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A Stochastic Capacitated Facility Location Model For Pre-Positioning Port Commodities During A Disaster

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A STOCHASTIC CAPACITATED FACILITY LOCATION MODEL FOR PRE-POSITIONING PORT COMMODITIES DURING A DISASTER

by

Jessye Leigh Bemley

A thesis submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE

Department: Industrial & Systems Engineering
Major: Industrial & Systems Engineering
Major Professor: Dr. Lauren Davis

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School of Graduate Studies
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has met the thesis requirements of
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BIOGRAPHICAL SKETCH

Jessye Leigh Bemley was born June 12, 1986, in Washington, DC. She received her Bachelor of Science degree in 2008 from North Carolina A&T State University in Industrial Engineering. On campus she participated in North Carolina A&T State University Gospel Choir, National Society of Black Engineers (NSBE) and Institute of Industrial Engineers (IIE). She has presented papers at numerous national and international engineering, scientific and computing conferences, symposia and meetings. She is a Master of Science candidate for Industrial & Systems Engineering.

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To God, my family, advisor and all the many people who have helped me through this process-without you this would not be possible.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Bemley, Jessye Leigh. A STOCHASTIC CAPACITATED FACILITY LOCATION MODEL FOR PRE-POSITIONING PORT COMMODITIES DURING A DISASTER. **(Major Advisor: Dr. Lauren Davis)**, North Carolina Agricultural and Technical State University.

As the intensity of natural disasters increases, there is a need to develop policies and procedures to assist various humanitarian relief groups, industry or government agencies with moving aid to affected areas. One of the biggest hindrances to this process is damage to transportation networks, in particular, waterways. To keep waterways safe, aids to navigation (ATONs) are placed in various areas to guide mariners and ships to their final destinations. If the ATONs are damaged, then the waterways are left unsafe and it is difficult to move supplies to repair them and recover from a disaster. A stochastic facility location model is presented to understand the advantage of prepositioning repair supplies in order to maximize the repair of ATONs. The first stage decisions focus on location determination of resources that are prepositioned. The second stage decisions consist of the distribution of supplies and teams to affected areas. The results will show the benefits of a prepositioning policy toward the responsiveness of restoring waterway.

CHAPTER 1

INTRODUCTION

1.1 Background

Ports and waterways are a vital part of the inter-modal transportation network and
allow for the movement of goods and people around the world. A port consists of
terminals, cranes, containers, and storage facilities. In addition, the ports are designed in a
manner to allow entrances for trucks and trains to carry commodities to their final
destination. Currently, the United States has 360 ports that are either publicly or privately
owned and operated. The public ports are operated and owned specifically by port
authorities. An example of this is the Port of Houston. The Port of Houston Authority
serves as a landlord by allowing different private companies to rent space at the port.
Each port has distinct terminals dedicated to a diverse group of cargo. Ports account for
95% of the country's shipped commercial cargo. According to the Association of
American Port Authorities (AAPA), ports enable waterborne commerce that injects about
$3.1 trillion into local, regional, and national economies and handles about 2 billion tons
of import and exports annually. Since ports and waterways are open to damage, major
disasters can leave these areas vulnerable to disruptions.

1.2 Impact of Disruption

Disruptions caused at ports can cause major economic impact which can be detrimental to certain industries, such as oil industries. Disruption can also occur due to natural or manmade disasters. For example, the 2002 west coast (Los Angeles/Long Beach) port shutdown due to labor disputes caused the U. S. Economy to lose approximately 6.3 to 19.4 billion dollars (Park, 2008). During Hurricane Katrina, ports on the Gulf Coast were shutdown causing oil prices to increase as a result of oil rigs having to close (Haveman, 2006).

The recovery process due to disruption can be lengthened if materials needed to rebuild are not readily available. For instance Hurricane Katrina was one of the most catastrophic natural disasters to hit the United States. As a result, Port Fourchon was the only petroleum handling facility that was 90% operational a year after the storm. The other two terminals in the area were still damaged which caused an influx of traffic at Port Fourchon (Ellis, 2005). Hurricane Ike caused 14 refineries in Texas to be shutdown which caused a major disruption in the energy supplies nationwide. Some energy officials even expected a possible rise in gasoline prices (Nichols, 2008). In the case of the recent Haiti Earthquake tragedy, the damage of the docks located at the port caused humanitarian aid not to be delivered to the affected victims (BBC, 2010).

Additionally, due to the geographical location of ports, there is a high chance that a terrorist can create a disruption. The Congressional Research Service (CRS) Report for Congress (2005) on terrorist attacks estimates that if a 10 to 20 kiliton weapon of mass destruction was to be detonated at a port it would result in killing 500,000 to 1,000,000

people and disrupt trade by $100 to $200 billion. These examples, illustrate the impact of disruptions caused by natural and manmade disasters and also demonstrates the need for guidelines that will help with preparation and recovery from disasters.

1.3 Motivation

During the recovery process there are many logistical issues such as: coordination among agencies, a lack of resources needed for damaged areas, when to pre-position relief commodities and determining locations to pre-position. Some examples of these issues can be seen in Hurricane Katrina, Hurricane Ike and the earthquake in Haiti. The CEO of the Port of New Orleans commented that one-third of the port infrastructure was damaged due to Hurricane Katrina. During that time period, no trade or vessels were coming in and out of the port (Ellis, 2005). After Hurricane Ike passed by Texas, various areas around Port Arthur were used as points of distribution to provide supplies to residents (VanderVelde, 2008)

For the case of the recent Haiti Earthquake tragedy, piers and equipment such as cranes were damaged at the port and ships were unable to be loaded (CNN, 2010).The port also had an airport, but there was not enough space or fuel for plane traffic from organizations to drop off humanitarian aid to those in need. In order to fix the damage at the port, the Prime Minister of Haiti asked other countries to bring salvage equipment such as cranes, tugs, barges and dredges (CNN, 2010). Due to the damage of the port, it was difficult for planes carrying aid to land. Many streets leading into the city were

impassable, making it difficult for humanitarian organizations to reach people that needed help.

Bharoas et. al (2009) discusses the various obstacles and challenges with information sharing among multiple agencies at the Port of Rotterdam in the Netherlands. Their study showed that relief workers want to receive rather than give out information that would be beneficial to other agencies or groups. These examples demonstrate the importance of the level of coordination, amount of resources and suppliers that are necessary to ensure a responsive recovery from a disaster. This reveals the need for developing a policy that will inform decision makers on when to pre-position resources and how to coordinate their efforts.

As large scale natural and manmade disasters increase in intensity there is a greater need for emergency preparedness and response tools, not just for responding to needs of the affected population, but other entities as well. From these disasters (e.g. Hurricane Katrina, 9/11) we have seen many people and locations going without basic necessities for long periods of time due to logistical issues among recovery agencies. Current research in humanitarian logistics/relief has focused on issues such as container security, emergency preparedness and response in regards to location of emergency services, evacuation from damaged areas and response after a disaster occurs (Johnstone et.al, 2004; Jia et.al., 2005; Chapman 2007; Kapucu et.al., 2007). However, there is a limited amount of research dealing with security, emergency preparedness and response in relation to ports (Green & Kolesar, 2004; Larson , 2004).

Currently some ports (e.g. Houston, NewYork/New Jersey, Louisiana, Alabama, Florida) have hurricane preparedness plans that are updated as needed. However, there is a lack of preparedness plans at ports specifically designed for other natural disasters. As a result of 9/11, ports have incorporated different security measures to adhere to Homeland Security maritime security initiatives such as the Transportation Worker Identification Card (TWIC), Container Security Initiative (CSI), and the Customs Trade Partnership Against Terrorism (C-TPAT). Most of the preparedness plans only consider basic preparation and recovery activities, in which very little pre-positioning are done.

Pre-positioning is not a novel concept, but has been used by the military on several occasions to expedite the response time for allocating resources for war (Johnstone et. al, 2004). However, many organizations and agencies have opted to use this technique (Duran et. al 2008). Rawls & Turnquist (2006) developed a stochastic model to determine locations for emergency supplies and allocation of those supplies needed. This model does not take into account the commodities or characteristics of a port that would be helpful in pre-positioning. Chapman (2007) proposes a model that determines the best cost strategy for pre-positioning supplies that are in a high risk path for a particular event. Although, Chapman comes up with a pre-positioning policy he does not consider time which is critical in response nor does the research address the unique challenges of pre-positioning resources for port recovery.

1.3.1 Pre-positioning Aids to Navigations

For this research we will focus on pre-positioning commodities in facilities that house equipment that is used to repair Aids to Navigation if a natural disaster were to occur. Aids to Navigation (ATONs) are considered the equivalent to a light used on roadways to control the flow of traffic and help the waterways to remain navigable. There are different types of ATONs such as lighted/ unlighted buoys, beacons, lights and lighthouses. The United States Coast Guard (USCG) is the primary organization in charge of ATONs along with the National Oceanic and Atmospheric Association (NOAA) and United States Army Corps of Engineers (USACOE).

The USCG responsibilities include: developing, administering and operating ATONs to serve maritime commerce, controlling private aids that are under the jurisdiction of the United States/continental shelf and on the high seas, and to mark wrecks to warn mariners of obstructions (United States Coast Guard, 2005). If ATONs are damaged or move from their original position, then ATONs teams are sent out to survey the aids and make repairs. All other federal agencies are responsible for maintenance, repairs and identity of their own aids unless under Coast Guard jurisdiction (United States Coast Guard, 2005).

According to the USCG, after Hurricane Katrina approximately 63% of aids in New Orleans, LA and 87% of aids in Mobile, AL were in the storm affected area on position, but their sound and light signals were working at low frequency (Guard, 2005). To obtain the equipment to fix the ATONs the Coast Guard consults with their personal Engineering and Logistics Center, other companies that sell products that are outfitted on

the aid (e.g. horn, bell reflectors, batteries) and the U.S. General Services Administration (GSA). The lack of pre-positioning models dedicated to ports and port commodities (i.e. ATONs) gives motivation for developing new policies in this area.

1.4 Research Scope

The purpose of this research is to identify a framework that can help with understanding the impact of a port disruption and the effectiveness of pre-positioning emergency commodities (e.g. GPS, Aids to Navigation Teams, buoy tenders, flashers, reflective tape, steel and plastic buoys) to provide rapid response for port recovery actions. The port preparation and recovery activities are modeled as a stochastic programming problem, where the first stage decisions will be based on known information about the disaster to help with pre-positioning. The second stage decisions will be based on responding to the damage after the disaster has occurred. Data based on supply and demand of commodities will be used to run the model.

The following model assumes that decision makers rely on historical data and experience to help with planning for emergency items needed during hurricane season. If inventory is unavailable, it is ordered and stored until needed after an event has occurred. Some supplies and commodities need to be pre-positioned ahead of the storm such as GPS, Aids to Navigation Teams, buoy tenders, flashers, reflective tape, steel and plastic buoys. The USCG polls the barge industry to receive these supplies and services in time to send them to a safe location. A safe location is considered any distance away that will not result in damage to the commodities. If a safe location is damaged, then the

commodities have to come from another port or terminal. The usage of safe locations will be determined, based on the probability that the hurricane will strike.

Since the magnitude of disasters changes over time there is always some level of uncertainty in coordination, quantity/ type of resources and availability of suppliers. The scope of this project will address three questions:

(1) How will pre-positioning affect the responsiveness of the port during the recovery phase?

(2) What are the optimal stocking quantities and location of resources given the uncertainty associated with a disaster (e.g hurricane, terrorist attack etc.)?

(3) What is the benefit of private, non-profits and government agencies working together to provide support?

