holloway (2013) outlined the implementation of a new Coastal Storm Plan evacuation zones and reviewed evacuation procedures. The authors also acknowledged the need for increased and accurate pre-storm communication and education of vulnerable area residents to maximize the evacuation numbers in future storms. Sandy’s damage to road and tunnel infrastructure also limited the mobility of fuel transportation to the city. New York City officials acknowledged the need for a task force to alleviate future fuel shortages during disaster situations (Gibbs & Holloway, 2013).

Likewise, FEMA established disability integration advisors (DIA), focusing on different missions during Sandy. While some DIAs assisted with lifesaving and life-sustaining efforts, others engaged with community partners to ensure equal access to communication and equipment (FEMA, 2013). Unfortunately, other FEMA responders had difficulty understanding DIA responsibilities. This confusion emphasized the need for better transparency and education as to the roles and responsibilities of DIAs. Additionally, FEMA recognized the complexity of the public assistance program. New York and New Jersey officials have also voiced their misunderstanding of the program's requirements, delaying recovery efforts.

New York City officials acknowledged the need for expediting the purchase of public safety equipment. The New York City police department and fire department enforced 12-hour shifts and deployed an additional 600 personnel during and after the storm to organize evacuation for elderly and handicap residents (Gibbs & Holloway, 2013). Personnel reported boats used were not acceptable for flood rescue because they did not have motors or towing capability. This limited the mobility and maneuverability through the strong currents. Many boats were also made of metal, so personnel had to be extremely careful around downed power lines. Specialized response teams did have access to inflatable boats with motors, which are easily transportable. Gibbs and Holloway (2013) recommended the acquisition of more inflatable watercraft.

New York City also stockpiled 5,700 pallets of medical, infant, and pet supplies, food, and personal care items to support the basic needs of residents in shelters for a short period of time (Gibbs & Holloway, 2013). Most shelters, located in public buildings based on location and accessibility, provided Meals Ready to Eat (MREs), but no showers or laundry facilities available. Unfortunately, many residents could not return to their homes causing further need of extended shelter operations. The DOD has used commodity councils to procure large amounts of the same requirement across branches. While this report does not focus on a disaster response commodity council that all governmental agencies could use, it is recommended in Chapter VI as a further research opportunity.

FEMA had reviewed its workforce training and education and demonstrated performance under a new qualification system. This study had found that qualified personnel filled only 47 percent of available positions, trainees filled 25 percent, and the remaining 28 percent of positions were vacant (FEMA, 2013). When Sandy made landfall, FEMA operated under the new qualification system, which further challenged operations. Sandy exposed the lack of comprehensive strategy to answer temporary challenges. One primary challenge throughout the response of Sandy was the difficulty in supporting a large deployed workforce. FEMA did not have a staging facility for personnel during the initial deployments and continued to lack one for three days after Sandy made landfall. Once established at Fort Dix, New Jersey, the staging area processed 1,127 personnel within 14 days (FEMA, 2013). However, this caused even more challenges because Fort Dix could not determine the number of personnel who required lodging each night, nor could it track personnel coming to and from Fort Dix and New York.

D. SUMMARY

This chapter discussed three of the four common areas from improvement this report found while performing literature reviews. Transportation and logistics found unpredictability in the timing and location, short lead times, and various requirements affect the ability to respond effectively. Communication and coordination concluded the overload of requirements make it difficult to identify what requests should be fulfilled and which should be acquired first. Finally resource and personnel management determined tracking number of resources and personnel is substantially more difficult during disaster response. The next chapter covers the final area of improvement, use of GIS technology.

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III. GEOGRAPHIC INFORMATION SYSTEM

A. INTRODUCTION

The fourth category for improvement in disaster response is the use of GIS technology. GIS provides local demographics information and operational locations such as gas stations and relief stations, while also maintaining connections to other agencies. Agencies using GIS could provide assistance and ease impact to higher risk disaster locations. DLA could collaborate with FEMA and collect response information and display visual maps in ArcGIS. GIS technology could lessen the burden of disasters through forecast patterns, optimization routing models, and increased communication. The need for the information GIS provides is critical. Data has allowed evaluation and exploration of consolidated spatial information. Available GIS programs could create a substantial knowledge database to help organizations respond to disaster operations.

Disasters are unpredictable; therefore, response agencies need a collective and current database. GIS creates a support system that is continuously updated and makes critical information readily available. A lack of coordination between agencies, previously discussed in Chapter II, is one of the primary challenges to creating a seamless disaster response. Although a single agency may not be able to collect all the information about a region, multiple agencies working together could gather a significant amount of data. When agencies combine their findings, GIS data provides a more accurate picture of the potential dangers. This collaborative database could give first responders specific locational knowledge such as infrastructure, terrain, and weather conditions in real-time.

Current use of GIS technology in DLA's disaster response is limited. Each team is responsible for maintaining a specific set of data points to keep operations current and the data must be inputted manually. This limited use has created vulnerability in minimal information or missing pieces crucial to adapting to emergencies. Not only can GIS inform and protect lives, but it can also be used as a tool for education. The maps and databases could increase the amount of knowledge for training operations. Training for potential disasters help mitigate issues that might arise. FEMA already has successfully implemented ArcGIS into its disaster response. Since ArcGIS requires only a subscription account, DLA could combine and advance training information with FEMA. DLA and FEMA partnership could allow an opportunity to incorporate standard operating procedures to mitigate disaster response issues and improve operations overall.

Finally, agencies using GIS technology would require access to a reliable database. The quality of the program would also have a significant impact on successfully processing data. A GIS program could improve response times, save lives, and train personnel. DLA and FEMA could provide teams that are used strictly into the one GIS program. Similarly, other NGOs and local agencies could also incorporate their compiled spatial information into the database. As long as the program is of the highest quality and the information is reliable, GIS will be beneficial in disaster event assistance.

B. AVAILABLE GIS TECHNOLOGY

Kaiser, Spiegel, Henderson, and Gerber (2003) has defined the main use of GIS in disaster response as providing visual aids with information overlay to help in decision-making and expanding data collection in the field. Agencies have used GIS for functions like rainfall estimation, site planning, population size, and boundary mapping. Van Hentenryck (2013) has described the strategic, tactical, response, and recovery levels using GIS for specific purposes in optimizing problem solving. FEMA has created the continuous improvement working group (CIWG) to continue disaster response research. Preparation before a disaster can be a key factor in determining the effectiveness of disaster response and recovery. Federal organizations should consolidate ideas, programs, and information to create a collective group to meet disaster response demands.

The use of Internet and mobile devices has brought the public closer to geospatial information (Carpenter & Snell, 2013). Individuals create geospatial data at low cost and identify patterns within the datasets to solve real-time problems. However, this growth in information has challenged the users to find the right information to solve the problem when needed. With the increase of geospatial information, there has been demand for larger, more integrated management systems. Currently, GIS is often customized to meet the needs of a specific government agency (Carpenter & Snell, 2013)

Using cloud computing for a GIS has also significantly increased, especially through demand of real-time data. Open source solutions have also grown with the government demanding acceptable, alternative solutions to data collection. Three trends seem to drive the acceptance of cloud computing in GIS (Carpenter & Snell, 2013). The first is free-to-use software significantly benefiting agencies, when resources are limited. Secondly, sharing and modifying data easily enable information exchange and promote a collective community. Finally, the sooner agencies introduce geospatial information to the workforce, the easier personnel can be comfortable and use GIS in daily operations.

Gunes and Kovel (2000) have outlined multiple uses of GIS during disaster operations. The authors have stated that agencies are limited in personnel and equipment when working without GIS. GIS can display information on the forecasted path of a disaster and report the vulnerable locations prior to and the initial damage assessment moments after a natural disaster. GIS can also address personnel and resource inventories, along with transportation routes and shelter status. Douglas County in Kansas has used a GIS-decision support system to simulate exercises and train the public and government officials in disaster response and what the local community can prepare for to protect themselves during a disaster (Gunes & Kovel, 2000).

Alsabhan and Ali (2012) have researched agency involvement in a GIS. The authors have found that 79 percent of 200 non-governmental agencies use GIS technology like Esri and MapInfo. Improving GIS capacity would increase response time, reliability, consistency and a more user-friendly system. Moving towards a more integrated GIS depends mostly on the local, state, and federal organizations overcoming various challenges, which this report discusses later in this chapter.

C. DLA SPECIFIC GIS TECHNOLOGY

The use of GIS has been successful through various domestic operations. FEMA has deployed WebEOC, a disaster management system, which allowed access to the most current information to meet the demands of disaster response. DLA used Google Maps during Hurricane Sandy to identify certain geographical locations such as available gas stations, medical facilities, evacuations centers, and personnel locations. Unfortunately, DLA personnel manually inputted each location on Google Maps. Figure 4 shows the detail of DLA recorded locations.

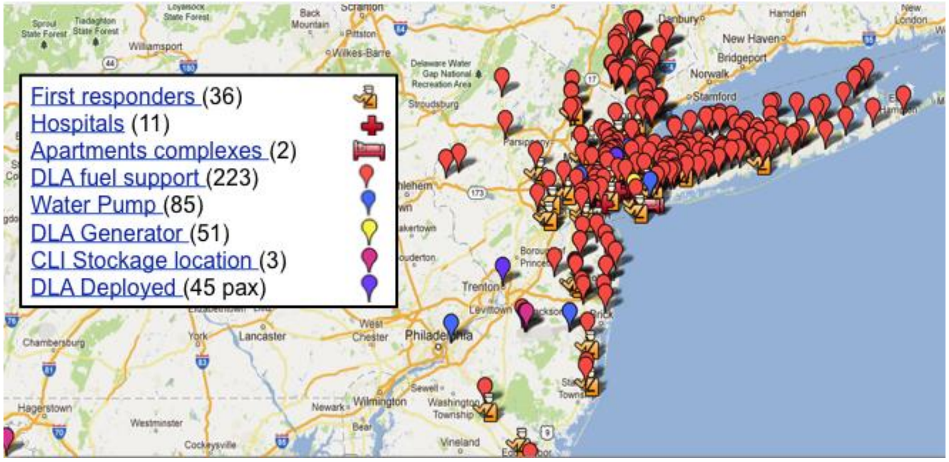


Figure 4. DLA inputted geographic locations of response services

Although this visual observation has helped the DLA maintain a proactive approach and forward presence during disaster response, manually inputting each location wasted valuable time and resources. DLA could have also benefited from a GIS technology provided information on the amount of resources needed at the various locations and the number of passible transportation routes. Following Hurricane Sandy, DLA has increased its command and control functions, enhancing reliance on information sharing and knowledge management. DLA has also acknowledged the importance of developing stronger relationships with its partners USNORTHCOM, FEMA, and other DOD organizations and NGOs.

D. CHALLENGES OF IMPLEMENTING GIS

The CRS report has explained in 2012 the challenges for the federal government in coordinating and managing geospatial information. Two examples of challenges are the duplication of data sets and effort and cost constraints of acquiring the data. Collecting accurate data was critical to understanding and addressing response and recovery needs following landfall of Hurricane Sandy. New York City officials did not have immediate access to information on multiple services. Power utilities, telecommunication services, fuel providers, and other critical services information took a few days to gather (Gibbs & Holloway, 2013).

Further challenges in implementing GIS technology include social, technical, and institutional factors (Mansourian, Rajabifard, Valadan, & Williamson, 2006). Increasing the awareness of using GIS at a policy, management, and operational levels could add to the value of geospatial information and other related technologies during disaster response. Organizations also need to develop appropriate standards supporting the relevancy of GIS in disaster operations and ensure they have an interoperable system that combines all information into one dataset. This would require all organizations to equip their emergency operations center (EOC) with the correct hardware and software for this type of data analysis have concluded that a spatial data infrastructure using web-based tools could fix these current problems with geospatial information and improve communication between disaster response agencies (Mansourian, Rajabifard, Valadan, & Williamson, 2006).

Government agencies may not have funding to procure GIS, which increases the gap between those who can afford technological developments and those who cannot (Carpenter & Snell, 2013). Outsourcing technology and data collection could lessen this risk but outsourcing requirements could also increase the risk of leaked confidential and classified data. Cloud computing and open source solutions also require significant hardware and software investment. GIS storage has played a large role in the amount of information organizations can manage and maintain. *The Defense Authorization Act of 2012* has mandated the DOD switch to storing data on commercially available cloud services.

However, the DOD has recognized the challenge of storing high risk, classified data through cloud services. The DOD has granted the Defense Information System Agency (DISA) permission to create milCloud, a DOD cloud-based service for unclassified data storage. DISA has established security standards and assesses and approves commercial offers that have met DOD security requirements. However, DISA has only authorized public and unclassified information approval to four commercial companies (McCaney, 2014). While cloud-based services are available to DLA, unclassified data storage on a classified network has not yet been authorized. Therefore, DLA cannot use this service until milCloud has met proper security requirements.

E. GIS OPTIMIZATION

Based on the information given, and conversations with expeditionary personnel, DLA spent a significant amount of time (approximately six days), locating and pinpointing disaster relief locations, such as hospitals, fuel demand sites, and evacuation centers, onto Google Maps. If DLA had used GIS such as ArcGIS, it could have saved time. ArcGIS map layering program allows a user to upload zipped shapefiles, delimited text files, or GPS Exchange Files with addresses or latitude and longitude coordinates. Using that information ArcGIS visually layers each location. Figure 10 shows the ease of adding latitude-longitude coordinates into a map, using DLA FR information.

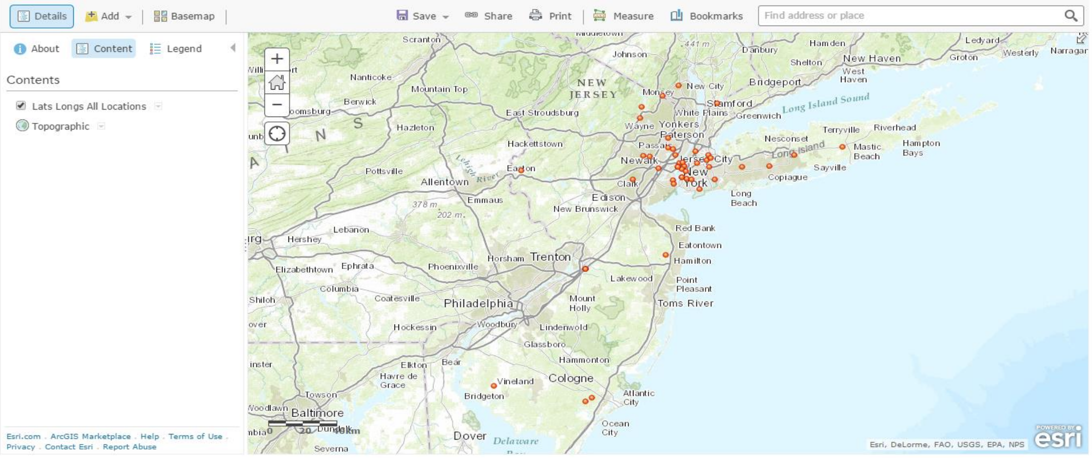
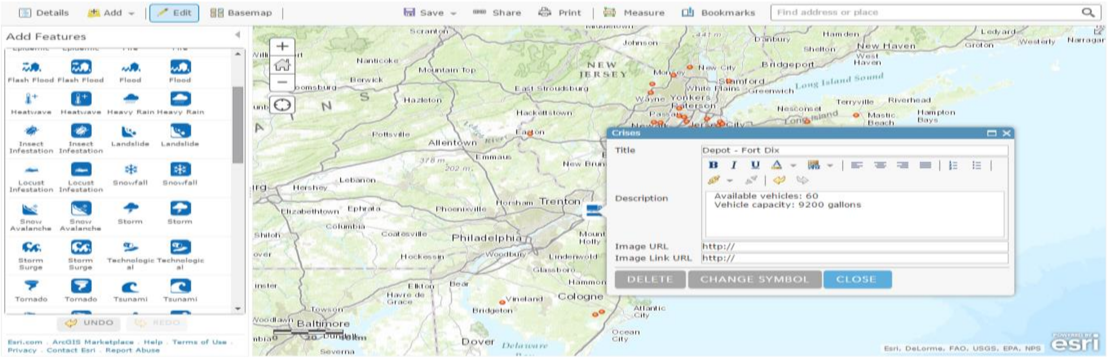


Figure 5. First responder latitude-longitude coordinates during Hurricane Sandy



Title: Depot - Fort Dix

Description: Available vehicles: 60
Vehicle capacity: 9200 gallons

Image URL: http://
Image Link URL: http://

Figure 6. *Map Notes* function in ArcGIS

Furthermore, ArcGIS allows a user to create *Map Notes* from previously inputted locations to add more information. Figure 6 shows the users inputting data. Chapter III described DLA using Google Maps to identify critical geographical points, and the significant amount of time and personnel used to find each location. ArcGIS used latitude-longitude coordinates to find each location within a matter of seconds.

Once created and saved, the user can share the layered map on ArcGIS or with social media such as Facebook and Twitter. Organizations can create accounts that can invite users to view all the data in order to eliminate redundancy and allow for up-to-date information. The user can also edit the information at any time during the disaster, and create presentations within programs such as PowerPoint by Microsoft Office.

F. SUMMARY

This chapter discussed the commercially available GIS technology, the technology DLA used during Hurricane Sandy, and the challenges implementing an integrated GIS technology. Internet and mobile devices have significantly decreased the gap between the user and geospatial information. Cloud computing has also improved the availability of geospatial data. However, government agencies may not have the funding to implement an integrated system. The next chapter defines the deployment optimization routing model this report used to calculate results in Chapter V.

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IV. DEPLOYMENT OPTIMIZATION

The goal of this report is to use the information provided by DLA to prove the significance of an integrated GIS system to increase response time, improve interagency coordination, lessen administrative redundancies, and further advance domestic disaster knowledge.

A. DLA INFORMATION BREAKDOWN

1. Set of Fuel Depots

This data includes one fuel depot, located at Fort Dix, New Jersey.

2. Set of Fuel Demand Locations

DLA provided fuel distribution information for 47 first responder locations, found in Appendix 1. Typically, DLA has used an email-based task system to deliver fuel. DLA processes the requirement and assigns a fuel truck to that tasking. Hurricane Sandy did not operate according to normal procedures. DLA did not use the “e-tasking” system due to a rapid increase in response time, which caused unreliable demand requirements. Figure 7 compares the fuel required to the fuel delivered for each location.

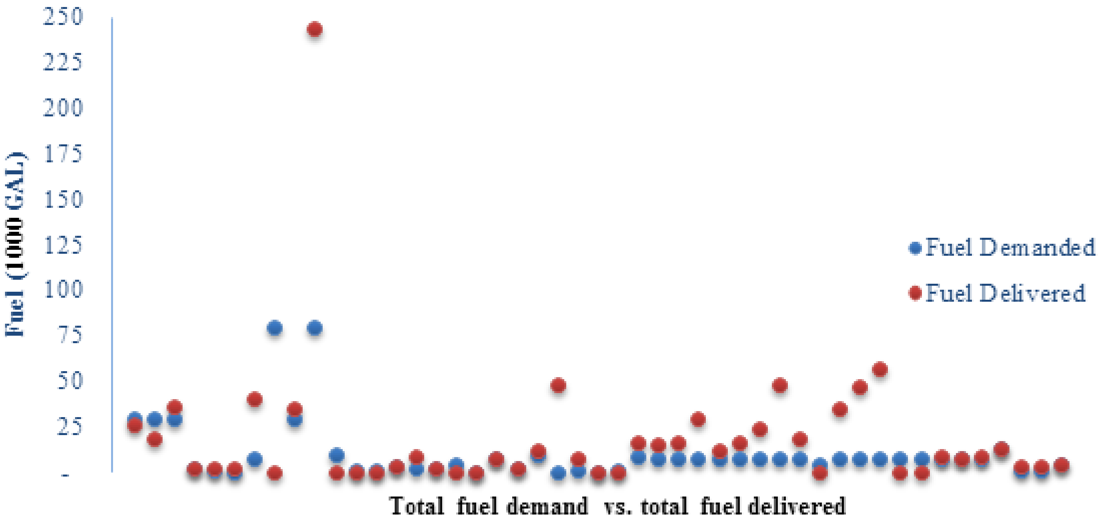

Figure 7. Comparison of total fuel demand and total fuel delivered at each location in thousands of gallons

Of the 47 FR locations, six received their total fuel demand in the exact amount, 28 locations received excess amounts of fuel compared to their requirements, and 13 locations did not receive their demanded requirement. The 47 first responder fuel locations required 502,000 gallons, but 893,840 gallons were delivered. The amount of fuel does not match the requirements because no system to order the fuel existed. This disabled DLA's ability to keep records of what went where and how much. The data reveals that DLA's operations during Hurricane Sandy were not as accurate as they needed to be to optimize fuel delivery and transportation.

3. Set of Time from Depot to Location

This model uses latitude-longitude coordinates from the 47 first responder locations to analyze the distance and amount of time to complete a vehicle route. Each day is a 24 hour period due to Hurricane Sandy is a declared disaster and the Stafford Act applies. This report focused strictly during November 5 through November 9, 2012 since the total amount of fuel delivered is the most significant during the two week period of delivery.

4. Set of Vehicles

This model based the number of vehicles provided for each day, on the total amount of fuel demand divided by the total capacity of the vehicle. Figure 8 shows the number of vehicles tasked for each day. The number of vehicles varied based on the amount of total fuel demanded each day.

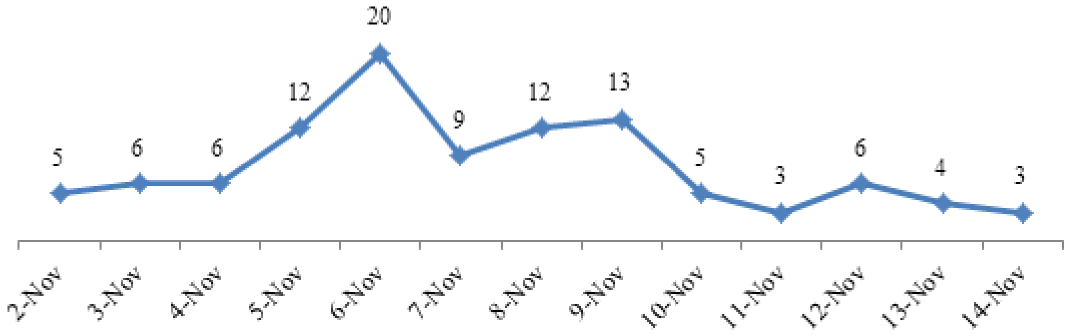

Figure 8. Number of vehicles tasked from Nov 2 to Nov 15, 2012

5. Set of Fuel Demand

Using information provided in Appendix 1, this report compared the frequency of fuel required, fuel met, and the difference between what was required and what was met. Figure 9 shows the frequency of the total amount required for each location. The histogram shows there is a skewed right distribution, where the average amount of fuel required equaled 10,691 gallons. The trucks used to distribute fuel could hold a maximum of 9,200 gallons. This analysis concludes that each location would need a minimum of two trucks dedicated to it to distribute fuel in a timely manner.

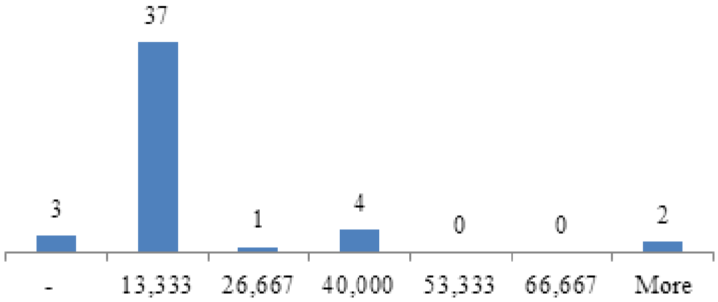

Figure 9. Frequency of total fuel required at each location in gallons

A prime example of the significant difference is Fort Bennett Field, NY which only required 80,000 gallons of fuel but received over 240,000 gallons of fuel. Figure 10 analyzes the frequency of the fuel amount that was actually delivered to each location. This histogram also has a skewed right distribution, where the average amount of fuel delivered was 19,018. Using this information, each location would have needed at least three trucks

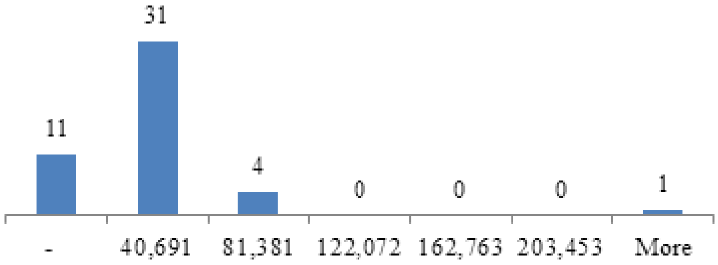

Figure 10. Frequency of total fuel delivered at each locations

Finally, Figure 11 shows the frequency of the difference between the total fuel required and total fuel delivered at each location. This histogram does have a normal distribution however; it is not a good result. On average, DLA delivered 8,326 gallons to each location more than what the location required. The average absolute difference between what was delivered and what was required was 14,083 gallons.