1.5 Thesis Overview

The remainder of this thesis is outlined as follows. The second chapter gives an overview of previous research on pre-positioning. The third chapter discusses the agency coordination in port environment. The fourth chapter explains the problem statement, model formulation and approach. The fifth chapter gives a numerical example of the preliminary model. The sixth chapter provides the experimental design created to answer the research questions posed. The seventh chapter provides results and data analysis of this research. The eighth chapter gives the conclusion and further directions for research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter consists of two sections. The first provides an overview of modeling that has been done in relation to ports, aids to navigation and pre-positioning. The differences between prior and proposed research are also addressed. The second section describes examples of various prepositioning models using realistic scenarios. The models are described in terms of specific input and output parameters, as well as objectives.

2.2 Overview of Port Modeling

Wright (2006) provides a literature review of various operations research models developed to address emergency preparedness and response, threat analysis, critical infrastructure protection and border/transportation security. The models are classified according to the Department of Homeland Security (DHS) research framework. DHS represents different government agencies that are responsible for securing the homeland. It contains five directorates: border and transportation security, emergency preparedness and response, science and technology, information and analysis and infrastructure protection, and management. Research performed at DHS can be found under the science and technology directorate. They focus on three main areas: countermeasures portfolios,

component-support portfolio, and cross-cutting portfolios. Under this framework there is very little research on port prepositioning. There has been some research on container security and inter-modal transportation (Lewis, 2003; Ozdamar, 2004).

2.3 Overview of Pre-positioning

Pre-positioning is defined by the Department of Air Force as "the stockpiling of equipment and supplies at, or near the point of planned use. It began with the military in which different weapons and ships needed to be moved for war (Johnstone et. al, 2004). As more large scale natural disasters arise many agencies and organizations have adopted this method to create better humanitarian relief efforts. For example, the Care International organization is one of the largest relief organizations that disperse supplies and resources to countries in need. They considered the effects of pre-positioning in regards to response time and determined the optimal configuration of the demand network to increase the response time of getting items to an affected area (Duran et. al, 2008).

Although pre-positioning is accepted, there have been instances where it has not been very favorable. Balick & Beamon (2008) state that pre-positioning can be costly and only a few organizations can support having distribution centers to store and distribute relief commodities (e.g. World Food Programme, World Vision International and United Nations Humanitarian Response Depot).

In order to determine the best pre-positioning approach the location and quantity of commodities must be considered. Depending on the length of time or type of

commodities being stockpiled, organizations or agencies should weigh usability and potential danger of locations based on the damage that can occur if a disaster strikes. Various models are presented to show the diversity of pre-positioning models and will be described under the following categories:

1. Location Selection

    - Humanitarian Relief

    - Military

2. Location and Commodity Quantity Selection

    - Humanitarian Relief

    - Military

2.4 Pre-positioning at Ports

Many ports have hurricane preparedness plans set in place ahead of a storm. The plan provides the preparation activities in 12 hour increments (i.e. 12 hrs., 24hrs., 36hrs., 72hrs.) until it shuts down completely. One of the main discrepancies post storm is the safety and navigability of waterways. ATONs are known for aiding in safety for boats, vessels and mariners on the waterways. If a disaster or emergency damages the aids to navigation then a team is sent out to fix them or the ATONs are sent to a facility where it can be refurbished.

The USCG currently has nine facilities dedicated to the repair of aids to navigation which are all located near a port. Most of the supplies needed to repair the aids are not sent out until after the hurricane occurs. The aids to navigation teams prioritize

the damage to the aids by the discrepancy response factor score. This score is a number given to an ATON to show the criticality of damage and determines the level of correction. The higher the score the more critical the damage is to the ATON and the higher the level of correction. Many states within a Coast Guard district only have one team. Depending on the amount of damages, it could take long periods of time to repair. This example shows one reason that pre-positioning is needed at ports to help keep the waterways safe.

2.5 Pre-positioning Models

2.5.1 Location Selection

2.5.1.1 Humanitarian Relief

Synder (2006) gives an overview of the various facility location models that deal with location selection with some level of uncertainty. They classify the models by the particular approach to solve for uncertainty and the type of facility location problem. They do not focus on models that involve congested facilities such as (e.g emergency services). Although there are many facility locations problems, they do not address large-scale emergencies.

Jia et. al (2005) refer to large-scale emergencies as "rare events that overwhelm local emergency responders and require regional and/or national assistance such as natural disasters." Most of the local responders only have enough capacity to handle small scale emergencies or frequent incidents. Since large-scale emergencies can also be classified as low frequency with high impact, this requires some changes in the facility

coverage. For example, having redundant facility medical stocks (e.g. protective equipment and antidotes) and determining how to position local staging centers. These staging centers should be able to receive, repackage and distribute medical supplies from a strategic national stockpile for a major natural disaster or a bioterrorist attack. The general goal of the model is to decide on the number and location of facilities.

Klose and Drexl (2004) also provide a literature review in which they give a list of criteria to classify traditional facility location models. Based on these criteria, three classifications of facility location models are discussed for emergency services. These models include: covering model, P-median model and P-center model. The covering model for emergency services is to provide coverage to demand points. A demand point is considered covered if serviced by a facility within a specified distance. There are two types of covering models: location set covering model and maximal covering location problem. A location set covering model tries to locate the least amount of facilities that are required to cover all demand points. The maximal covering location problem looks for maximal coverage with a given number of facilities. The stochastic covering models also incorporate scenario planning to represent parameters over a certain time period.

The P-median model determines the location of P facilities to minimize the average distance between demands and facilities. When the total distance decreases, it increases the effectiveness and accessibility of the facilities. The P-center model seeks to minimize the worst case performance of the system and address certain situations where unfair service is more important than the average system performance. It also minimizes the maximum distance between any demand point and the closest facility.

The model proposed in Jia et. al (2005) takes into account all the characteristics mentioned for a large-scale emergency. There are a set of demand points and possible facility locations. From these sets, there are three decisions that are made: whether to place a facility at a particular location, whether a facility services a demand point and whether demand is covered. The demand for this model is uncertain and dependent on the emergency scenario, impact of the emergency, and how likely the emergency will affect a demand point. The authors created two likelihood parameters one represents the likelihood that a certain emergency situation affects a demand point, the other is the impact that the emergency situation has on the population of a demand point and the last one captures the geographical effect of emergency situation in regards to the location of the event. Characteristics of the likelihood parameters are as follows: there can be more than one emergency occurring simultaneously; they do not sum to one over all demand points; and there can be multiple demand points simultaneously affected by an emergency. The decision variables are configured to optimize a function that represents the efficiency in covering the uncertain demand.

Three input parameters are considered: (1) the minimum number of facilities that must be assigned to a demand point so that it is consider covered, (2) the reduction in service capability of a facility under an emergency scenario and (3) the maximal number of facilities that can be placed in a set location. The model is formulated to locate facilities to address an emergency scenario, this requires that facilities service demand points with the same level of quality. The input parameters that are considered consist of the minimum number of facilities to be assigned to a demand point, the reduction in

service capability of a facility under a particular emergency scenario, and the maximum number of facilities that can be placed in a certain location. The general objective function can either maximize or minimize the amount of facilities needed to address a certain demand area.

Ukkursuri & Yushimito (2008) propose a model to assist planners during the preparedness stage while designing logistics efforts for humanitarian relief that mitigates and reduces the risk of disruption within a humanitarian relief network. The focus of this research is pre-positioning supplies for post-disaster relief. The model is developed using the location routing problem which took into consideration the selection of locations for pre-positioning humanitarian supplies based on the reliability of the ground transportation network. The probability of a route failing is independent but the proposed research accounts for all disruptions in a transportation network. All affected zones must be satisfied by a chosen pre-positioned location and an integer programming model chooses the pre-positioning facilities after evaluating the most reliable path in the network.

2.5.1.2 Military

Johnstone et. al(2004) developed a model to be used for pre-positioning using the Agile Combat System (ACS) with the addition of the afloat pre-positioning fleet (APF). Since the United States Air Force (USAF) cannot pre-position every commodity that is needed, they use a starter stock and swing stock. A starter stock is munitions that are loaded onto aircraft before a conflict begins. The swing stock uses the APF, the standard air munitions package (STAMP) and standard tank, racks, adapters, and pylons packages (STRAPP). These packages are put onto pallets and stored at a safe location until needed

for deployment. The munitions inventory is very diverse from bombs to precision-guided weapons. The munitions levels are based on targets from the Joint Chiefs of Staff. Once these targets are met then they are moved into a storage location.

Using this method allows the USAF to keep the proper levels of stock in order to be operational at the appointed time. This model is a mixed integer program of munitions flow named Pre-Po. The USAF makes the following assumptions for their model: the APF stocks level of munitions and where they are moved to unload cargo; the ships depth requirements and the net explosive weight restriction (NEW) for each port that is visited. The net explosive weight is the actual weight of various explosives used to determine limits and quantities of explosives. They model the offload times based on ships and port configurations; the munitions are transported to the airbases based on the available transportation method; last they model the STAMP, STRAPP and theater hub munitions inventory which support the APF and try to reduce the unmet demand at an airbase. A theater is a large geographical area in which military operations are coordinated.

Brown et. al. (2005) presents a method for pre-positioning a defensive interceptor platform which is a platform, with anti-missile and other systems. This system is used by the United States to combat enemies using theater ballistic missiles (biological, high explosive, chemical or nuclear warheads) that can go over long distances. They used a bi-level optimization to solve the problem. Bi-level optimization refers to two entities, each have information regarding each other's plans but want to counter the attacks that will be made against them. The model first considers the enemies course of action and maximizes the expected damage that is known by the defensive strategy of the enemy.

Next, the model minimizes the maximum pre-positioning of the various defensive platforms that intercept these strategies. The results from this model aid the Joint Task Force's air defense commander in better defense planning and assessments.

Ghanmi & Shaw (2008) create a Monte Carlo simulation framework to model the various strategic lift and pre-positioning options under consideration by the Canadian forces. To understand comparisons between the different options, they used a common set of parameters within the simulation for a three year period. These parameters focused on deployment locations, frequency of flights and flying times for aircraft which were given stochastically. They also consider two different force packages: the first package is related to the taskforce which was based on a light battle group and the second package is related to the Disaster Assistance Response Team (DART).

For the strategic lift simulation, the focus is on the movement of equipment and supplies. Historical data is used from the Canadian Forces past operations, deployment locations, failing states and their airports/seaports. The pre-positioning option was developed as a subset of historical data of an operation conducted by the Canadian Forces. The different supplies are moved by different modes of transportation (e.g. air, sealift or combination) to a particular theater or area where supplies are needed. The performance of a pre-positioning option depends on the location and manifest (list of materials) that has been pre-positioned.

2.5.2 Location and Commodity Quantity Selection

2.5.2.1 Humanitarian Relief

Rawls and Turnquist (2009) model a pre-positioning policy for emergency supply needed during a recovery effort. For this model, they use the Gulf Coast states to create their network. A set of damage scenarios are developed from past data on eight historical hurricanes that passed through this area. Each scenario is given a probability of occurrence. They focus on only three different supplies: water, food and medical kits. Their demands are based on the number of people sheltered in various locations for the historical storms. Based on this data, a table is constructed that shows the amount of each supply that is required in each city for each of the eight storms.