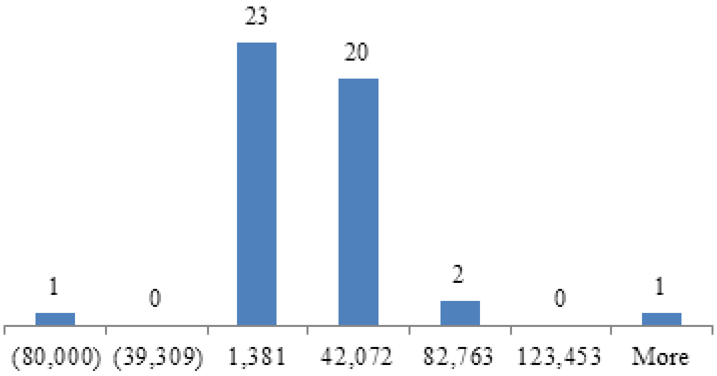

Figure 11. Frequency between total fuel required and total fuel delivered

For the purpose of the model, this report uses the total fuel delivered for each day to result in the more optimal solution to reduce time of delivery. Because the disparity between fuel required and fuel delivered is so significant, the following assumptions apply:

- The amount of fuel delivered to each location per day is the fuel demand for the location.
- Each location is in continuous contact with DLA, giving the fuel demand for each day.

6. Set of Deliveries per Vehicle Route

The number of deliveries a vehicle can make cannot exceed the vehicles capacity of 9,200 gallons. Figure 12 shows the total amount of fuel delivered from November 1 through November 15, 2012. Based on the total amount of fuel delivered, this report assumes the number of vehicles needed for each day varies.

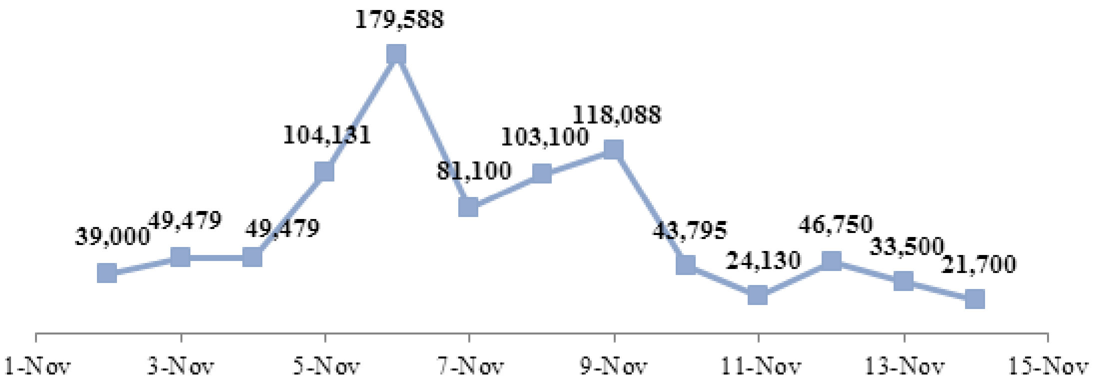

Figure 12. Total amount of fuel delivered from Nov 1 through 15 Nov, 2012

B. SUMMARY

Using an integrated GIS program, DLA could increase the accuracy of deliveries. ArcGIS allows agencies to coordinate immediate delivery locations since it is a web-bases subscription program. Each FR location could update its own information and DLA could respond with greater reliability, accuracy, and efficiency. This chapter discussed the different factors that significant affect the optimization model. Chapter V continues with the results from this information.

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V. RESULTS

This report used data from DLA’s fuel delivery during Hurricane Sandy to demonstrate how GIS technology could benefit DLA in disaster relief operations. This model selected the optimal route for each fuel truck to minimize the total distance traveled, subject to the constraint that each location receives the required amount of fuel. The vehicle optimization routing model required that the amount of fuel demanded at each location is known. GIS technology used the latitude and longitude coordinates of each fuel demand location to calculate the distance and approximate time to travel between each location. Each location could record its fuel demand for each day. GIS technology could then upload this information into DLA’s system. DLA would know how much fuel is required and how many trucks to send out. The model in this report assumed that a best-case scenario: the amount of fuel demanded is known at each fuel location and all roads are passable. The model concluded that GIS technology could benefit disaster response if locations know their fuel demand on a given day or given period.

This report uses the data on fuel delivery from DLA during November 5 to November 9, 2012. The model assumed fuel delivered each day is the demand at each location. The results serve as an example of how knowledge of fuel demand and GIS technology demand could help DLA decision makers. This model does not take into account fueling time but for the purpose this report, the model assumes it is a fixed amount of time regardless of the fuel demand amount.

The vehicle optimization routing problem is solved as follows. Given the daily fuel demand at each location and the capacity of each fuel truck, the model calculated the number of fuel trucks required by dividing the total fuel required by the capacity of each truck. Each fuel truck has a maximum capacity of 9,200 gallons. If a location required more than the capacity of fuel truck, multiple trucks must stop at that location. Then, the model calculates the distance and time that it takes to travel between each of the locations. Next, the model used the distance between locations, the demand at each location, and the number of trucks to calculate the optimal route for each truck to minimize the total distance traveled and satisfy all fuel demands. This report used the Vehicle Routing Problem (VRP) Spreadsheet Solver, developed by Erdogan (2013), to calculate the solution. It used Excel Solver to solve the optimization problem and Bing Maps to calculate the distances and travel times between each location. A user can download the Vehicle Routing Problem Spreadsheet Solver at no cost.

A. FINDINGS

1. November 5, 2012

Table 1 defines the customers' location and demand so the model could calculate to the optimal driving route to meet demand and minimize the amount of time. If a customer requires more than 9,200 gallons of fuel, the Vehicle Routing Problem Spreadsheet Solver requires that the customer is listed multiple times to indicate that multiple trucks will need to visit that location. Figure 13 shows how the user can upload excel information into ArcGIS Maps to create a visual map of the demand locations.

Table 1. Customer location and demand for Nov 5, 2012

Name	Address	Latitude (y)	Longitude (x)	Demand
Depot	Fort Dix	40.0216789	-74.6291122	0
Customer 1	1 Brewster Road Newark, NJ	40.7078379	-74.1732515	2112
Customer 2	JFK International Airport, NY	40.6437111	-73.7900085	2130
Customer 3	Floyd Bennett Field NY South Aviation Drive Brooklyn NY	40.6452217	-73.9493866	9200
Customer 4	Floyd Bennett Field NY South Aviation Drive Brooklyn NY	40.6452217	-73.9493866	9150
Customer 5	123-01 Roosevelt AVE Flushing, NY	40.7634583	-73.8153076	8400
Customer 6	1290 Fulton Avenue, Uniondale, NY,	40.7137413	-73.6048431	9200
Customer 7	1290 Fulton Avenue, Uniondale, NY,	40.7137413	-73.6048431	3550
Customer 8	116 39th Ave, Brooklyn, NY	40.6559070	-74.0124970	9000
Customer 9	126 Bruckner Boulevard, Bronx, NY	40.8038410	-73.9211650	8300
Customer 10	951 Bay Street, Staten Island, NY	40.6194080	-74.0697100	8000
Customer 11	635 Hwy 33,Freehold NJ	39.4738500	-75.3002550	9006
Customer 12	107 Newark Pomton Turnpike, Riverdale NJ	40.9879558	-74.3023885	8903
Customer 13	600 Rahway Ave., Westfield,07090 NJ	40.6429372	-74.3489657	8280
Customer 14	Riverdale , National Guard NJ	40.1387825	-74.6769104	8900

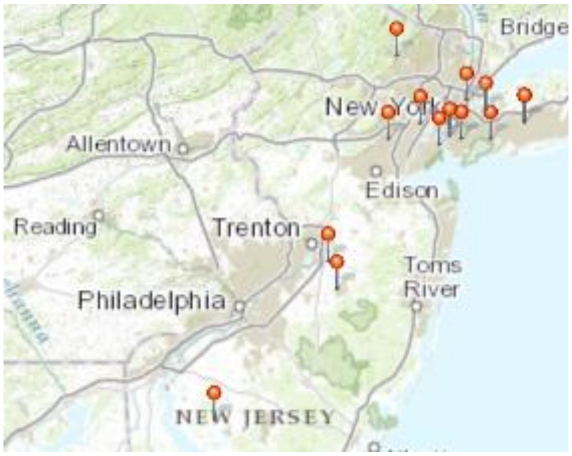


Figure 13. Geographical demand locations for Nov. 5, 2012

The total demand for November 5, 2012 was 104,131 gallons of fuel. Based on the assumption that the maximum capacity of a fuel truck is 9,200 gallons, 12 trucks are needed to deliver fuel for that day. Each location had its specific demand, defined in Table 1. Using the VRP Spreadsheet Solver in excel, Table 2 shows the optimal solution.

Table 2. Optimal vehicle tasking for Nov 5, 2012

Vehicle:	**A 1**	**Stops:**	**2**	**Vehicle:**	**A 7**	**Stops**	**2**
Stop	**Location name**	**Delivered**	**Driving time**	**Stop**	**Location name**	**Delivered**	**Driving time**
0	Depot	0	0:00	0	Depot	0	0:00
1	Customer 14	8900	0:16	1	Customer 3	9200	1:45
2	Depot	8900	0:33	2	Depot	9200	3:51
Vehicle:	**A 2**	**Stops:**	**2**	**Vehicle:**	**A 8**	**Stops:**	**2**
0	Depot	0	0:00	0	Depot	0	0:00
1	Customer 13	8280	1:28	1	Customer 4	9150	1:45
2	Depot	8280	2:57	2	Depot	9150	3:51
Vehicle:	**A 3**	**Stops:**	**2**	**Vehicle:**	**A 9**	**Stops:**	**2**
0	Depot	0	0:00	0	Depot	0	0:00
1	Customer 6	9200	2:08	1	Customer 9	8300	1:57
2	Depot	9200	4:34	2	Depot	8300	4:04
Vehicle:	**A 4**	**Stops:**	**2**	**Vehicle:**	**A 10**	**Stops:**	**2**
0	Depot	0	0:00	0	Depot	0	0:00
1	Customer 10	8000	1:32	1	Customer 12	8903	1:41
2	Depot	8000	3:04	2	Depot	8903	3:23
Vehicle:	**A 5**	**Stops:**	**2**	**Vehicle:**	**A 11**	**Stops:**	**2**
0	Depot	0	0:00	0	Depot	0	0:00
1	Customer 11	9006	1:23	1	Customer 5	8400	1:56
2	Depot	9006	2:47	2	Depot	8400	4:07
Vehicle:	**A 6**	**Stops:**	**2**	**Vehicle:**	**A 12**	**Stops:**	**4**
0	Depot	0	0:00	0	Depot	0	0:00
1	Customer 8	9000	1:35	1	Customer 7	3550	2:08
2	Depot	9000	3:39	2	Customer 2	5680	2:30
				3	Customer 1	7792	3:17
				4	Depot	7792	4:54

Table 2 shows the optimal routes to meet the total demand at each location. The longest route duration is vehicle A12 with a four hour and fifty-four minute drive time. The shortest duration is vehicle A1 with a thirty-three minute drive time. If only one fuel truck was available, it would take seventeen hours and forty-four minutes to complete the entire route.

2. November 6, 2012

Table 3 defines the customers' location and demand so the model could calculate to the optimal driving route to meet demand and minimize the amount of time. Figure 14 shows how the user can upload excel information into ArcGIS Maps to create a visual map of the demand locations.

Table 3. Customer location and demand for Nov 6, 2012

Name	Address	Latitude (y)	Longitude (x)	Demand
Depot	Fort Dix	40.0216789	-74.6291122	0
Customer 1	NGA West Orange NJ	40.7732391	-74.2324219	8400
Customer 2	NGA Freehold NJ	40.1387825	-74.6769104	9200
Customer 3	NGA Freehold NJ	40.1387825	-74.6769104	9200
Customer 4	NGA Freehold NJ	40.1387825	-74.6769104	7600
Customer 5	Floyd Bennett Field NY South Aviation Drive Brooklyn NY	40.6452217	-73.9493866	9200
Customer 6	Floyd Bennett Field NY South Aviation Drive Brooklyn NY	40.6452217	-73.9493866	9200
Customer 7	Floyd Bennett Field NY South Aviation Drive Brooklyn NY	40.6452217	-73.9493866	9200
Customer 8	Floyd Bennett Field NY South Aviation Drive Brooklyn NY	40.6452217	-73.9493866	9200
Customer 9	Floyd Bennett Field NY South Aviation Drive Brooklyn NY	40.6452217	-73.9493866	9200
Customer 10	Floyd Bennett Field NY South Aviation Drive Brooklyn NY	40.6452217	-73.9493866	3066
Customer 11	Rutherford, NJ	40.8255882	-74.1087418	3000
Customer 12	Floyd Bennett Field NY	40.5911255	-73.8941040	8550
Customer 13	Hoboken Ferry Terminal	40.7371597	-74.0309677	8000
Customer 14	USACE, 3 Chapel Ave, Jersey city, NJ	40.7174683	-74.0438385	2700
Customer 15	595 County Ave, Secaucus, NJ	40.7840811	-74.0567847	9200
Customer 16	595 County Ave, Secaucus, NJ	40.7840811	-74.0567847	3300
Customer 17	123-01 Roosevelt AVE Flushing, NY	40.7634583	-73.8153076	9200
Customer 18	123-01 Roosevelt AVE Flushing, NY	40.7634583	-73.8153076	1200
Customer 19	116 39th Ave, Brooklyn, NY	40.6559070	-74.0124970	4000
Customer 20	951 Bay Street, Staten Island, NY	40.6194080	-74.0697100	2500

Name	Address	Latitude (y)	Longitude (x)	Demand
Customer 21	5033 English Creek Ave., Teeneck, NJ	39.4018780	-74.6330110	8700
Customer 22	1350 Pleasant Valley Ave., West Orange, NJ	40.7789540	-74.2786134	9200
Customer 23	1350 Pleasant Valley Ave., West Orange, NJ	40.7789540	-74.2786134	9200
Customer 24	1350 Pleasant Valley Ave., West Orange, NJ	40.7789540	-74.2786134	8800
Customer 25	635 Hwy 33,Freehold NJ	39.4738500	-75.3002550	8572

Figure 14. Geographical demand locations for Nov. 6, 2012

The total demand for November 6, 2012 was 179,588 thousand gallons of fuel, which requires 20 trucks Each location had its specific demand, defined in Table 3. Using the VRP Spreadsheet Solver in Excel, Table 4 shows the optimal solution.

Table 4 shows the optimal routes to meet the total demand at each location. The longest route duration is vehicle A8 with a four hour and twenty-eight minute drive time. The shortest duration is vehicle A1, A2, and A3 with a thirty-thee minute drive time. If only one fuel truck was available, it would take sixteen hours to complete the entire route. Vehicle A18 does not have enough fuel to meet the total demand of customer 11, but this model could be adjusted to take advantage of the excess fuel from other vehicles that might be in the area. GIS technology would benefit from similar situations as all first responders could continuously update the integrated program. DLA would know which vehicle had excess fuel and task it to meet customer 11’s requirement.

Table 4. Optimal vehicle tasking for Nov 6, 2012

Vehicle:	**A 1**	**Stops**	**2**	**Vehicle:**	**A 11**	**Stops:**	**2**
Stop	**Location name**	**Delivered**	**Driving time**	**Stop**	**Location name**	**Delivered**	**Driving time**
0	Depot	0	0:00	0	Depot	0	0:00
1	Customer 2	9200	0:16	1	Customer 25	8572	1:23
2	Depot	9200	0:33	2	Depot	8572	2:47
Vehicle:	**A 2**	**Stops**	**2**	**Vehicle:**	**A 12**	**Stops:**	**2**
0	Depot	0	0:00	0	Depot	0	0:00
1	Customer 3	9200	0:16	1	Customer 23	9200	1:39
2	Depot	9200	0:33	2	Depot	9200	3:22
Vehicle:	**A 3**	**Stops:**	**2**	**Vehicle:**	**A 13**	**Stops:**	**2**
0	Depot	0	0:00	0	Depot	0	0:00
1	Customer 4	7600	0:16	1	Customer 5	9200	1:45
2	Depot	7600	0:33	2	Depot	9200	3:51
Vehicle:	**A 4**	**Stops:**	**2**	**Vehicle:**	**A 14**	**Stops:**	**2**
0	Depot	0	0:00	0	Depot	0	0:00
1	Customer 21	8700	1:21	1	Customer 6	9200	1:45
2	Depot	8700	2:43	2	Depot	9200	3:51
Vehicle:	**A 5**	**Stops:**	**3**	**Vehicle:**	**A 15**	**Stops:**	**2**
0	Depot	0	0:00	0	Depot	0	0:00
1	Customer 13	8000	1:44	1	Customer 7	9200	1:45
2	Customer 18	9200	2:17	2	Depot	9200	3:51
3	Depot	9200	4.:28				
Vehicle:	**A 6**	**Stops**	**2**	**Vehicle:**	**A 16**	**Stops:**	**2**
0	Depot	0	0:00	0	Depot	0	0:00
1	Customer 1	8400	1:42	1	Customer 8	9200	1:45
2	Depot	8400	3:26	2	Depot	9200	3:51
Vehicle:	**A 7**	**Stops:**	**2**	**Vehicle:**	**A 17**	**Stops:**	**2**
0	Depot	0	0:00	0	Depot	0	0:00
1	Customer 24	8800	1:39	1	Customer 9	9200	1:45
2	Depot	8800	3:22	2	Depot	9200	3:51
Vehicle:	**A 8**	**Stops:**	**4**	**Vehicle:**	**A 18**	**Stops:**	**4**
0	Depot	0	0:00	0	Depot	0	0:00
1	Customer 14	2700	1:44	1	Customer 10	3066	1:45
2	Customer 19	6700	2:05	2	Customer 16	6366	2:22
3	Customer 20	9200	2:21	3	Customer 11	9366	2:33
4	Depot	9200	3:53	4	Depot	9366	4:22
Vehicle:	**A 9**	**Stops:**	**2**	**Vehicle:**	**A 19**	**Stops:**	**2**
0	Depot	0	0:00	0	Depot	0	0:00
1	Customer 15	9200	1:50	1	Customer 12	8550	1:47
2	Depot	9200	3:38	2	Depot	8550	3:36
Vehicle:	**A 10**	**Stops:**	**2**	**Vehicle:**	**A 20**	**Stops:**	**2**
0	Depot	0	0:00	0	Depot	0	0:00
1	Customer 17	9200	1:56	1	Customer 22	9200	1:39
2	Depot	9200	4:07	2	Depot	9200	3:22

Figure 15 shows the multiple locations available to fill the demand for customer 11. Customer 11 still requires 166 gallons of fuel. Combining the optimization model and ArcGIS Maps, vehicle A6 tasked to customer 1 is the closest location with remaining fuel to supply customer 11. Vehicle A6 still has 800 gallons of fuel capacity remaining. This would increase vehicle A6’s route by two hours and eight minutes; however, DLA would be able to meet every customer demand in eighteen hours and eight minutes.

Figure 15. Demand locations near customer 11

3. November 7, 2012

Table 5 defines the customers' location and demand so the model could calculate to the optimal driving route to meet demand and minimize the amount of time. Figure 16 shows how the user can upload excel information into ArcGIS Maps to create a visual map of the demand locations.

Table 5. Customer location and demand for Nov 7, 2012

Name	Address	Latitude (y)	Longitude (x)	Demand
Depot	Fort Dix	40.0216789	-74.6291122	0
Customer 1	140 republic airport Rd, E. Farmingdale, NY	40.7206374	-73.4170778	7400
Customer 2	Floyd Bennett Field NY South Aviation Drive Brooklyn NY	40.6452217	-73.9493866	9200
Customer 3	Floyd Bennett Field NY South Aviation Drive Brooklyn NY	40.6452217	-73.9493866	9200
Customer 4	Floyd Bennett Field NY South Aviation Drive Brooklyn NY	40.6452217	-73.9493866	5600
Customer 5	123-01 Roosevelt AVE Flushing, NY	40.7634583	-73.8153076	3500
Customer 6	116 39th Ave, Brooklyn, NY	40.6559070	-74.0124970	8000
Customer 7	126 Bruckner Boulevard, Bronx, NY	40.8038410	-73.9211650	3700
Customer 8	635 Hwy 33,Freehold NJ	39.4738500	-75.3002550	8600
Customer 9	152 Chestnut St., City-Toms River, County-Ocean, NJ	40.8796010	-74.1072240	9200
Customer 10	152 Chestnut St., City-Toms River, County-Ocean, NJ	40.8796010	-74.1072240	4300
Customer 11	2 Bloomfield St, Manhattan, NY (Grounservant Pier)	40.7405448	-74.0093947	3700
Customer 12	52-35 58th St, Woodside, NY	40.7348438	-73.9099270	3700
Customer 13	1 Orechio Ave. Wanaque NJ	41.0510406	-74.2890091	5000

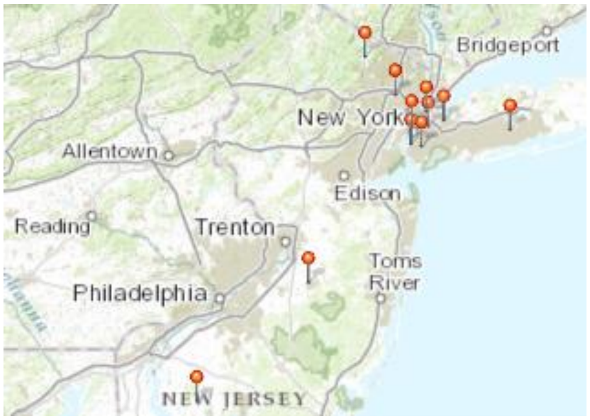


Figure 16. Geographical demand locations for Nov. 7, 2012

The total demand for November 7, 2012 was 81,100 gallons of fuel, and nine trucks are required Each location had its specific demand, defined in Table 5. Using the VRP Spreadsheet Solver in excel, Table 6 shows the optimal solution.

Table 6. Optimal vehicle tasking for Nov 7, 2012

Vehicle:	**A 1**	**Stops:**	**2**	**Vehicle:**	**A 6**	**Stops:**	**2**
Stop	**Location name**	**Delivered**	**Driving time**	**Stop**	**Location name**	**Delivered**	**Driving time**
0	Depot	0	0:00	**0**	Depot	0	0:00
1	Customer 8	8600	1:23	**1**	Customer 6	8000	1:35
2	Depot	8600	2:47	**2**	Depot	8000	3:39
Vehicle:	A 2	Stops:	3	**Vehicle:**	A 7	Stops:	3
0	Depot	0	0:00	**0**	Depot	0	0:00
1	Customer 1	7400	2:17	**1**	Customer 13	5000	1:47
2	Customer 5	10900	2:56	**2**	Customer 7	8700	2:30
3	Depot	10900	5:07	**3**	Depot	8700	4:37
Vehicle:	**A 3**	**Stops:**	**3**	**Vehicle:**	**A 8**	**Stops:**	**2**
0	Depot	0	0:00	**0**	Depot	0	0:00
1	Customer 4	5600	1:45	**1**	Customer 9	9200	1:51
2	Customer 11	9300	2:10	**2**	Depot	9200	3:45
3	Depot	9300	4:00				
Vehicle:	**A 4**	**Stops:**	**2**	**Vehicle:**	**A 9**	**Stops:**	**3**
0	Depot	0	0:00	**0**	Depot	0	0:00
1	Customer 2	9200	1:45	**1**	Customer 12	3700	1:47
2	Depot	9200	3:51	**2**	Customer 10	8000	2:28
Vehicle:	A 5	Stops:	2	**3**	Depot	8000	4:22
0	Depot	0	0:00				
1	Customer 3	9200	1:45				
2	Depot	9200	3:51				

Table 6 shows the optimal routes to meet the total demand at each location. The longest route duration is vehicle A2 with a five hour and 7 minute drive time. The shortest duration is vehicle A1 with a two hour and 27 minute drive time. If only one fuel truck was available, it would take 35 hours and 59 minutes to complete the entire route. However, vehicle A2 could not the total demand of customer 5 and vehicle A3 could not met the total demand of customer 11.

Figure 17 shows the multiple locations available to fill the demand for customer 5 and customer 11. Customer 5 still requires 1,700 gallons of fuel where customer 11 requires 100 gallons. Combining the optimization model and ArcGIS Maps, vehicle A9 tasked to customer 12 and customer 10 is the closest location with remaining fuel to supply customer 5. Vehicle A9 could supply 1,200 gallons to customer 5 and then resume its route to customer 12 and customer 10. This would increase vehicle A9's route by thirty-eight minutes. Customer 7 is the next closest location to customer 5.