Damage to a transportation network can be shown by reductions in capacity on links or complete loss of capacity. Depending on where the storm hits, the supplies pre-positioned at a node can be partially or completely damaged. From these components, it is possible to determine where storage facilities are located, the capacity, and the amount of the commodity that should be stored. The formulation is developed using a multi-source, multi-sink flow network. The model determines the maximum flow across all the network of sources and sinks. The source represents the starting point of the entity and the sink represents the ending point of the entity. For this particular research, a network is created with a set of nodes with arc capacities and a set of maximum capacities. The set of maximum capacities can vary based on the type of scenario. Each node is assigned a set cost per unit, fixed unit cost and unit resource purchase cost. Each scenario shows the variability in forecasted demand at nodes in the network for specific commodities and arc

capacities. The authors represent the loss of different commodities at a node by dividing it into twin nodes known as the excess supply (sink) and unmet demand (source). The links to the twin nodes have an infinite capacity and a link cost of zero. This occurs when a supply facility is destroyed due to a natural disaster causing commodities to be damaged.

The objective function minimizes the expected costs over all possible scenarios based on supplier locations, resource purchase and allocations to the supply facilities and the shipments of the supplies to the demand points, including the flow in the arcs that represent unmet demand and excess supplies. The first stage variables represent the location and capacity of the supply facilities and the resource quantity of each commodity to be allocated at each facility. This stage is not scenario dependent. The second stage variables consider the flow of commodities, arc capacities and costs that are constrained by the first stage decisions. Rawls and Turnquist noticed that there was a combination of structural elements used within the two-stage stochastic model that allowed the model to be solved using a specialized procedure. The benefit of this method is its ability to decompose the overall problem into smaller sub-problems that can be solved more easily.

Chapman (2007) develops a model that shows the benefits of pre-positioning different local commodities that are in a high-risk area. For this research, supply locations and capacities are known and contain some initial inventory to satisfy demand during normal operations. After a hurricane makes landfall, the initial inventory is used in the response phase to satisfy demand in the affected population. This demand level is unlike

the demand seen during regular operations. Sometimes when an event strikes, there is a possibility that the stored initial supply will be damaged.

The goal of this model is to minimize the amount of supply that would be lost. This model is a single commodity, supply chain network that is modeled using a stochastic linear programming and network flow framework. The objective function minimizes the total cost of pre-positioning supplies, redistribution, distribution, transportation, supply loss, and shortage cost. This ensures that the minimal amount of supplies move from initial supply facilities to safer locations and that supplies; are efficiently redistributed to minimize unmet demand. First stage decisions consist of pre-positioning existing supplies to minimize the supply loss. Second stage decisions maximize the responsiveness of the system by allocating supplies to satisfy demand.

Duran et. al (2008) develop a model to study the effects of pre-positioning. Care International has a specific approach it uses to respond to disasters. First, they identify suppliers, conduct a procurement process, identify potential warehouse sites and they outsource their transportation. Two of the biggest challenges that Care International has when responding to a disaster is a lack of transportation and a low level of preparedness due to funding. To receive supplies, they consider local and international suppliers. However, they prefer local supplies because they have fast delivery and culturally acceptable products. Issues with procuring locally are the uncertainty in product quality, availability, and production capacity. Also, the prices may be inflated due to scarcity of a certain item. They explore the idea of using pre-positioning to improve their emergency

response time. This strategy would allow them to store items in warehouses set up in strategic locations around the world to be deployed after the disaster.

The United Nations Humanitarian Response Depot has started to lease warehouse storage space to different international humanitarian organizations. Therefore, the pre-positioning network became feasible to try. They use a mixed integer programming inventory location model that considers a set of typical demand instances given a specified upfront investment. The model finds the configuration of the supply network that minimizes the average response time over all demand instances. They obtain demand from historical data of different natural disasters. The supply network consists of the number and location of warehouses and the quantity and type of items held in inventory in each warehouse. The objective of the model is to minimize the average of the weighted response time over 233 demand instances.

Balick & Beamon (2008) consider a distribution system where a relief organization locates a distribution center to satisfy the immediate needs of those affected by a disaster. Within the disaster area there would be uncertainties such as resources and damage. They address the issue of determining the quantity and location of the distribution centers and the amount of inventory to stock in order to maximize the relief provided to affected people. They use a facility location and stock pre-positioning model to address the problem. The objective of this model is to maximize the total expected demand covered by the chosen distribution centers. The inventory associated with the chosen distribution center cannot be smaller than the maximum amount of demand that

the distribution center would encounter from a single disaster. The amount of inventory must not exceed capacity.

In addition, pre-disaster expenses that are related to a chosen distribution center and holding inventory must not exceed the pre-disaster budget. The results shows that transportation costs incurred between distribution centers and each disaster scenario are less than the expected post-disaster budget. The amount of supplies sent to satisfy the demand of a disaster scenario does not exceed the actual demand. A non-negativity constraint is set to proportion the demand satisfied.

Salmeron and Apte (2010) develop an enhanced pre-positioning model created by Tean (2006) to position relief assets to specified relief locations in order to supply affected areas. The affected areas are categorized into three major populations: critical, stay-back and transfer. It is assumed that if the critical population is not evacuated, their health will deteriorate. In addition, a percentage of the stay back population will not receive any supplies and eventually perish. For this research a multi-objective, two staged stochastic mixed integer optimization program is used.

The objective of this model is to minimize the number of casualties from the critical and stay back population. The second objective is to minimize the expected transfer population to temporary relief locations. The first stage decisions are to determine the location and capacity of relief assets. The second stage decisions are the consequences due to the knowledge received after the disaster has occurred. Included in this decision is the means of transportation used to evacuate the critical and transfer

population to the various relief locations and delivering different commodities to the stay back population.

2.5.2.2 Military

Ee Shen (2006) modeled a pre-positioning policy that takes into consideration logistics and budget constraints. To test this model two different cases are used (earthquake and hurricane). First they develop a deterministic model that considers fundamental data such as: affected areas(AA)/ relief locations (RL), potential survivors in AAs, commodities needed in each AA, workers required to handle commodities in each AA, available help personnel and warehouse at each RL, available ramp space at each AA, available transportation means with associated capacity for survivors, commodities and relief workers, time to travel between the AAs/RLs and available operating hours and operation range and allocated budget for pre-positioning of additional health personnel. This data is used in the stochastic model.

The objective function maximizes the total expected number of rescued survivors by all transportation means from all AAs but, a penalty is applied if, unmet commodities at an AA occurs. The first stage decisions: expansion of warehouses, medical facilities and their health care personnel and ramp space to facilitate the supply of commodities by aircraft to the AAs. The second stage: logistics problem represented as a network, maximize the expected rescued survivors and delivery of required commodities. This is accomplished by various transportation means and relief workers. An unmet commodity penalty is built in the objective function to penalize the total number of rescued survivors.

2.6 Research Contribution

Table 1 summarizes the relevant parameters of prior research. Previous research has one common goal either to minimize cost, minimize response time, maximize covering demand, minimize damage, and maximize life. The research objective across all the articles focuses on evaluating pre-positioning policies. Each model has either a single or multiple commodities that should be pre-positioned. The basic context of the models, are humanitarian relief and military. The first set of papers focuses on pre-positioning models dedicated to location selection. The second set of papers, refer to pre-positioning models that focus on location and quantity selection. Some of the approaches used were stochastic linear programming, simulation, mixed-integer programming facility location models. The research proposed in this paper considers information from a weather related disaster and port preparation activities to help decision makers determine a pre-positioning policy. The contribution to the literature is developing a pre-positioning policy that uses multiple commodities for repairing aids to navigation to help provide reduced response time to port recovery tasks based on a natural disaster striking the area of a port. Throughout major disasters, various organizations come together to help with recovery. However, as seen with Hurricane Katrina, the level of coordination needed among agencies to respond to these situations has been low. This problem would not be classified as humanitarian relief but as business continuity. Business continuity planning considers disaster recovery, contingency planning and crisis management. This plan outlines the best way to recover from disruptions that can cause problems to critical

functions needed in order to provide continued services for compensation. These key

elements are not shown in prior literature.

Table 1. Location selection humanitarian relief

Location Selection	Objective Function	Model	Commodities	Level of Uncertainty
Humanitarian Relief				
Jia et. al (2005)	Minimize distance; Maximize covering demand	Facility Location	Facilities, equipment and drugs needed for different diseases	Facility location
Synder (2006)		Facility Location		Facility Location
Ukkurusi & Yushimito (2008)	Minimize the maximum reliability of reach a demand point	Location Routing	Facilities and inventory	Location

Table 2. Location/ quantity selection humanitarian relief

Location/Quantity Selection	Objective function	Model	Commodities	Level of Uncertainty
Humanitarian Relief				
Rawls and Turnquist (2006)	Minimize Cost	Two-Staged Stochastic Mixed Integer	Water, food and medical kits	Demand, damage to facilities and roads
Chapman (2007)	Minimize Cost	Stochastic Linear Programming/ Network Flow Model	Supplies	Demand and available supply
Duran et. Al	Minimize Response Time	Mixed Integer Inventory Location Model	Food, water, shelter and sanitation	Location, inventory
Balick & Beamon (2008)	Maximize the benefit to affected people	Maximal Location Covering Model	Food, water, medicine and shelter	Number and location of distribution centers
Salmeron & Apte (2010)	Minimize the number of casualties and expected transfer population	Two-Staged Stochastic Mixed Integer Optimization Model	Relief units and assets	Location and capacity of relief assets, number of casualties

Table 3. Location selection military

Location Selection	Objective Function	Model	Commodities	Level of Uncertainty
Military				
Johnstone et. al (2006)	Minimize Response time	Mixed Integer Program	Munitions	
Brown et. al (2005)	Minimize maximum total expected damage to targets	Bi-level Optimization	Ballistic missile defense platforms	Secrecy and deception from attacker and defender
Ghanmi &Shaw (2008)	Minimize movement costs and closure time	Monte Carlo Simulation/ Optimization Model	Equipment, personnel and packages	

Table 4. Location/ quantity selection military

Location/ Quantity Selection	Objective Function	Model	Commodities	Level of Uncertainty
Miltary				
Ee Shen (2006)	Maximize expected number of survivors	Two-Staged Stochastic Optimization Model	Relief units and assets	Commodity demand and potential survivors

CHAPTER 3

AGENCY COORDINATION

Ports and related organizations have created procedures and guidelines to help with the preparation and recovery process after terrorist attacks and hurricanes. They begin by preparing the port to terminate operations until safe to resume. Immediately after the disaster has ended the various assessment teams are deployed to capture data of damage in waterways and at the port. Many agencies and teams play a major role in the recovery process such as the United States Army Corps of Engineers (USACOE), United States Coast Guard (USCG), assessment teams, barge industry, and the logistics support center. The following, descriptions of these agencies and their role in the recovery process is unique to the ports located in the Gulf Coast. Figure 1 displays the different response organizations in the gulf coast and their coordination activities.
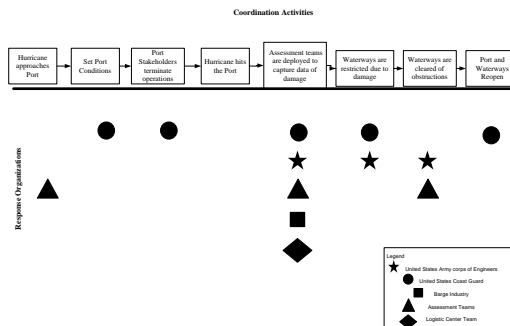
Figure 1. Coordination among response organizations

3.1 Federal Agencies

3.1.1 United States Coast Guard (USCG)

The USCG was created to provide safety to the nation's maritime interest (e.g ports, sea). They are also responsible for protecting the maritime economy and environment, defending maritime borders and saving vessels, people or facilities that have been impacted by hurricanes, floods, or earthquakes (Guard, 2010). During the event of a hurricane, they coordinate communication of four port conditions (e.g. Whiskey, X-Ray, Yankee, Zulu) to port stakeholders. The purpose of port conditions is to inform stakeholders on what preparation activities need to be carried out to shutdown the port before the storm strikes land. In addition, they make judgments on when to open and close waterways. Prior to the strike of a storm, they discuss waterway closures with port stakeholders (e.g. port coordination team, vessel owners). Upon completion of the storm, they request participation from the air transportation industry and other agencies (e.g. NOAA, Navy) to collect data of waterway obstructions and provide additional planes to perform over-flight assessments. This information assists in creating deployment plans to conduct more detailed surveys. After finalizing the status of waterway closures they communicate this information to the USACOE (Team 2009).