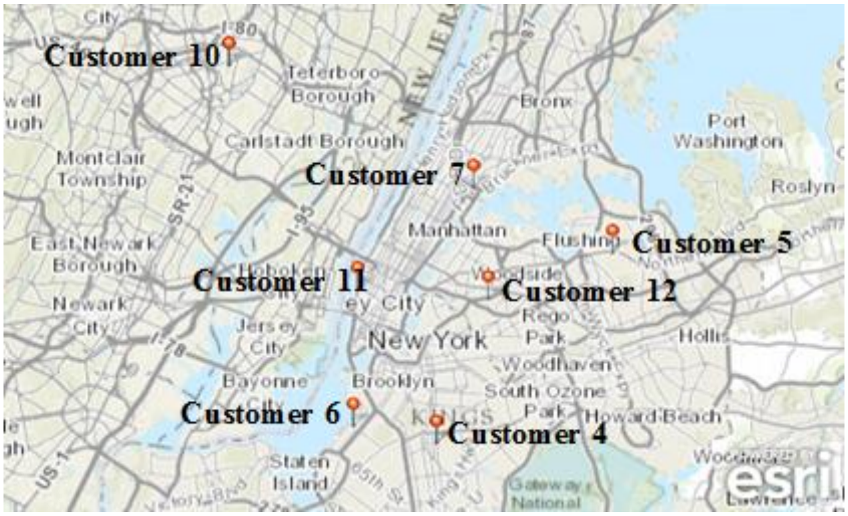


Figure 17. Demand locations near customer 5 and customer 11

Vehicle A7 has the remaining 500 gallons of fuel capacity to meet customer 5's demand. This would increase vehicle A7's route by twenty-five minutes. Vehicle A6 tasked to customer 6 is the closest location with remaining fuel to supply customer 11's demand.

This would increase vehicle A6's route by thirty-eight minutes. DLA would be able to meet every customer demand in thirty-seven hours and forty minutes.

4. November 8, 2012

Table 7 defines the customers' location and demand so the model could calculate to the optimal driving route to meet demand and minimize the amount of time. Figure 18 shows how the user can upload excel information into ArcGIS Maps to create a visual map of the demand locations.

Table 7. Customer location and demand for Nov 8, 2012

Name	Address	Latitude (y)	Longitude (x)	Demand
Depot	Fort Dix	40.0216789	-74.6291122	0
Customer 1	ATL City OEM Egg harbor NJ	40.1387825	-74.6769104	5000
Customer 2	140 republic airport Rd, E. Farmingdale, NY	40.7206374	-73.4170778	2400
Customer 3	120-01 Roosevelt AVE, NY	40.7541590	-73.8473698	8500
Customer 4	Floyd Bennett Field NY South Aviation Drive Brooklyn NY	40.6452217	-73.9493866	9200
Customer 5	Floyd Bennett Field NY South Aviation Drive Brooklyn NY	40.6452217	-73.9493866	9200
Customer 6	Floyd Bennett Field NY South Aviation Drive Brooklyn NY	40.6452217	-73.9493866	9200
Customer 7	Floyd Bennett Field NY South Aviation Drive Brooklyn NY	40.6452217	-73.9493866	9200
Customer 8	Floyd Bennett Field NY South Aviation Drive Brooklyn NY	40.6452217	-73.9493866	9200
Customer 9	Floyd Bennett Field NY South Aviation Drive Brooklyn NY	40.6452217	-73.9493866	5000
Customer 10	1 Met Life Stadium Dr. E. Rutherford, Nj	40.8151920	-74.0747883	9200
Customer 11	1 Met Life. E. Rutherford, NJ	40.8151920	-74.0747883	3800
Customer 12	126 Bruckner Boulevard, Bronx, NY	40.8038410	-73.9211650	3700
Customer 13	5033 English Creek Ave., Teeneck, NJ	39.4018780	-74.6330110	7500
Customer 14	635 Hwy 33,Freehold NJ	39.4738500	-75.3002550	9200
Customer 15	635 Hwy 33,Freehold NJ	39.4738500	-75.3002550	2800

Figure 18. Geographical demand locations for Nov. 8, 2012

The total demand for November 8, 2012 was 103,100 gallons of fuel, and 12 trucks are required to meet demand. Each location had its specific demand, defined in Table 7. Using the VRP Spreadsheet Solver in excel, Table 8 shows the optimal solution.

Table 8. Optimal vehicle tasking for Nov 8, 2012

Vehicle:	**A 1**	**Stops:**	**2**	**Vehicle:**	**A 7**	**Stops:**	**2**
Stop	**Location name**	**Delivered**	**Driving time**	**Stop**	**Location name**	**Delivered**	**Driving time**
0	Depot	0	0:00	**0**	Depot	0	0:00
1	Customer 3	8500	1:53	**1**	Customer 4	9200	1:45
2	Depot	8500	4:02	**2**	Depot	9200	3:51
Vehicle:	**A 2**	**Stops:**	**2**	**Vehicle:**	**A 8**	**Stops:**	**2**
0	Depot	0	0:00	**0**	Depot	0	0:00
1	Customer 13	7500	1:21	**1**	Customer 5	9200	1:45
2	Depot	7500	2:43	**2**	Depot	9200	3:51
Vehicle:	**A 3**	**Stops:**	**2**	**Vehicle:**	**A 9**	**Stops:**	**2**
0	Depot	0	0:00	**0**	Depot	0	0:00
1	Customer 14	9200	1:23	**1**	Customer 6	9200	1:45
2	Depot	9200	2:47	**2**	Depot	9200	3:51
Vehicle:	**A 4**	**Stops:**	**3**	**Vehicle:**	**A 10**	**Stops:**	**2**
0	Depot	0	0:00	**0**	Depot	0	0:00
1	Customer 15	2800	1:23	**1**	Customer 7	9200	1:45
2	Customer 1	7800	2:37	**2**	Depot	9200	3:51
3	Depot	7800	2:54				
Vehicle:	**A 5**	**Stops:**	**2**	**Vehicle:**	**A 11**	**Stops:**	**2**
0	Depot	0	0:00	**0**	Depot	0	0:00
1	Customer 10	9200	1:56	**1**	Customer 8	9200	1:45
2	Depot	9200	3:47	**2**	Depot	9200	3:51
Vehicle:	**A 6**	**Stops:**	**3**	**Vehicle:**	**A 12**	**Stops:**	**3**
0	Depot	0	0:00	**0**	Depot	0	0:00
1	Customer 2	2400	2:17	**1**	Customer 11	3800	1:56
2	Customer 9	7400	3:05	**2**	Customer 12	7500	2:22
3	Depot	7400	5:11	**3**	Depot	7500	4:29

Table 8 shows the optimal routes to meet the total demand at each location. The longest route duration is vehicle A6 with a five hour and eleven minute drive time. The shortest duration is vehicle A2 with a two hour and forty-three minute drive time. If only one fuel truck was available, it would take forty-five hours and eight minutes to complete the entire route.

5. November 9, 2012

Table 9 defines the customers' location and demand so the model could calculate to the optimal driving route to meet demand and minimize the amount of time. Figure 19 shows how the user can upload excel information into ArcGIS Maps to create a visual map of the demand locations.

Table 9. Customer location and demand for Nov 9, 2012

Location ID	Name	Address	Latitude (y)	Longitude (x)	Demand
0	Depot	Fort Dix	40.0216789	-74.6291122	0
1	Customer 1	140 republic airport Rd, E. Farmingdale, NY	40.7206374	-73.4170778	3800
2	Customer 2	120-01 Roosevelt AVE, NY	40.7541590	-73.8473698	8000
3	Customer 3	Floyd Bennett Field NY South Aviation Drive Brooklyn NY	40.6452217	-73.9493866	9200
4	Customer 4	Floyd Bennett Field NY South Aviation Drive Brooklyn NY	40.6452217	-73.9493866	9200
5	Customer 5	Floyd Bennett Field NY South Aviation Drive Brooklyn NY	40.6452217	-73.9493866	9200
6	Customer 6	Floyd Bennett Field NY South Aviation Drive Brooklyn NY	40.6452217	-73.9493866	9200
7	Customer 7	Floyd Bennett Field NY South Aviation Drive Brooklyn NY	40.6452217	-73.9493866	9200
8	Customer 8	Floyd Bennett Field NY South Aviation Drive Brooklyn NY	40.6452217	-73.9493866	9200
9	Customer 9	Floyd Bennett Field NY South Aviation Drive Brooklyn NY	40.6452217	-73.9493866	9200
10	Customer 10	Floyd Bennett Field NY South Aviation Drive Brooklyn NY	40.6452217	-73.9493866	1328
11	Customer 11	1 Met Life. E. Rutherford, NJ	40.8151920	-74.0747883	9200
12	Customer 12	1 Met Life. E. Rutherford, NJ	40.8151920	-74.0747883	7360
13	Customer 13	123-01 Roosevelt AVE Flushing, NY	40.7634583	-73.8153076	8000
14	Customer 14	126 Bruckner Boulevard, Bronx, NY	40.8038410	-73.9211650	8000
15	Customer 15	951 Bay Street, Staten Island, NY	40.6194080	-74.0697100	8000

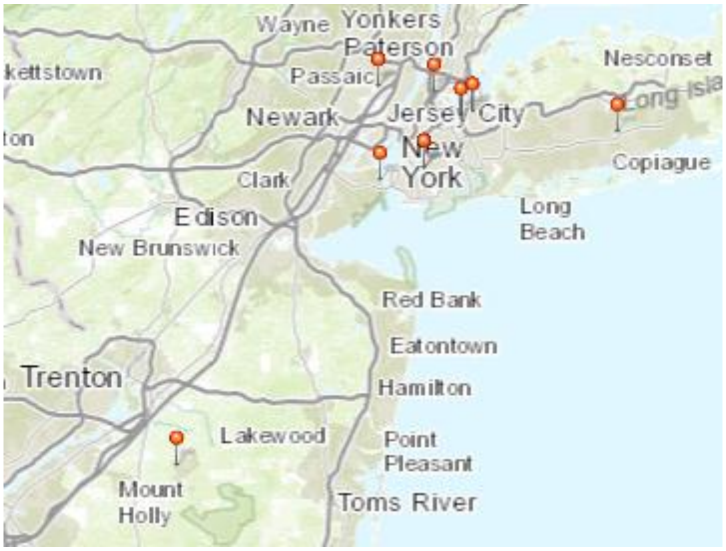


Figure 19. Geographical demand locations for Nov. 9, 2012

The total demand for November 9, 2012 was 118,088 gallons of fuel, which requires 13 trucks. Each location had its specific demand, defined in Table 9. Using the VRP Spreadsheet Solver in excel, Table 10 shows the optimal solution.

Table 10. Optimal vehicle tasking for Nov 9, 2012

Vehicle:	**A 1**	**Stops:**	**2**	**Vehicle:**	**A 8**	**Stops:**	**2**
Stop	**Location name**	**Delivered**	**Driving time**	**Stop**	**Location name**	**Delivered**	**Driving time**
0	Depot	0	0:00	**0**	Depot	0	0:00
1	Customer 15	8000	1:32	**1**	Customer 7	9200	1:45
2	Depot	8000	3:04	**2**	Depot	9200	3:51
Vehicle:	**A 2**	**Stops:**	**2**	**Vehicle:**	**A 9**	**Stops:**	**2**
0	Depot	0	0:00	**0**	Depot	0	0:00
1	Customer 11	9200	1:56	**1**	Customer 8	9200	1:45
2	Depot	9200	3:47	**2**	Depot	9200	3:51
Vehicle:	**A 3**	**Stops:**	**3**	**Vehicle:**	**A 10**	**Stops:**	**2**
0	Depot	0	0:00	**0**	Depot	0	0:00
1	Customer 1	3800	2:17	**1**	Customer 9	9200	1:45
2	Customer 12	11160	3:26	**2**	Depot	9200	3:51
3	Depot	11160	5:17				
Vehicle:	**A 4**	**Stops:**	**2**	**Vehicle:**	**A 11**	**Stops:**	**3**
0	Depot	0	0:00	**0**	Depot	0	0:00
1	Customer 3	9200	1:45	**1**	Customer 10	1328	1:45
2	Depot	9200	3:51	**2**	Customer 13	9328	2:17
Vehicle:	**A 5**	**Stops:**	**2**	3	Depot	9328	4:28
0	Depot	0	0:00				
1	Customer 4	9200	1:45				
2	Depot	9200	3:51				
Vehicle:	**A 6**	**Stops:**	**2**	**Vehicle:**	**A 12**	**Stops:**	**2**
0	Depot	0	0:00	**0**	Depot	0	0:00
1	Customer 5	9200	1:45	**1**	Customer 14	8000	1:57
2	Depot	9200	3:51	**2**	Depot	8000	4:04
Vehicle:	**A 7**	**Stops:**	**2**	**Vehicle:**	**A 13**	**Stops:**	**2**
0	Depot	0	0:00	**0**	Depot	0	0:00
1	Customer 6	9200	1:45	**1**	Customer 2	8000	1:53
2	Depot	9200	3:51	**2**	Depot	8000	4:02

Table 10 shows the optimal routes to meet the total demand at each location. The longest route duration is vehicle A3 with a five hour and seventeen minute drive time. The shortest duration is vehicle A1 with a three hour and four minute drive time. If only one fuel truck was available, it would take fifty-one hours and thirty-nine minutes to complete the entire route. However, vehicle A3 could not the total demand of customer 12 and vehicle A11 could not met the total demand of customer 13.