3.1.2 United States Army Corps of Engineers (USACOE)

The mission of the USACOE is to provide engineering services during peace and war to strengthen the nation's security, stimulate the economy and reduce risks associated with disasters. As the leader of waterway restoration, they assess and verify the channel conditions and assign other agencies (e.g. USCG, Navy) to assist with surveying areas.

Depending on the severity of channel obstructions they will issue emergency

contracts to clear the shoaled areas. After verifying the channel, they develop a

spreadsheet to hold the data of project depths and channel damage, this information is

distributed to the USCG in order to communicate waterway restrictions. Besides handling

destruction in waterways, they are responsible for shutting down and starting up lock

structures that vessels travel through to get to other areas of the waterway. During the

response phase, the USACOE communicates with the Logistics Center operated by the

inland barge industry via the River Industry Executive Task Force (RIETF) to receive

information on equipment and services (Team, 2009; CNN, 2010).

3.2 Assessment Teams

The assessment teams follow a command structure similar to the National

Response Framework. This structure consists of an Incident Command that facilitates

activities in command, operations, planning, logistics and finance/administration. The

incident commander is responsible for all response activities such as: developing

strategies and the order/ release of resources. They also manage the operations at the site

of the incident (Security, 2008).

The assessment teams (e.g. Incident Command, Industry Command, Self Help)

include various representatives from federal agencies and industry. Each team has unique

functions such as: creating assignments for deployment, serving as liaisons between

agencies, assisting in towing vessels, governing traffic flow of vessels to assess the

waterways, and transporting/repositioning ATONs. All of these teams work together with the incident commander to create an effective response (Team, 2009).

3.3 Logistic Support Center Teams

The River Industry Executive Task Force (RIETF) a committee under the American Waterway Operators Association (AWOA) is responsible for setting up the Logistics Support Center. The Logistic Support Center provides an avenue for agencies and suppliers to communicate the types of equipment and supplies needed for response efforts. Many contacts are received from the barge industry due to their large network (Team, 2009; CNN, 2010).

3.4 Private Industry

3.4.1 Barge Industry

During the response phase the barge industry provides information to the Logistics Center that allows the USACOE and USCG to carry out their functions. This industry also provides personnel to the assessment teams to provide expertise on waterway towing services to increase response. They move equipment and supplies to disaster stricken areas, lock structures and vessels deployed before the storm. The information they solicit from fuel and coal shippers/terminals on critical supply inventory and vessel operations can assist in determining when the waterways will close or re-open (Team, 2009).

CHAPTER 4

METHODOLOGY

4.1 Problem Overview

For this research, we consider a hurricane hitting a particular area in which ATONs are damaged. Facilities are designated pre-storm in order to hold items to repair ATONs. Each facility is supplied by federal organizations as well as industry. Based on the level of damage and location of ATONs, items are pre-positioned after the storm for repair efforts. Aids to navigation will use a priority system of critical, urgent and routine when determining which aids to fix.

4.2 Problem Description and Assumptions

The following assumptions are considered for this research:

1. There will be four regions used: Alabama, Florida, Louisana and Mississippi because they are part of the gulf coast and prone to hurricanes.

2. Each region has a specified amount of safe locations for the various commodities needed to repair aids to navigation.

3. Each safe location has flashers, radar reflectors, discrepancy buoys and cutters that can be pre-positioned pre-disaster.

4. The process to repair aids to navigation will use the following priority system:

    a. Critical- based on damage requires the use of discrepancy buoy until original buoy is repaired;

    b. Urgent- the damage is able to be fixed on the scene;

    c. Routine- there is less damage and repair can take place after the most critical aids to navigation;

5. Commodities used for on scene repair are flashers and radar reflectors.

6. Commodities used in place of buoys are transferred back to safe location to be repaired are a discrepancy buoy.

7. Each teams gets a cutter, therefore the number of cutters needed is directly related to teams.

8. The demand for these commodities is unknown until after a disaster has occurred.

9. Aids to navigation teams are needed to move cutters to damaged areas.

10. Based on the path of the hurricane these commodities have the potential to be damaged.

4.3 Model Formulation

A two-stage stochastic facility location program is developed to solve this problem. A two-stage stochastic program uses first stage and second stage decisions. The first stage decisions, are represented by a vector. These decisions are taken without knowing the full information of some random event. The second stage decisions or recourse, or corrective actions based on the information received from the first stage

decisions. According to (Birge, 1997), the general mathematical notation for this model with recourse is as follows:

$$\min c^T x + E_\xi \, Q(x, \xi) \tag{1}$$

$$s.t. \quad Ax = b \tag{2}$$

$$x \geq 0 \tag{3}$$

Recourse Function

$$Q(x, \xi) = min\{q^T y | W_y = h - T_{x,y} \geq 0\} \tag{4}$$

The objective function (1) minimizes the cost c^T associated with the first stage decisions x plus the expected cost of the second stage decisions. ξ represents the full information of some random event and $Q(x, \xi)$ or recourse function represents the dependency of the random vector on different scenarios. Constraints (2, 3) are related to the first stage decisions of the model. Constraint (4) is related to the second stage decisions of the model.

4.3.1 Overview of Stage 1

Using this framework the model illustrates the processes a port takes to become operational based on the repair of ATONs while providing a rapid response time. The first stage decisions determine the amount of teams and commodities that are allocated to safe locations pre-landfall of a hurricane. That means, x_i is the number of teams that are assigned to a safe location i before the storm strikes land. The demand $D_{jv\omega}$ for each

region j for a priority v is considered a random variable. A cost c_k is associated with one

unit of procuring repair items k.

4.3.2 Overview of Stage 2

The second stage decisions determine the amount of teams needed to fix ATONs

that are damaged in each region, in regards to the repair type (i.e. critical, urgent,

routine). Based on the demand there is a probability associated with each repair type

scenario for each region. Table 3 represents the notation used for the parameters and

variables of this model.

Table 5. Model notation

Category	Symbol	Description
Index Sets	L	Set of supply locations
	I	Set of safe locations
	K	Set of commodities used in repair activity
	V	Set of possible ATON repair types (based on urgency)
	J	Set of demand areas possibly affected
First Stage Decision Variables	x_i	The number of teams assigned to safe location i
	s_{ik}	The number of supplies of commodity type k assigned to safe location i
	y_{li}	The number of teams transferred from supply location l to safe location i
Second Stage Decision Variables	$z_{ij\omega}$	The number of teams assigned from location i to demand region j in scenario ω
	$h_{ijk\omega}$	The number of commodities of type k transferred from location i to affected area j in scenario ω
	$u_{ijv\omega}$	Unrepaired ATONs of type v region j in scenario ω by teams from safe location i.
	$r_{ijv\omega}$	Repaired ATONs of type v region j in scenario ω by teams from safe location i.

Table 6. Model notation cont.

Category	Symbol	Description
Parameters	M	Maximum load that each team can carry (lbs.)
	w_k	Weight associated with commodity k (lbs.)
	N_l	Number of teams based at location l
	a_{vk}	Amount of commodity k used in repair of type v
	B	Maximum allowable cost associated with pre-positioning commodities
	α_v	Criticality weight associated with ATON repair of type v
	c_k	Per unit cost associated with pre-positioning commodity k
	p_ω	Scenario specific probability
	e_{ij}	The travel time between safe location i and demand region j
	$t_{v\omega}$	Scenario specific repair time for ATON of type v
	γ_k	The number of supplies available for commodity type k
	$D_{jv\omega}$	Amount of ATONS in need of repair of type v in region j under scenario ω

Using the notation above, a two-stage stochastic facility location model is formulated as follows:

$$\text{Max} \sum_v \sum_j \sum_\omega \sum_i p_\omega \alpha_v r_{ijv\omega} \qquad (5)$$

s.t.

Flow Balance (Pre-positioning)

$$\sum_l y_{li} = x_i \quad \forall i \qquad (6)$$

$$\sum_i y_{li} \leq N_l \ \forall l \qquad (7)$$

Supply Constraint

$$\sum_k w_k s_{ik} \leq M x_i \quad \forall i \tag{8}$$

$$\sum_i s_{ik} \leq \gamma_k \quad \forall k \tag{9}$$

Budget Constraint

$$\sum_k \sum_i c_k s_{ik} \leq B \tag{10}$$

Aid to Navigation Team Constraint

$$\sum_j z_{ij\omega} \leq x_i \quad \forall i, \omega \tag{11}$$

Repair Time Constraint

$$\sum_v \sum_i t_{v\omega} r_{ijv\omega} \leq \sum_i z_{ij\omega} * (36 - e_{ij}) \quad \forall j, \omega \tag{12}$$

Inventory Balance Constraint

$$\sum_i (r_{ijv\omega} + u_{ijv\omega}) = D_{jv\omega} \quad \forall j, v, \omega \tag{13}$$

Repaired ATONs to pre-positioned supplies Constraint

$$\sum_v a_{vk} r_{ijv\omega} \leq h_{ijk\omega} \quad \forall i, j, k, \omega \tag{14}$$

Affected Area Constraints

$$\sum_j h_{ijk\omega} \leq s_{ik} \quad \forall i, k, \omega \tag{15}$$

$$\sum_k w_k * h_{ijk\omega} \leq M * z_{ij\omega} \quad \forall i, j, \omega \tag{16}$$

Non-negativity Constraints

$$x_i, s_{ik}, z_{ij\omega}, h_{ijk\omega}, u_{ijv\omega}, r_{i,j,v\omega}, y_{li} \geq 0 \qquad (17)$$

The objective function (5) maximizes the expected amount of aids to navigation that are repaired in the response phase. The first set of constraints (6, 7) represent the flow balance equations to ensure the amount of teams transferred from a supply location do not exceed the teams at the supply location and are equal to the amount teams at a safe location. Constraint (8) ensures that supplies stored at a safe location do not exceed the weight of the amount of items that a team can carry to that location. Constraint (9) shows the amount of supplies available for each commodity type. Constraint (10) ensures that the total number of items prepositioned cannot exceed the available budget. Constraint (11) makes certain the number of teams dispatched per location and scenario cannot exceed available team supply per location. Constraint (12) ensures the time to repair items at the demand region per scenario cannot exceed the available operation hours of teams allocated to an affected area. Constraint (13) makes certain that the amount of repaired and unrepaired ATONs equals the total demand. Constraint (14) represents the relationship between repaired ATONs and pre-positioned supplies. The next set of constraints (15,16) are dedicated to affected areas. The amount of supplies sent to an affected area cannot exceed available supply and commodities can only be allocated to an affected area if the teams are allocated to that area. The last constraint (17) makes sure the variables are not negative.

CHAPTER 5

NUMERICAL EXAMPLE

5.1 Numerical Example

Based on the model formulation given by equations (5)-(16) an example is illustrated. The supply chain data is represented by $l = 3$ supply location, $j = 4$ regions and $i = 3$ safe locations with three damage scenarios (ω) shown in 5. In Table 5 for scenario 1 the total demand is 485 ATONs, for scenarios 2 the total demand is 550 and for scenario 3 the total demand is 610. The total demand for damaged ATONs that are classified as critical is 545, routine is 605 and urgent is 495. For this example only one repair item is considered. The solution for this model is based on the data from Table 4 and 5 entered into GAMS linear programming software.

Table 7. Model parameters for numerical example

Parameters	Levels	Values
(M) the max lbs. a team can carry	1	200 lbs.
(w_k) the weight associated with commodity	1	1 lb.
(N_l) # of teams at a supply location	3	[50,20,30]
(a_{vk}) amount of commodity used in a repair type	3	[1,0,0;1,0,0;1,0,0]
(B)the max cost associated with prepositioning commodities	1	$609,937

Table 8. Model Parameters for numerical example cont.

Parameters	Levels	Values
(α_v) criticality weight of ATON Repair type	3	[3,2,1]
(c_k) cost per unit commodity	3	[$40, $120, $90]
(p_ω) scenario specific probability	3	[0.6, 0.3, 0.1]
$(t_{v\omega})$ scenario specific time repair	3	[2,1,0.75; 2,1,0.75; 2,1,0.75]
(e_{ij}) travel time	4	[2, 2,3,1;2,4,3,2;2,2,4,3]

Table 9. Damage scenarios

Scenario	Region	Critical ATON Demand	Routine ATON Demand	Urgent ATON Demand
1	1	20	15	50
1	2	35	40	25
1	3	25	15	75
1	4	55	70	60
2	1	55	75	45
2	2	40	15	30
2	3	15	45	20
2	4	65	95	50
3	1	70	30	50
3	2	90	80	35
3	3	60	80	30
3	4	15	45	25

5.2 Results

According to Figure 2, commodities are only sent to all three safe locations, one commodity is considered for this model. Since, the amount of teams is dependent on commodities each supply location must send a team to each safe location. In Figure 3, all safe locations are sent teams from only one supply location, which supports the amount of commodities received. Both of these figures also represent the decisions that are made within the first stage of the model.
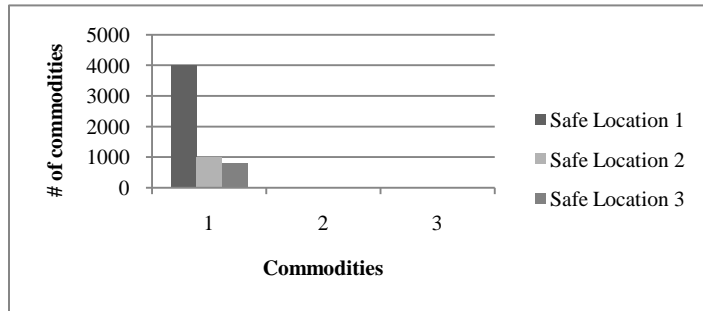
Figure 2. Repair items sent to safe locations
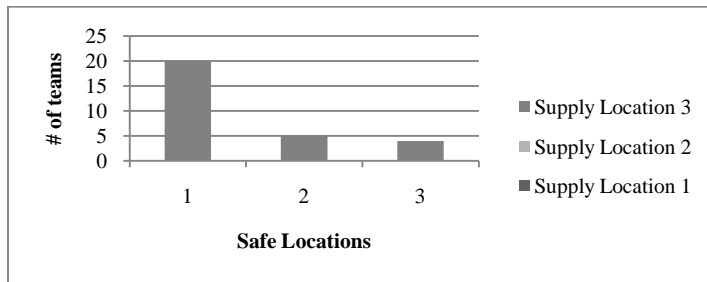
Figure 3. Teams sent to safe locations

The second stage decisions determine the amount of commodities and teams needed for each demand region per scenario. Figures 4(a)-4(d) depicts the amount of teams sent to the demand regions from a safe location. The results show that certain safe locations supply teams to specific regions. Safe location 1 supplies the most teams over all.
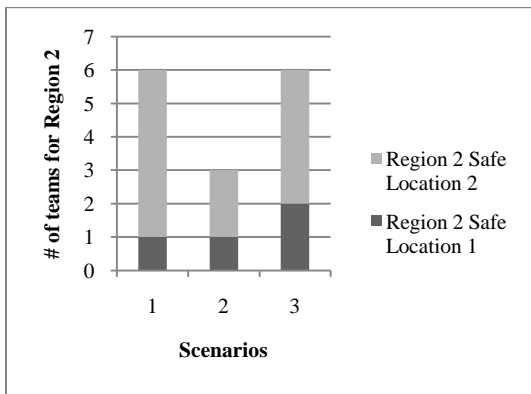
(a)
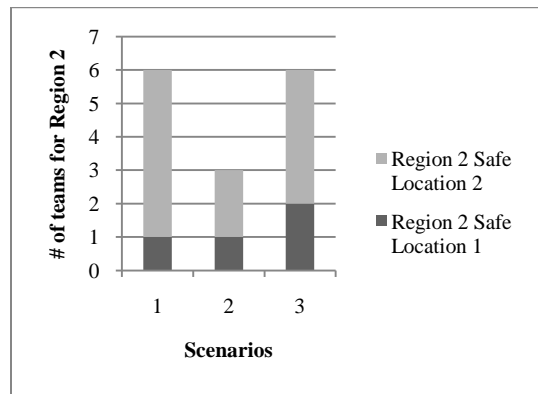
(b)
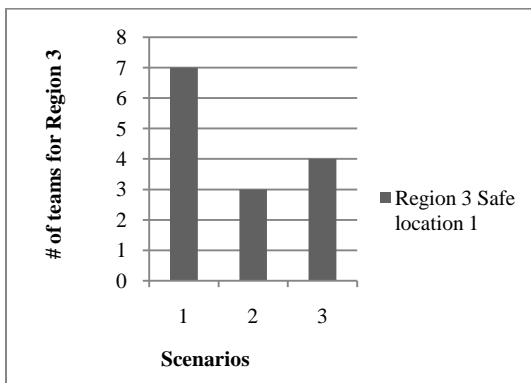
(c)
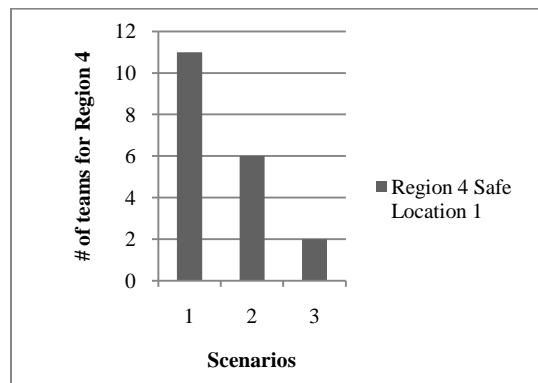
(d)

Figure 4. Teams sent to demand regions (a) region 1, (b) region 2, (c) region 3, (d) region 4

Figures 5(a)-5(d) represent the amount of commodities sent to a demand region from a safe location. The results show that all regions are supplied one commodity by specific safe locations. For regions one and two the amount of utilize the most commodities per scenario from more than one safe location. Regions three and four only utilize one safe location. Each region shows that the amount of teams sent matches up with commodities.
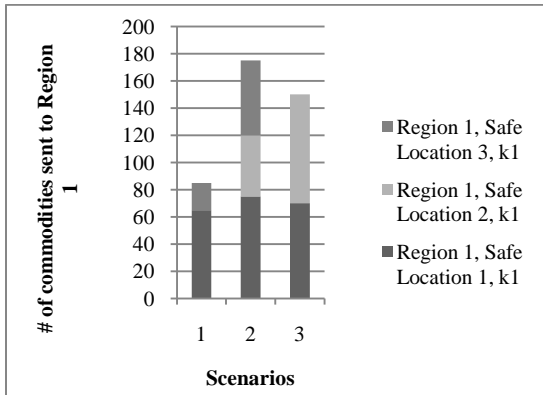
(a)
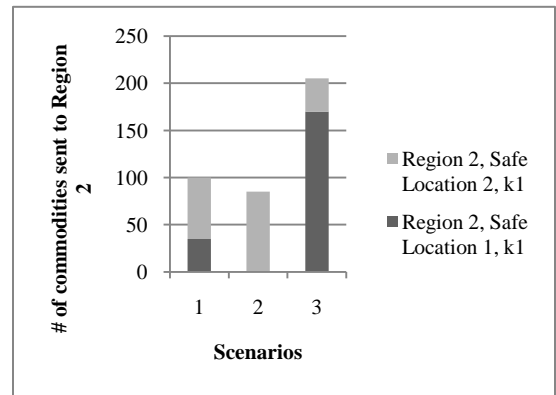
(b)
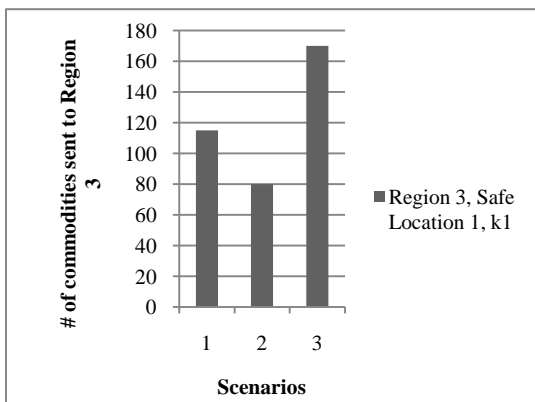
(c)
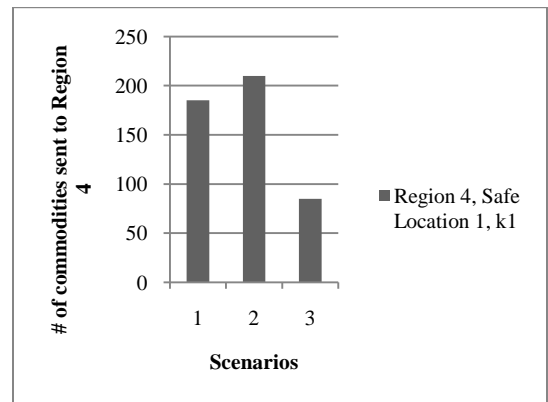
(d)

Figure 5. Commodities sent to demand regions (a) region 1, (b) region 2, (c) region 3, (d) region 4