Figure 20 shows the multiple locations available to fill the demand for customer 12 and customer 13. Customer 12 still requires 196,000 gallons of fuel where customer 13 requires 128 gallons. Combining the optimization model and ArcGIS Maps, vehicle A12 tasked to customer 14 and is the closest location with 1.2 thousand gallons of fuel remaining fuel to supply customer 12. This would increase vehicle A12’s route by ten minutes. Customer 2 is the next closest location to customer 12. Vehicle A13 has the remaining 760 gallons of fuel capacity to meet customer 12’s demand. Vehicle A13 then could deliver the remaining fuel to supply customer 13’s demand. This would increase vehicle A13’s route by fifty-two minutes. DLA would be able to meet every customer demand in fifty-two hours and forty-one minutes.

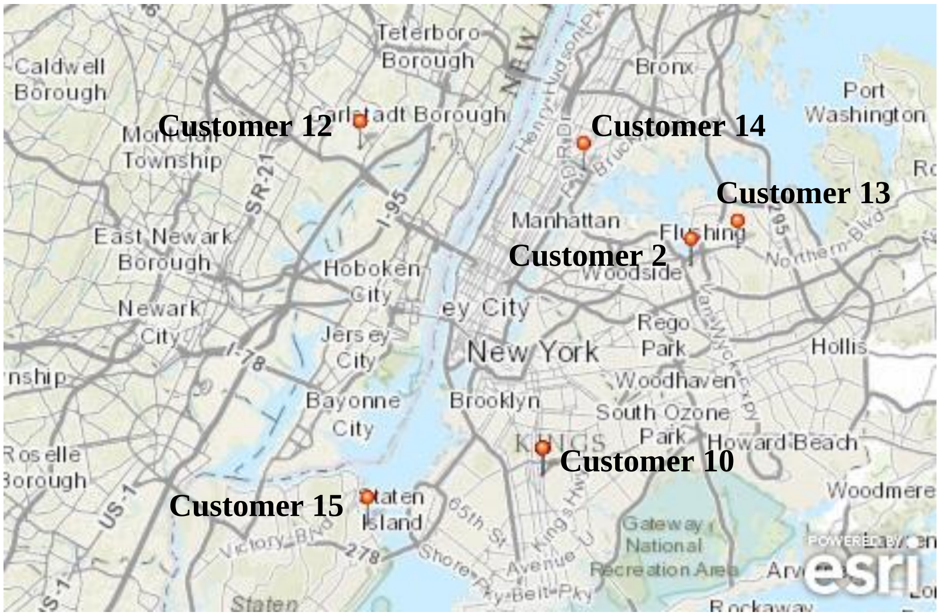


Figure 20. Demand locations near customer 12 and customer 13

B. SUMMARY

This chapter showed the optimal number of routes during the most significant fuel demand requirements. From the results, this report concludes that an integrated GIS program along with an optimization modeling program would significantly benefit DLA and other disaster response agencies. The amount of vehicles tasked varied based on the amount of fuel demand for each day.

Figure 21 shows the total time to complete a vehicle route for November 5 through November 9, 2012. Based on the VRP Spreadsheet Solver and Ersi Maps, the longest route for a single vehicle was five hours and seventeen minutes. The shortest amount of time to complete a single route was thirty-three minutes. Based on the results, this report concludes the average amount of time for a vehicle to complete a single route was three hours and forty minutes.

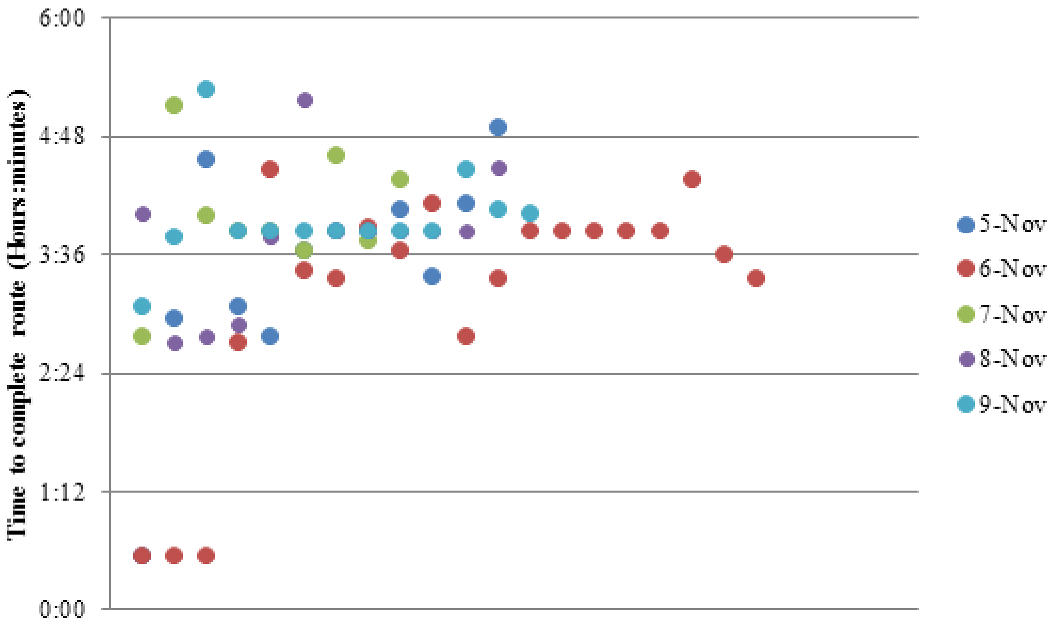


Figure 21. Total amount of time to complete vehicle route

What took weeks to accomplish in fuel distribution has been reduced to a number of days. There are many assumptions using these programs which DLA would still need to address. Fuel distribution time varies depending on the amount of fuel, where this model assumed time is constant for all fuel deliveries. This report also assumed there is little or no damage to the vehicle route infrastructure. In actual disasters roadways could have severe damage making the route impassable and vehicles would need to use an alternate route. GIS technology can mitigate problems through real-time information. Overall, GIS technology paired with an optimization model is a suitable tool for simplifying disaster response decision-making.

VI. CONCLUSION AND FURTHER RESEARCH OPPORTUNITIES

A. CONCLUSION

Chapter I introduced the topics of disaster response operations and the types of GIS technology. It identified the different agencies that respond to disasters and how each agency must comply with regarding policies and regulations. Chapter I also explained the sequence of events during Hurricane Sandy and what roles DLA and FEMA played during the disaster.

Chapter II identified four areas for improvements in disaster response as revealed in the disaster relief literature. It discussed three of the four areas, transportation and logistics, communication and coordination, and resource and personnel management. Transportation and logistics found that the unpredictability of timing and location, short lead times, and various requirements affect the ability to respond. Communication and coordination concluded the overload of requirements make it difficult to identify what requests should be fulfilled and which should be acquired first. Finally resource and personnel management determined tracking the number of resources and personnel is substantially more difficult during disaster response.

Chapter III defined the final area for improvement, the use of GIS technology. GIS technology can provide disaster response agencies with the necessary tools to accomplish the mission. Layered maps allow the user to understand where problems occurred and what can be done for future disasters. Not only can the user review previous disasters, but layered maps can also train personnel. However, government agencies may not have the funding to implement an integrated system.

Chapter IV explored the data provided by DLA on its fuel distribution during Hurricane Sandy from November 2 to November 17, 2013. The 47 locations required 502,500 gallons of fuel, but DLA delivered 893,840 gallons. On average, DLA delivered 8,326 gallons to each location more than what the location required. The average absolute difference between what was delivered and what was required was 14,083 gallons. The lack of a good information system connecting DLA and the locations demanding fuel helps explain this disparity.

Finally, Chapter V showed the results of the optimization model and outlined how GIS could also improve on the model. It concluded that an integrated GIS program along with an optimization modeling program could benefit DLA and other disaster response agencies. While this report assumed there is little or no damage to the vehicle route infrastructure, roadways could have severe damage making the route impassable and vehicles would need to use an alternate route. GIS technology can mitigate that increased time through real-time information.

Although ArcGIS is more user-friendly and takes less time to input information, a user still must manually input information for each location. There are multiple platforms available within Esri such as the *Disaster Response Program* that is supported by Esri experts and allows monitoring and updates 24 hours a day. *Esri Maps for Microsoft Office* is a beneficial program because it combines *Microsoft Excel* and ArcGIS. The transportation analysis Esri program can allow the user to conduct post route analysis of planned and actual routes, perform what-if scenarios, and understand the characteristics of the most optimal routes. ArcGIS for Transportation Analytics can help the user create vehicle routes, manage complex schedules, and monitor progress throughout the day (Esri, 2014). While the initial set up takes substantial time, the program is relatively simple to use and the time for planning and response can be significantly decreased. This report recommends further research on the costs and benefits of implementing a GIS program for disaster response agencies.

This report used the basic *Esri Maps for Microsoft Office* to show the results of the model. More advanced programs are available to DLA. ArcGIS requires an organization subscription which would make it easier for DLA and FEMA to coordinate during disasters. DLA also has the available technology to maintain a satellite connection for internet access. Connectivity would not be an issue as long as DLA could access a satellite. FEMA could also access this technology since DLA directly supports it during disaster response. However, DLA must further collaborate with FEMA to gain access to the ArcGIS program that FEMA is currently using.

The model makes various assumptions. This report assumed time was constant for delivering fuel. DLA would need to include time to deliver fuel to the holding station for each location. This report also assumed there was little to no damage to infrastructure along the optimal route. GIS technology could show DLA the amount of damage along the route to determine if a truck would need to take an alternative route. Fuel demand locations would also need to communicate the amount of fuel needed during disaster response. The report assumed the fuel delivered each day was the demand for each location, and it may be necessary to prioritize certain demand locations over other locations if there is not enough supply. DLA would at least need an estimated amount of fuel for each location. ArcGIS could help share this information, and DLA personnel could access the same program to input demand information for each location.

B. FURTHER RESEARCH OPPORTUNITIES

GIS technology can use "lean-thinking" to improve flow, value, synchronization, and transparency within an agency, or between multiple agencies. Lean thinking will help where there is an ultimate end goal to save money and lives by limiting resource waste. This report recommends further research as to whether incorporating an integrated GIS would cut waste and create synergy with the use of a "Lean" program.

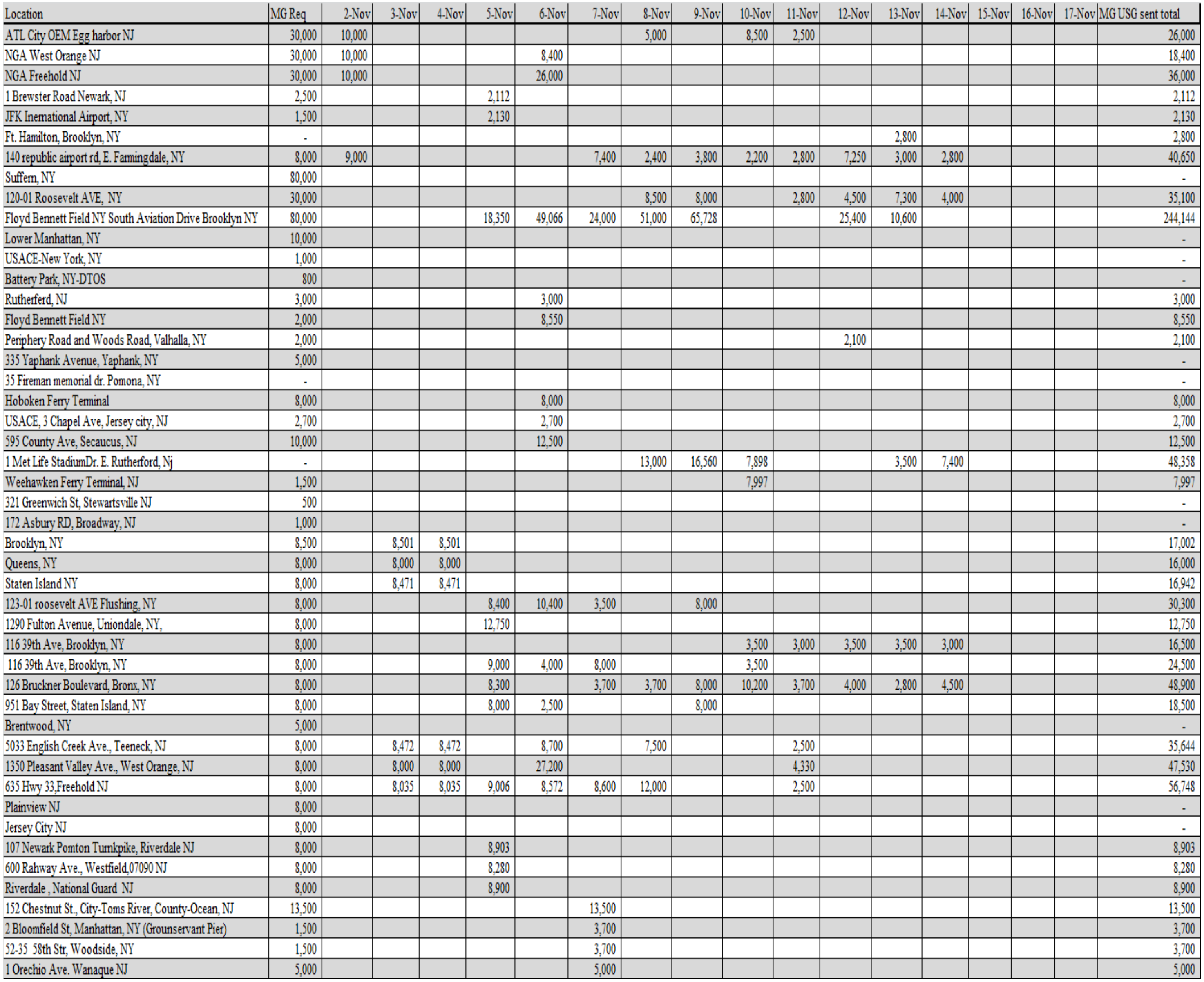
The DOD has used commodity councils to procure large amounts of the same requirement across branches. It would be beneficial to research whether agencies could implement commodity councils specifically for disaster response. The commodity council would create the contracts that would be used during disasters. The contractors that are awarded the contracts will also be involved in training exercises to synchronize all agencies.

The model in this report only used data from November 5 to November 9, 2012 based on the significant amount of fuel delivered during that period. This report recommends that further analysis should use all data provided from November 2 to November 15, 2012. Future optimization models may have in different results than this report, however the conclusion that GIS technology would improve DLA's disaster response should remain constant.

Because disasters have a lot of unknowns, exploring how uncertainty impacts decision making during a disaster is also important. GIS technology can help reduce some of that uncertainty by providing a means to share and store information. However, there could still be uncertainty about how much fuel is required or what supplies are needed at a given location. Further research can be conducted to identify some of the key uncertainties in a disaster and how decision making can be improved while incorporating that uncertainty.

APPENDIX

Appendix 1. DLA Raw Data for FR locations and fuel demand



Location	MG Req	2-Nov	3-Nov	4-Nov	5-Nov	6-Nov	7-Nov	8-Nov	9-Nov	10-Nov	11-Nov	12-Nov	13-Nov	14-Nov	15-Nov	16-Nov	17-Nov	MG USG sent total
ATL City OEM Egg harbor NJ	30,000	10,000						5,000		8,500	2,500							26,000
NGA West Orange NJ	30,000	10,000				8,400												18,400
NGA Freehold NJ	30,000	10,000				26,000												36,000
1 Brewster Road Newark, NJ	2,500				2,112													2,112
JFK Inemational Airport, NY	1,500				2,130													2,130
Ft. Hamilton, Brooklyn, NY	-												2,800					2,800
140 republic airport rd, E. Farmingdale, NY	8,000	9,000					7,400	2,400	3,800	2,200	2,800	7,250	3,000	2,800				40,650
Suffern, NY	80,000																	-
120-01 Roosevelt AVE, NY	30,000							8,500	8,000		2,800	4,500	7,300	4,000				35,100
Floyd Bennett Field NY South Aviation Drive Brooklyn NY	80,000				18,350	49,066	24,000	51,000	65,728			25,400	10,600					244,144
Lower Manhattan, NY	10,000																	-
USACE-New York, NY	1,000																	-
Battery Park, NY-DTOS	800																	-
Rutherferd, NJ	3,000					3,000												3,000
Floyd Bennett Field NY	2,000					8,550												8,550
Periphery Road and Woods Road, Valhalla, NY	2,000											2,100						2,100
335 Yaphank Avenue, Yaphank, NY	5,000																	-
35 Fireman memorial dr. Pomona, NY	-																	-
Hoboken Ferry Terminal	8,000					8,000												8,000
USACE, 3 Chapel Ave, Jersey city, NJ	2,700					2,700												2,700
595 County Ave, Secaucus, NJ	10,000					12,500												12,500
1 Met Life StadiumDr. E. Rutherford, Nj	-							13,000	16,560	7,898			3,500	7,400				48,358
Weehawken Ferry Terminal, NJ	1,500									7,997								7,997
321 Greenwich St, Stewartsville NJ	500																	-
172 Asbury RD, Broadway, NJ	1,000																	-
Brooklyn, NY	8,500		8,501	8,501														17,002
Queens, NY	8,000		8,000	8,000														16,000
Staten Island NY	8,000		8,471	8,471														16,942
123-01 roosevelt AVE Flushing, NY	8,000				8,400	10,400	3,500		8,000									30,300
1290 Fulton Avenue, Uniondale, NY,	8,000				12,750													12,750
116 39th Ave, Brooklyn, NY	8,000									3,500	3,000	3,500	3,500	3,000				16,500
116 39th Ave, Brooklyn, NY	8,000				9,000	4,000	8,000			3,500								24,500
126 Bruckner Boulevard, Bronx, NY	8,000				8,300		3,700	3,700	8,000	10,200	3,700	4,000	2,800	4,500				48,900
951 Bay Street, Staten Island, NY	8,000				8,000	2,500			8,000									18,500
Brentwood, NY	5,000																	-
5033 English Creek Ave., Teeneck, NJ	8,000		8,472	8,472		8,700		7,500			2,500							35,644
1350 Pleasant Valley Ave., West Orange, NJ	8,000		8,000	8,000		27,200					4,330							47,530
635 Hwy 33,Freehold NJ	8,000		8,035	8,035	9,006	8,572	8,600	12,000			2,500							56,748
Plainview NJ	8,000																	-
Jersey City NJ	8,000																	-
107 Newark Pomton Turnkpike, Riverdale NJ	8,000				8,903													8,903
600 Rahway Ave., Westfield,07090 NJ	8,000				8,280													8,280
Riverdale , National Guard NJ	8,000				8,900													8,900
152 Chestnut St., City-Toms River, County-Ocean, NJ	13,500						13,500											13,500
2 Bloomfield St, Manhattan, NY (Grounservant Pier)	1,500						3,700											3,700
52-35 58th Str, Woodside, NY	1,500						3,700											3,700
1 Orechio Ave. Wanaque NJ	5,000						5,000											5,000

Appendix 2: Amount of time taken to travel from one customer to another

	Depot	Customer 1	Customer 2	Customer 3	Customer 4	Customer 5	Customer 6	Customer 7	Customer 8	Customer 9	Customer 10	Customer 11	Customer 12	Customer 13	Customer 14
Depot	0:00	1:32	1:54	1:45	1:45	1:56	2:08	2:08	1:35	1:57	1:32	1:23	1:41	1:28	0:16
Customer 1	1:37	0:00	0:42	0:36	0:36	0:39	0:54	0:54	0:28	0:38	0:35	2:26	0:35	0:28	1:24
Customer 2	2:17	0:47	0:00	0:28	0:28	0:18	0:23	0:23	0:31	0:28	0:35	3:07	1:08	1:08	2:04
Customer 3	2:06	0:37	0:24	0:00	0:00	0:32	0:39	0:39	0:15	0:33	0:25	2:56	1:02	0:58	1:54
Customer 4	2:06	0:37	0:24	0:00	0:00	0:32	0:39	0:39	0:15	0:33	0:25	2:56	1:02	0:58	1:54
Customer 5	2:11	0:41	0:16	0:32	0:32	0:00	0:27	0:27	0:25	0:19	0:35	3:01	0:48	1:02	1:58
Customer 6	2:26	0:56	0:22	0:40	0:40	0:28	0:00	0:00	0:40	0:34	0:47	3:16	1:02	1:17	2:13
Customer 7	2:26	0:56	0:22	0:40	0:40	0:28	0:00	0:00	0:40	0:34	0:47	3:16	1:02	1:17	2:13
Customer 8	2:04	0:34	0:32	0:16	0:16	0:30	0:46	0:46	0:00	0:31	0:16	2:54	1:00	0:55	1:51
Customer 9	2:07	0:38	0:34	0:36	0:36	0:20	0:47	0:47	0:28	0:00	0:38	2:57	0:38	0:59	1:55
Customer 10	1:32	0:26	0:34	0:25	0:25	0:36	0:48	0:48	0:16	0:37	0:00	2:22	0:59	0:36	1:19
Customer 11	1:24	2:24	2:46	2:37	2:37	2:48	3:01	3:01	2:28	2:49	2:25	0:00	2:33	2:21	1:14
Customer 12	1:42	0:35	1:09	1:03	1:03	1:05	1:21	1:21	0:57	0:38	1:02	2:32	0:00	0:41	1:29
Customer 13	1:29	0:23	1:01	0:50	0:50	1:01	1:15	1:15	0:41	0:57	0:38	2:19	0:43	0:00	1:16
Customer 14	0:17	1:20	1:42	1:32	1:32	1:44	1:56	1:56	1:23	1:44	1:20	1:15	1:29	1:16	0:00

November 5, 2012: Time taken to travel from each customer to another (hours:minutes)