The next, set of decisions made within the second stage are the number of repaired and unrepaired items for each region. Figures 6(a)-6(d) show the amount of ATONs that are repaired for each region. The results show that the all critical, urgent, routine ATONs are repaired for all regions leaving none unrepaired. This shows that there were enough commodities and teams sent to get all of the ATONs repaired.
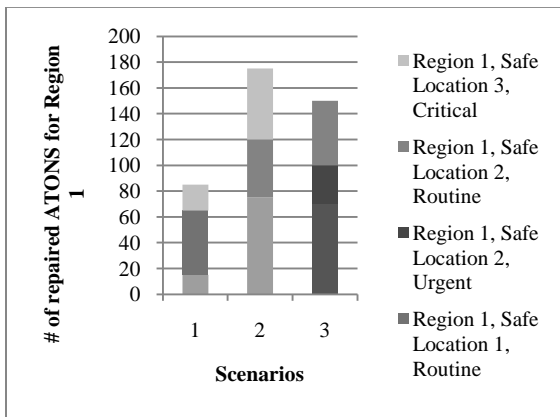
(a)
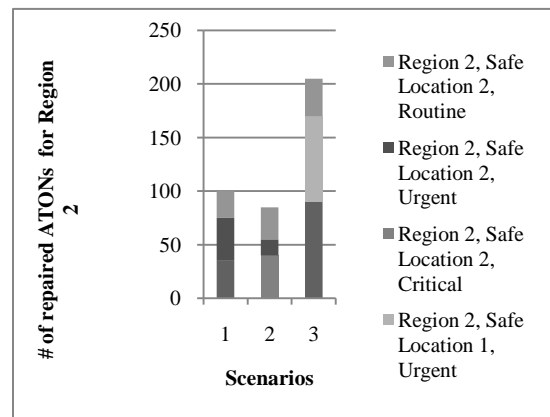
(b)
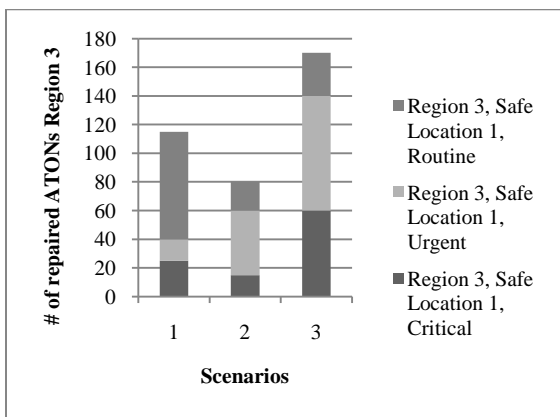
(c)
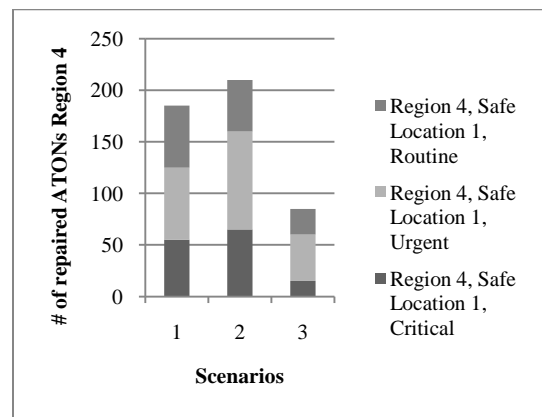
(d)

Figure 6. Number of repaired ATONs (a) region 1, (b) region 2, (c) region 3, (d) region 4

5.3 Results Summary

The expected number of ATONs that required repair was 1393.5 for all demand regions and scenarios combinations. The optimal solution revealed there were on average 1008 ATONs repaired which is more than half of the expected demand. The figures, for each stage of the model, acknowledge that all safe locations are utilized but not all supply locations. However, all safe locations do not supply all regions for the scenario specific decisions. Our, objective is to maximize the expected number of ATONs over the response phase; the pre-positioning cost ($232,000) was below the budget of ($609,937).

CHAPTER 6

EXPERIMENTAL DESIGN

The objective of this research is to determine the effect of a prepositioning policy on the repair commodities in order to help with the recovery phase of waterways from a hurricane. Specifically, we will focus on the following:

1. The effect of parameters on the optimal pre-positioning policy;

2. The optimal stocking quantities and location of resources;

3. The benefit of the pre-positioning policy to the response phase.

Figure 7 illustrates the supply chain network of supply locations, safe locations and affected areas. Tables 10 and 11 show the actual names of locations and total time it takes to get to each one. The amount of hours between locations was calculated and the following ranking applied: **1**-(1-3hrs.), **2**-(4-6hrs.), **3**-(7-above). The ranking between supply and safe locations is negligible for this model. Each supply location is representative of USCG sectors within the eighth district. The eighth district represents states within the gulf coast region. The safe locations are different ports located within a region. The affected areas shown are regions that have ATONs that are damaged. Table 12 lists the parameters used for the model.
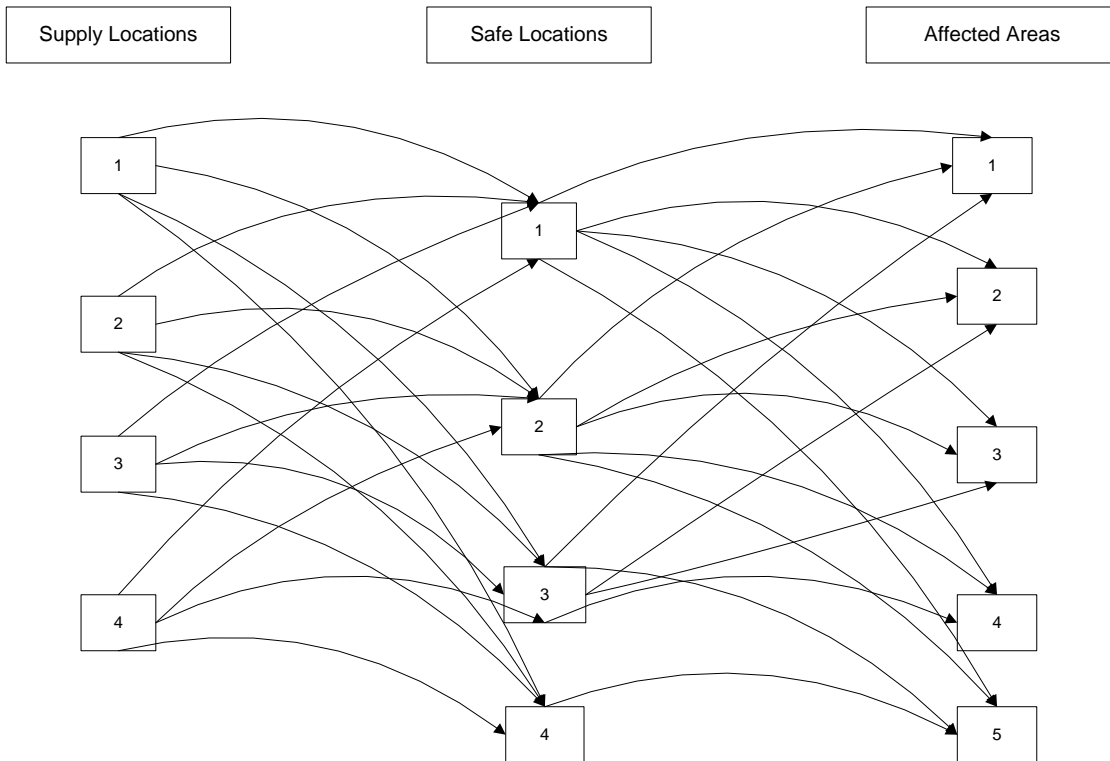
Figure 7. Supply chain diagram

Table 10. Supply/safe locations and regions

Supply Locations	Safe Locations	Region
Sector New Orleans(l1)	Port of New Orleans(i1)	Alabama(j1)
Sector Mobile(l2)	Port of Mobile(i2)	Florida(j2)
Sector Lower Mississippi River (l3)	Port of Gulfport(i3)	Louisiana(j3)
Sector Upper Mississippi River(l4)	Port of Jacksonville(i4)	Mississippi(j4)
		Mississippi/Louisiana(j5)

Table 11. Distance between safe locations and regions

Safe Locations/Regions	j1	j2	j3	j4	j5
i1	2	3	1	1	1
i2	1	3	2	1	1
i3	2	3	2	1	1
i4	3	1	3	3	3

Table 12. Model parameters

Parameters	Levels	Values
(M) the max lbs. a team can carry	1	1500 lbs.
(w_k) the weight associated with commodity	1	[190, 1, 6] lbs
(N_l) # of teams at a supply location	3	[50,20,30,25]
(a_{vk}) amount of commodity used in a repair type	3	[1,0,0;0,1,0;0,0,1]
(α_v) criticality weight of ATON Repair type	3	[3,2,1]
(c_k) cost per unit commodity	3	[$350, $179, $139]
(p_ω) scenario specific probability	3	[0.05, 0.15, 0.25,0.25,0.30]
($t_{v\omega}$) scenario specific time repair	3	[2,1,0.75;2,1,0.75;2,1,0.75;2,1,0.75;2,1,0.75] (hrs.)
(e_{ij}) travel time	4	[2,1,2,3,1;3,3,3,3,1;1,2,2,3;1,1,1,3;1,1,1,3] (hrs.)

6.1 Model Data

The data for this model consists of information from various hurricanes and aids to navigation. The national hurricane center provides the path of hurricanes based on the Saffir/Simpson scale. They also give the strike probabilities of the hurricane in relation to the path of cities and states the hurricane will strike in a 24 hour period. The Light List provided by the USCG shows information on all aids to navigation throughout each district (United States Coast Guard, 2010).

Also, a list was provided from the USCG District 8 of damaged ATONs in the locations affected by Hurricane Katrina (Tables 34-38 Appendix 1). This information consists of the location measured in latitude and longitude, characteristics (e.g. flashers, bells, whistles) and other remarks of importance to the aid. This data was later formatted and clustered by region. The USCG website provides a table with various costs of the supplies used to repair ATONs (United States Coast Guard, 2010). Various manuals and documents were provided by the USCG to understand the entire ATON repair process.

6.2 Scenario Generation

The scenarios constructed for this case study are generated from realistic information. Each scenario is constructed using the projected storm path for Hurricane Katrina along with probabilities of the storm taking on a particular category (i.e. $\omega 1$-tropical storm, $\omega 2$-Category 1, $\omega 3$-Category 2, $\omega 4$-Category 3 and $\omega 5$-Category 4/5). Figure 8 shows the actual forecast for Hurricane Katrina on August 26, 2005 at 11pm. The ATONs located inside the red circle are considered damaged.

The different colored circles represent the actual ATONs for different regions (i.e. blue-Louisiana, orange-Alabama, yellow-Mississippi/Louisiana, green-Florida, purple-Mississippi). The small green circles on the figure represent the safe locations. Based on the damage information received from the Coast Guard, the ATONs discrepancies were classified under the different repair types (e.g. critical, urgent and routine) for each region (Table 13). The repair items needed to fix the ATONs are discrepancy buoys(k1), flashers(k2) and radar reflectors(k3).
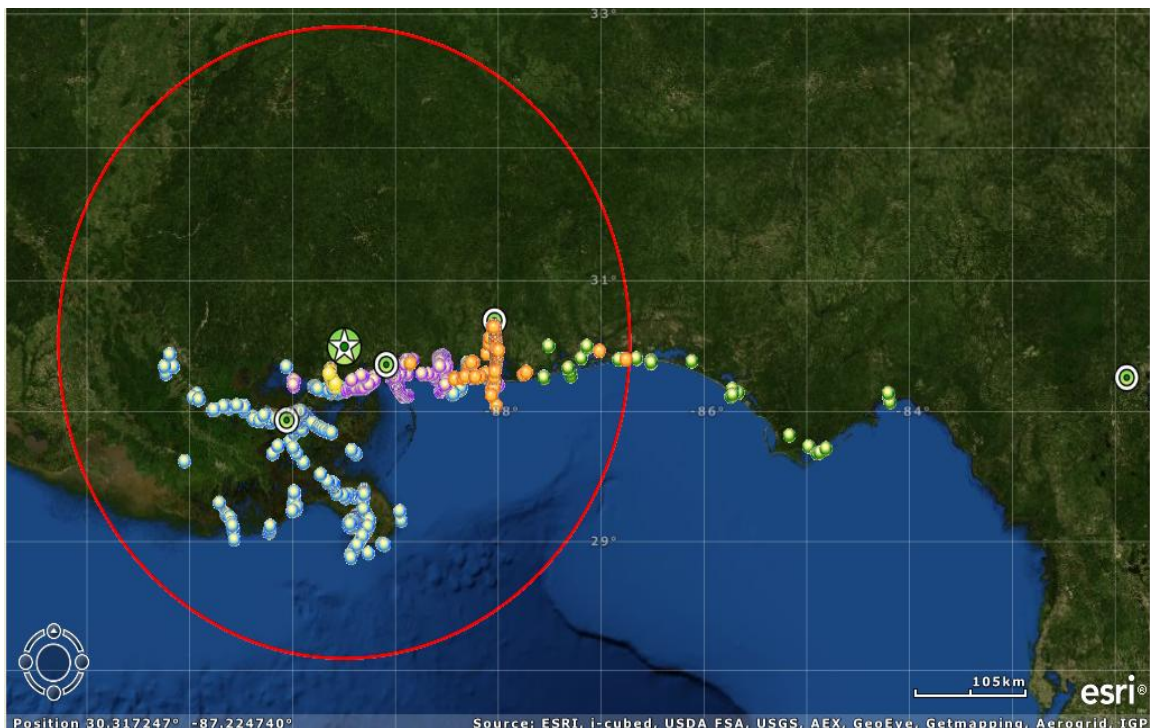
Figure 8. ATONs inside the hurricane path