	Depot	Customer 1	Customer 2	Customer 3	Customer 4	Customer 5	Customer 6	Customer 7	Customer 8	Customer 9	Customer 10	Customer 11	Customer 12	Customer 13	Customer 14	Customer 15	Customer 16	Customer 17	Customer 18	Customer 19	Customer 20	Customer 21	Customer 22	Customer 23	Customer 24	Customer 25
Depot	0:00	1:42	0:16	0:16	0:16	1:45	1:45	1:45	1:45	1:45	1:45	1:49	1:47	1:44	1:44	1:50	1:50	1:56	1:56	1:35	1:32	1:21	1:39	1:39	1:39	1:23
Customer 1	1:44	0:00	1:31	1:31	1:31	0:43	0:43	0:43	0:43	0:43	0:43	0:20	0:54	0:22	0:21	0:25	0:25	0:47	0:47	0:36	0:42	2:50	0:08	0:08	0:08	2:34
Customer 2	0:17	1:30	0:00	0:00	0:00	1:32	1:32	1:32	1:32	1:32	1:32	1:36	1:34	1:32	1:31	1:38	1:38	1:44	1:44	1:23	1:20	1:25	1:27	1:27	1:27	1:15
Customer 3	0:17	1:30	0:00	0:00	0:00	1:32	1:32	1:32	1:32	1:32	1:32	1:36	1:34	1:32	1:31	1:38	1:38	1:44	1:44	1:23	1:20	1:25	1:27	1:27	1:27	1:15
Customer 4	0:17	1:30	0:00	0:00	0:00	1:32	1:32	1:32	1:32	1:32	1:32	1:36	1:34	1:32	1:31	1:38	1:38	1:44	1:44	1:23	1:20	1:25	1:27	1:27	1:27	1:15
Customer 5	2:06	0:43	1:54	1:54	1:54	0:00	0:00	0:00	0:00	0:00	0:00	0:43	0:19	0:27	0:28	0:37	0:37	0:32	0:32	0:15	0:25	3:10	0:48	0:48	0:48	2:56
Customer 6	2:06	0:43	1:54	1:54	1:54	0:00	0:00	0:00	0:00	0:00	0:00	0:43	0:19	0:27	0:28	0:37	0:37	0:32	0:32	0:15	0:25	3:10	0:48	0:48	0:48	2:56
Customer 7	2:06	0:43	1:54	1:54	1:54	0:00	0:00	0:00	0:00	0:00	0:00	0:43	0:19	0:27	0:28	0:37	0:37	0:32	0:32	0:15	0:25	3:10	0:48	0:48	0:48	2:56
Customer 8	2:06	0:43	1:54	1:54	1:54	0:00	0:00	0:00	0:00	0:00	0:00	0:43	0:19	0:27	0:28	0:37	0:37	0:32	0:32	0:15	0:25	3:10	0:48	0:48	0:48	2:56
Customer 9	2:06	0:43	1:54	1:54	1:54	0:00	0:00	0:00	0:00	0:00	0:00	0:43	0:19	0:27	0:28	0:37	0:37	0:32	0:32	0:15	0:25	3:10	0:48	0:48	0:48	2:56
Customer 10	2:06	0:43	1:54	1:54	1:54	0:00	0:00	0:00	0:00	0:00	0:00	0:43	0:19	0:27	0:28	0:37	0:37	0:32	0:32	0:15	0:25	3:10	0:48	0:48	0:48	2:56
Customer 11	1:49	0:19	1:36	1:36	1:36	0:43	0:43	0:43	0:43	0:43	0:43	0:00	0:53	0:19	0:21	0:10	0:10	0:46	0:46	0:35	0:48	2:53	0:24	0:24	0:24	2:39
Customer 12	1:49	0:56	2:06	2:06	2:06	0:20	0:20	0:20	0:20	0:20	0:20	0:56	0:00	0:40	0:41	0:50	0:50	0:31	0:31	0:25	0:27	3:23	1:01	1:01	1:01	3:09
Customer 13	1:46	0:22	1:33	1:33	1:33	0:30	0:30	0:30	0:30	0:30	0:30	0:18	0:40	0:00	0:07	0:14	0:14	0:33	0:33	0:22	0:40	2:51	0:27	0:27	0:27	2:35
Customer 14	1:48	0:23	1:35	1:35	1:35	0:29	0:29	0:29	0:29	0:29	0:29	0:25	0:39	0:08	0:00	0:18	0:18	0:33	0:33	0:21	0:37	2:53	0:28	0:28	0:28	2:37
Customer 15	1:48	0:23	1:35	1:35	1:35	0:36	0:36	0:36	0:36	0:36	0:36	0:11	0:47	0:12	0:14	0:00	0:00	0:40	0:40	0:29	0:42	2:52	0:28	0:28	0:28	2:38
Customer 16	1:48	0:23	1:35	1:35	1:35	0:36	0:36	0:36	0:36	0:36	0:36	0:11	0:47	0:12	0:14	0:00	0:00	0:40	0:40	0:29	0:42	2:52	0:28	0:28	0:28	2:38
Customer 17	2:11	0:48	1:58	1:58	1:58	0:32	0:32	0:32	0:32	0:32	0:32	0:44	0:29	0:31	0:33	0:40	0:40	0:00	0:00	0:25	0:35	3:14	0:53	0:53	0:53	3:01
Customer 18	2:11	0:48	1:58	1:58	1:58	0:32	0:32	0:32	0:32	0:32	0:32	0:44	0:29	0:31	0:33	0:40	0:40	0:00	0:00	0:25	0:35	3:14	0:53	0:53	0:53	3:01
Customer 19	2:04	0:41	1:51	1:51	1:51	0:16	0:16	0:16	0:16	0:16	0:16	0:40	0:25	0:24	0:26	0:35	0:35	0:30	0:30	0:00	0:16	3:08	0:46	0:46	0:46	2:54
Customer 20	1:32	0:39	1:19	1:19	1:19	0:25	0:25	0:25	0:25	0:25	0:25	0:43	0:27	0:30	0:32	0:40	0:40	0:36	0:36	0:16	0:00	2:38	0:45	0:45	0:45	2:22
Customer 21	1:22	2:51	1:26	1:26	1:26	2:52	2:52	2:52	2:52	2:52	2:52	2:56	2:54	2:51	2:51	3:02	3:02	3:03	3:03	2:42	2:39	0:00	2:51	2:51	2:51	1:02
Customer 22	1:43	0:08	1:30	1:30	1:30	0:46	0:46	0:46	0:46	0:46	0:46	0:23	0:56	0:24	0:24	0:28	0:28	0:50	0:50	0:39	0:45	2:50	0:00	0:00	0:00	2:33
Customer 23	1:43	0:08	1:30	1:30	1:30	0:46	0:46	0:46	0:46	0:46	0:46	0:23	0:56	0:24	0:24	0:28	0:28	0:50	0:50	0:39	0:45	2:50	0:00	0:00	0:00	2:33
Customer 24	1:43	0:08	1:30	1:30	1:30	0:46	0:46	0:46	0:46	0:46	0:46	0:23	0:56	0:24	0:24	0:28	0:28	0:50	0:50	0:39	0:45	2:50	0:00	0:00	0:00	2:33
Customer 25	1:24	2:34	1:14	1:14	1:14	2:37	2:37	2:37	2:37	2:37	2:37	2:41	2:39	2:37	2:36	2:42	2:42	2:48	2:48	2:28	2:25	1:00	2:32	2:32	2:32	0:00

November 6, 2012: Time taken to travel from each customer to another (hours:minutes)

	Depot	Customer 1	Customer 2	Customer 3	Customer 4	Customer 5	Customer 6	Customer 7	Customer 8	Customer 9	Customer 10	Customer 11	Customer 12	Customer 13
Depot	0:00	2:17	1:45	1:45	1:45	1:56	1:35	1:57	1:23	1:51	1:51	1:48	1:47	1:47
Customer 1	2:37	0:00	0:48	0:48	0:48	0:39	0:51	0:44	3:27	1:01	1:01	0:56	0:40	1:20
Customer 2	2:06	0:48	0:00	0:00	0:00	0:32	0:15	0:33	2:56	0:49	0:49	0:25	0:24	1:11
Customer 3	2:06	0:48	0:00	0:00	0:00	0:32	0:15	0:33	2:56	0:49	0:49	0:25	0:24	1:11
Customer 4	2:06	0:48	0:00	0:00	0:00	0:32	0:15	0:33	2:56	0:49	0:49	0:25	0:24	1:11
Customer 5	2:11	0:39	0:32	0:32	0:32	0:00	0:25	0:19	3:01	0:36	0:36	0:30	0:14	0:55
Customer 6	2:04	0:55	0:16	0:16	0:16	0:30	0:00	0:31	2:54	0:47	0:47	0:23	0:21	1:08
Customer 7	2:07	0:59	0:36	0:36	0:36	0:20	0:28	0:00	2:57	0:26	0:26	0:19	0:23	0:44
Customer 8	1:24	3:09	2:37	2:37	2:37	2:48	2:28	2:49	0:00	2:43	2:43	2:41	2:39	2:38
Customer 9	1:54	1:02	0:49	0:49	0:49	0:53	0:42	0:24	2:44	0:00	0:00	0:26	0:44	0:32
Customer 10	1:54	1:02	0:49	0:49	0:49	0:53	0:42	0:24	2:44	0:00	0:00	0:26	0:44	0:32
Customer 11	1:50	0:55	0:25	0:25	0:25	0:28	0:17	0:22	2:40	0:29	0:29	0:00	0:19	0:50
Customer 12	2:02	0:41	0:23	0:23	0:23	0:14	0:16	0:23	2:52	0:41	0:41	0:21	0:00	1:01
Customer 13	1:48	1:40	1:10	1:10	1:10	1:10	1:04	0:43	2:38	0:33	0:33	0:49	1:00	0:00

November 7, 2012: Time taken to travel from each customer to another (hours:minutes)

	Depot	Customer 1	Customer 2	Customer 3	Customer 4	Customer 5	Customer 6	Customer 7	Customer 8	Customer 9	Customer 10	Customer 11	Customer 12	Customer 13	Customer 14	Customer 15
Depot	0:00	0:16	2:17	1:53	1:45	1:45	1:45	1:45	1:45	1:45	1:56	1:56	1:57	1:21	1:23	1:23
Customer 1	0:17	0:00	2:04	1:41	1:32	1:32	1:32	1:32	1:32	1:32	1:43	1:43	1:44	1:25	1:15	1:15
Customer 2	2:37	2:04	0:00	0:37	0:48	0:48	0:48	0:48	0:48	0:48	1:09	1:09	0:44	3:40	3:27	3:27
Customer 3	2:09	1:56	0:38	0:00	0:30	0:30	0:30	0:30	0:30	0:30	0:40	0:40	0:19	3:12	2:59	2:59
Customer 4	2:06	1:54	0:48	0:30	0:00	0:00	0:00	0:00	0:00	0:00	0:42	0:42	0:33	3:10	2:56	2:56
Customer 5	2:06	1:54	0:48	0:30	0:00	0:00	0:00	0:00	0:00	0:00	0:42	0:42	0:33	3:10	2:56	2:56
Customer 6	2:06	1:54	0:48	0:30	0:00	0:00	0:00	0:00	0:00	0:00	0:42	0:42	0:33	3:10	2:56	2:56
Customer 7	2:06	1:54	0:48	0:30	0:00	0:00	0:00	0:00	0:00	0:00	0:42	0:42	0:33	3:10	2:56	2:56
Customer 8	2:06	1:54	0:48	0:30	0:00	0:00	0:00	0:00	0:00	0:00	0:42	0:42	0:33	3:10	2:56	2:56
Customer 9	2:06	1:54	0:48	0:30	0:00	0:00	0:00	0:00	0:00	0:00	0:42	0:42	0:33	3:10	2:56	2:56
Customer 10	1:51	1:38	1:04	0:41	0:40	0:40	0:40	0:40	0:40	0:40	0:00	0:00	0:26	2:56	2:41	2:41
Customer 11	1:51	1:38	1:04	0:41	0:40	0:40	0:40	0:40	0:40	0:40	0:00	0:00	0:26	2:56	2:41	2:41
Customer 12	2:07	1:55	0:59	0:17	0:36	0:36	0:36	0:36	0:36	0:36	0:28	0:28	0:00	3:11	2:57	2:57
Customer 13	1:22	1:26	3:24	3:00	2:52	2:52	2:52	2:52	2:52	2:52	3:03	3:03	3:04	0:00	1:02	1:02
Customer 14	1:24	1:14	3:09	2:46	2:37	2:37	2:37	2:37	2:37	2:37	2:48	2:48	2:49	1:00	0:00	0:00
Customer 15	1:24	1:14	3:09	2:46	2:37	2:37	2:37	2:37	2:37	2:37	2:48	2:48	2:49	1:00	0:00	0:00

November 8, 2012: Time taken to travel from each customer to another (hours:minutes)

	Depot	Customer 1	Customer 2	Customer 3	Customer 4	Customer 5	Customer 6	Customer 7	Customer 8	Customer 9	Customer 10	Customer 11	Customer 12	Customer 13	Customer 14	Customer 15
Depot	0:00	2:17	1:53	1:45	1:45	1:45	1:45	1:45	1:45	1:45	1:45	1:56	1:56	1:56	1:57	1:32
Customer 1	2:37	0:00	0:37	0:48	0:48	0:48	0:48	0:48	0:48	0:48	0:48	1:09	1:09	0:39	0:44	0:55
Customer 2	2:09	0:38	0:00	0:30	0:30	0:30	0:30	0:30	0:30	0:30	0:30	0:40	0:40	0:05	0:19	0:33
Customer 3	2:06	0:48	0:30	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:42	0:42	0:32	0:33	0:25
Customer 4	2:06	0:48	0:30	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:42	0:42	0:32	0:33	0:25
Customer 5	2:06	0:48	0:30	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:42	0:42	0:32	0:33	0:25
Customer 6	2:06	0:48	0:30	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:42	0:42	0:32	0:33	0:25
Customer 7	2:06	0:48	0:30	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:42	0:42	0:32	0:33	0:25
Customer 8	2:06	0:48	0:30	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:42	0:42	0:32	0:33	0:25
Customer 9	2:06	0:48	0:30	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:42	0:42	0:32	0:33	0:25
Customer 10	2:06	0:48	0:30	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:42	0:42	0:32	0:33	0:25
Customer 11	1:51	1:04	0:41	0:40	0:40	0:40	0:40	0:40	0:40	0:40	0:40	0:00	0:00	0:44	0:26	0:45
Customer 12	1:51	1:04	0:41	0:40	0:40	0:40	0:40	0:40	0:40	0:40	0:40	0:00	0:00	0:44	0:26	0:45
Customer 13	2:11	0:39	0:05	0:32	0:32	0:32	0:32	0:32	0:32	0:32	0:32	0:43	0:43	0:00	0:19	0:35
Customer 14	2:07	0:59	0:17	0:36	0:36	0:36	0:36	0:36	0:36	0:36	0:36	0:28	0:28	0:20	0:00	0:38
Customer 15	1:32	0:57	0:33	0:25	0:25	0:25	0:25	0:25	0:25	0:25	0:25	0:45	0:45	0:36	0:37	0:00

November 9, 2012: Time taken to travel from each customer to another (hours:minutes)

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