Table 13. ATON classification

Critical	Urgent	Routine
Light Extinguished	Dayboard Damaged	Buoy Damaged
Dayboard Destroyed	Topmark Damaged	
Missing	Missing/Dayboard Damaged	
Temporarily Replaced	Reduced Intensity	
Missing/Temporarily Replaced		
Light Extinguished/ Dayboard Destroyed		
Temporarily Replaced/Extinguished		
Off station		
Light Extinguished/ Improper Characteristics		
Light Extinguished/ Dayboard Destroyed		
Light Extinguished/Daybeacon Destroyed		
Off station/ Light Extinguished		
Daybeacon Destroyed		

A discrepancy factor was created to develop ATON damage estimates for each hurricane category (Table 14). Category three was used as the base since data was obtained from Hurricane Katrina to build case. The discrepancy factor for category three is calculated as follows the ratio of damaged ATONS to total ATONS per region. The other categories were scaled up or down from these numbers based on the intensity of the hurricane. This factor is multiplied by the total number of damaged ATONs in order to get the demand per region $D_{jv\omega}$ (Table 15). The probabilities for each scenario are found in Table 16.

Table 14. Discrepancy factor for each hurricane category

Category 1					
Repair type	**Alabama**	**Florida**	**Louisiana**	**Mississippi**	**Mississippi/Louisiana**
Critical	0.670	0.526	0.593	0.837	0.455
Urgent	0.168	0.263	0.204	0.062	0.364
Routine	0.162	0.211	0.204	0.100	0.182
Category 2					
Repair type	**Alabama**	**Florida**	**Louisiana**	**Mississippi**	**Mississippi/Louisiana**
Critical	0.782	0.763	0.699	0.861	0.591
Urgent	0.151	0.158	0.170	0.091	0.318
Routine	0.067	0.079	0.131	0.048	0.091
Category 3					
Repair type	**Alabama**	**Florida**	**Louisiana**	**Mississippi**	**Mississippi/Louisiana**
Critical	0.905	0.842	0.869	0.919	0.818
Urgent	0.095	0.105	0.131	0.077	0.182
Routine	0.000	0.053	0.000	0.005	0.000
Category 4/5					
Repair type	**Alabama**	**Florida**	**Louisiana**	**Mississippi**	**Mississippi/Louisiana**
Critical	0.961	0.921	0.973	0.957	0.909
Urgent	0.039	0.053	0.027	0.043	0.091
Routine	0.000	0.026	0.000	0.000	0.000

Table 15. Demand for base case

Category1						
Repair type	**Alabama**	**Florida**	**Louisiana**	**Mississippi**	**Mississippi/ Louisiana**	**Total Repair Type**
Critical	109	5	177	15	90	396
Urgent	3	1	6	0	2	12
Routine	0	0	0	0	0	0
Total	112	6	183	15	92	
Category2						
Repair type	**Alabama**	**Florida**	**Louisiana**	**Mississippi**	**Mississippi/ Louisiana**	**Total Repair Type**
Critical	127	8	208	171	11	525
Urgent	3	0	5	1	1	10
Routine	0	0	0	0	0	0
Total	130	8	213	172	12	
Category3						
Repair type	**Alabama**	**Florida**	**Louisiana**	**Mississippi**	**Mississippi/ Louisiana**	**Total Repair Type**
Critical	147	8	259	182	15	611
Urgent	2	0	4	0	1	7
Routine	0	0	0	0	0	0
Total	149	8	263	182	16	
Category4/5						
Repair type	**Alabama**	**Florida**	**Louisiana**	**Mississippi**	**Mississippi/ Louisiana**	**Total Repair Type**
Critical	156	9	290	189	16	661
Urgent	1	0	1	0	0	2
Routine	0	0	0	0	0	0
Total	157	9	291	189	16	

Table 16. Scenario probabilities based on hurricane advisory

Scenarios	Probability
Tropical Storm	0.05
Category 1	0.15
Category 2	0.25
Category 3	0.25
Category 4&5	0.30

6.3 Performance Measures

During recovery or response phases there are many tasks to complete. The performance measures considered for this model are the impact of responsiveness based on the repair of ATONs and value of coordination among agencies and organizations. Based on pre-positioning, the responsiveness is defined as a ratio

$$Response\ Ratio = \frac{\sum_v \sum_j \sum_\omega \sum_i p_\omega \alpha_v r_{ijv\omega}}{\sum_\omega \sum_v \sum_j p_\omega \alpha_v D_{jv\omega}} \tag{17}$$

Where ($\sum_v \sum_j \sum_\omega \sum_i p_\omega \alpha_v r_{ijv\omega}$) is the expected number of ATONs that are repaired during the response phase and ($\sum_\omega \sum_v \sum_j p_\omega \alpha_v D_{jv\omega}$) the expected number of ATONs needing repair. The value of supply is calculated by using the following formula $relative\ value = \frac{f(base\ case) - f(experiment)}{f(base\ case)}$ which corresponds to the amount of ATONs repaired. The collaboration between different agencies or industry is imperative and expected to be of benefit to each party involved. The value of coordination is established by leaving out the first stage pre-positioning decisions associated with material, adding

extra time account for acquiring supplies after the event, and changing the budget

constraint to be scenario specific rather than applied to the first stage prepositioning

decision. This policy is tested against the original model for consistency.

6.4 Sensitivity Analysis

The following inputs are varied throughout the experiment: the supply, the

workers response time, budget and supply acquisition time. The supply is changed based

on the need of supplies for damaged ATONs due to the storm and the availability of

supplies. The criteria used for the supply variations are increase, decrease and no change.

An increase in supply could be necessary if the storm path strikes numerous regions or if

damage is significant. A decrease in supply might be due to regions receiving no damage

or supply locations being low on supplies. No change in supply can be due to no damage

or supplies are evenly distributed.

The workers response time is changed based on the same time used for hurricane

forecast. Since, damage within this model is uncertain, the budget will be changed to fit

the need of the various scenarios. The supply acquisition time is used to decrease the

response time for cases where pre-positioning is not taken to account. The following

parameters as summarized in Tables (17 and 18) will be used in the experimental design.

Table 17. Experimental design

Experiment #	Supply	Response Time	Budget	Supply Acquisition Time
1 (base case)	Normal	36	$609,937	None
2	Increase 10%	36	$609,937	None
3	Increase 20%	36	$609,937	None
4	Increase 30%	36	$609,937	None
5	Decrease 10%	36	$609,937	None
6	Decrease 20%	36	$609,937	None
7	Decrease 30%	36	$609,937	None
8	Normal	36	$607,655	None
9	Normal	36	$1,002,000	None
10	Normal	36	$609,937	0hrs.
11	Normal	36	$609,937	12hrs.
12	Normal	36	$609,937	24hrs.
13	Normal	72	$609,937	None
14	Increase 10%	72	$609,937	None
15	Increase 20%	72	$609,937	None
16	Increase 30%	72	$609,937	None
17	Decrease 10%	72	$609,937	None

Table 18. Experimental design cont.

Experiment #	Supply	Response Time	Budget	Supply Acquisition Time
18	Decrease 20%	72	$609,937	None
19	Decrease 30%	72	$609,937	None
20	Normal	72	$607,655	None
21	Normal	72	1,002,000	None
22	Normal	72	$609,937	0hrs.
23	Normal	72	$609,937	12hrs.
24	Normal	72	$609,937	24hrs.
25	Normal	72	$609,937	48hrs.

CHAPTER 7

RESULTS

7.1 Overview

The results generated from the experimental design for the model determine the optimal policy for pre-positioning repair items for ATONs and maximizes the expected ATONs repaired during the response phase. This chapter consists of four sections to give detailed analysis of the experiments. The first section shows results from the base model. The second section discusses the performance measures used to assess the effect of pre-positioning on the responsiveness during the response phase and the value of coordination among organizations. The third section summarizes the sensitivity analysis on the supply, worker response time, budget and travel time. The last section shows the actual optimal policies.

7.2 Base Model

Table 15 shows the total demand of ATONs for each region and repair type. All three repair items are considered in this model (discrepancy buoy-k1, flasher-k2 and radar reflector-k3). The optimal quantities of teams and repair items for experiment 1 are shown in Figures 9 and 10. All safe locations are utilized to hold repair items for ATONs except safe location 2. For this model only discrepancy buoys and flashers are sent to each of the safe locations. The total supply prepositioned for discrepancy buoys are 707

and for flashers are 12. The radar reflectors are not demanded. The supply locations are all utilized but, they do not send commodities to every safe location.
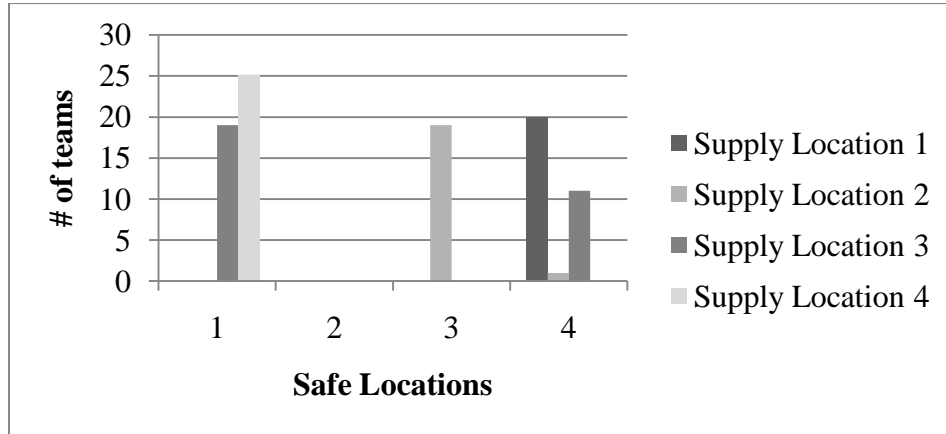
Figure 9. Number of teams sent to safe locations
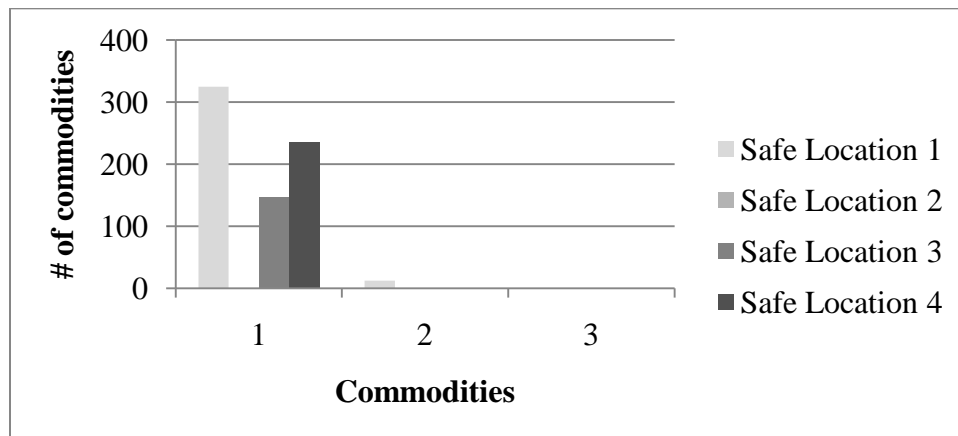
Figure 10. Number of commodities sent to safe locations

Figures 11a-11e illustrates the optimal quantities of teams sent to the actual affected areas with ATONs. For scenario two, which refers to a Category one storm, regions one (Figure 11a) and five (Figure 11e) receive the majority of the teams. The other regions have more teams sent for a category five storm.
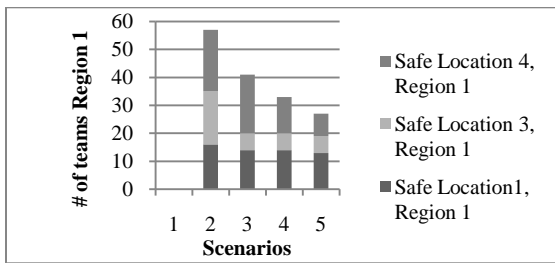
(a)
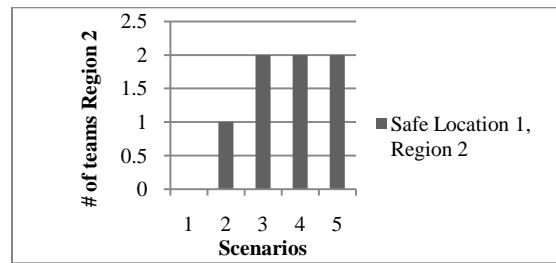
(b)
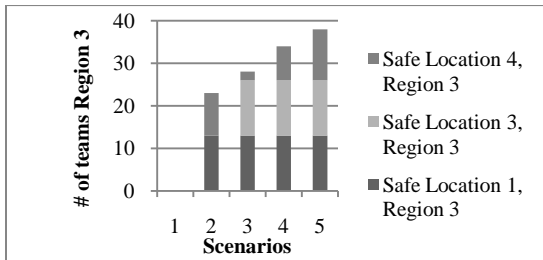
(c)
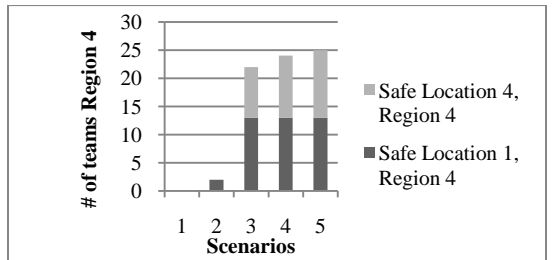
(d)
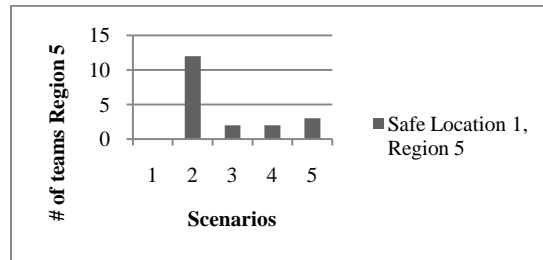
(e)

Figure 11. Number of teams sent to demand regions (a) region 1, (b) region 2, (c) region 3, (d) region 4, (e) region 5

Figures 12(a)-12(e) represents the optimal quantities of repair items sent to each

affected area. The amount of commodities for region one (Alabama) and five

(Mississippi/Louisiana) for Category one match up with large amount of teams found in

Figures 11(a) and 11(e). This increased amount could be due to total demand.

Throughout all the regions we can see that the discrepancy buoy (k1) is sent the most

which means that a lot of ATONs are damaged beyond repaired.

(a)

(b)

(b)

(d)

(e)
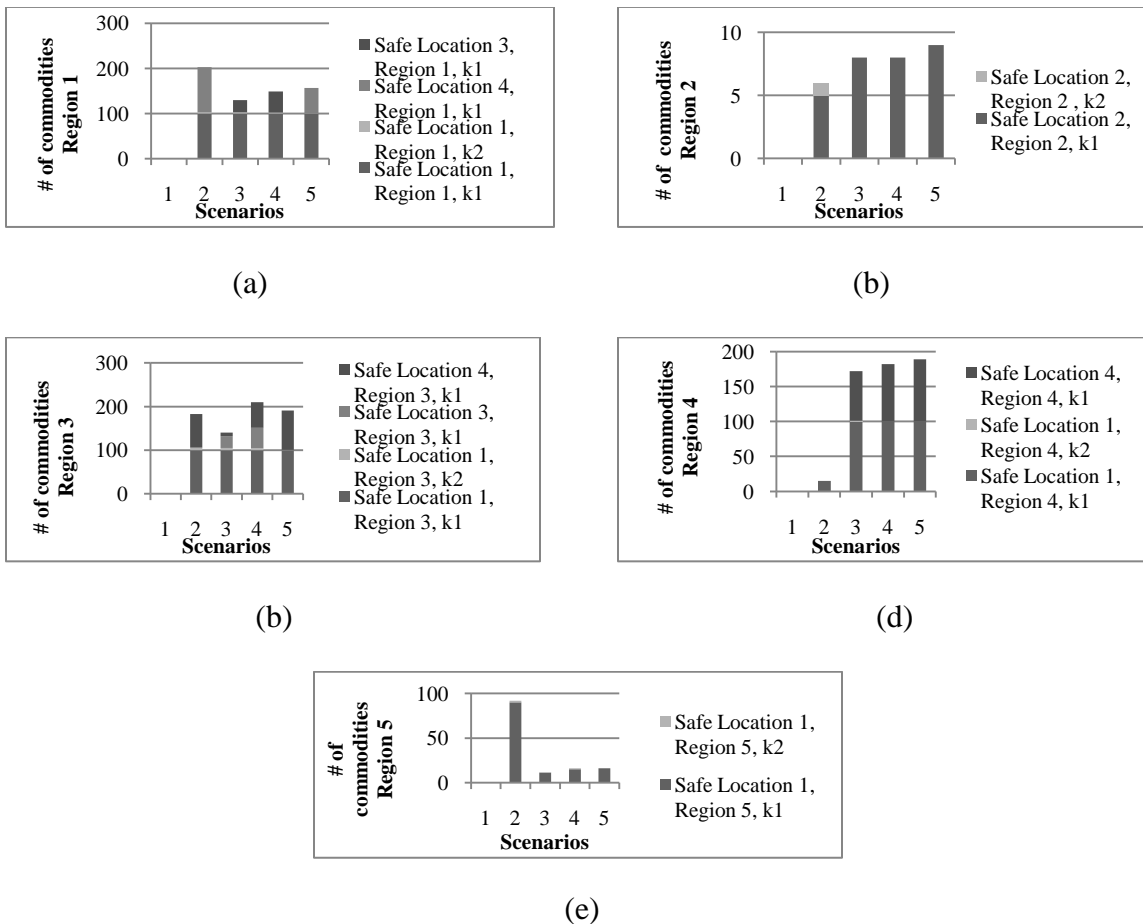
Figure 12. Number of commodities sent to affected regions (a) region 1, (b) region 2, (c) region 3, (d) region4, (e) region 5

Figures 13a-13e show the amount of ATONs repaired within each region. Each region repairs only the critical and urgent ATONs. Figures 13(a), 13(b) and 13(d) Category 5 has the most critical ATONs which are due to the intensity of the storm. In figure 13(e) shows that region 5 scenario 2 has the most ATONs being repaired this is due to the demand. Based on the demand there are no routine ATONs repaired.
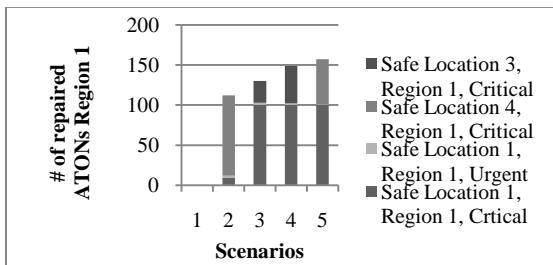
(a)
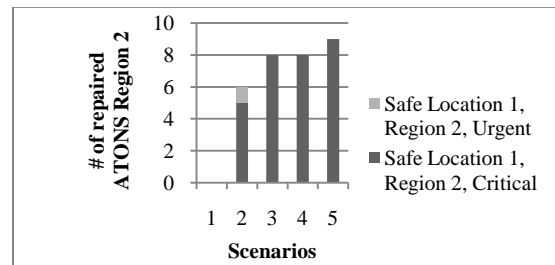
(b)
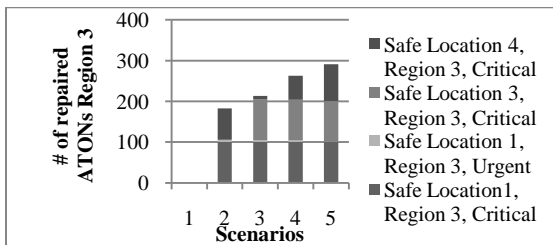
(c)
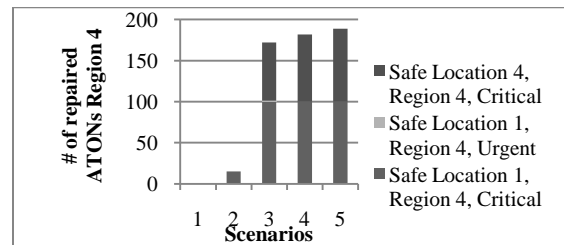
(d)
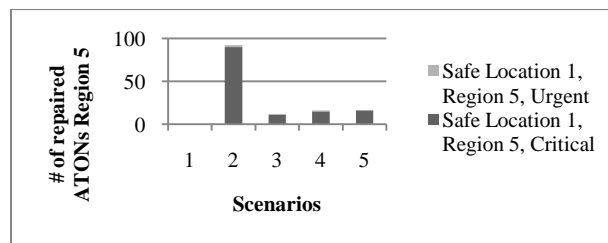
(e)

Figure 13. Number of repaired ATONs for each region (a) region 1, (b) region 2, (c) region 3, (d) region 4, (e) region 5

7.3 Sensitivity Analysis

7.3.1 Supply, Worker Response Time, Budget

Tables 19 gives a list of the variation of supply from the base model for the different response times based on the unconstrained supply model. This model tells the optimal amount of supply given the model parameters. Tables 20 and 21 show the results of putting the supply numbers back into the supply constrained model under gamma(k) as a parameter. The experiments listed below only use two different response times (i.e. 36 hrs. and 72 hrs.). At the different response time of (Table 20 and 21) the increase in supply has no effect on the overall policy, a change does not occur until the supply is decreased. The amount of supplies used for the increased supply remains the same this is because the model gives the best amount of supply available given the time.

Table 19. Supply variation for unconstrained supply model

Supply	Response Time	Supplies		Total Supply Available gamma(k)
		k1	k2	
base case(normal)	36	707	12	719
10%	36	778	13	791
20%	36	848	14	862
30%	36	919	16	935
-10%	36	636	11	647
-20%	36	566	10	576
-30%	36	495	8	503
Normal	72	762	17	779
10%	72	838	19	857
20%	72	914	20	934
30%	72	991	22	1013
-10%	72	686	15	701
-20%	72	610	14	624
-30%	72	533	12	545

Table 20. Supply variation for 36 hour response time

Experiment #	Supply	Response Time	Supplies		Supply pre-positioned S(i,k)	Expected Number repaired
			k1	k2		
1	base case(normal)	36	707	12	719	1638
2	10%	36	707	12	719	1638
3	20%	36	707	12	719	1638
4	30%	36	707	12	719	1638
5	-10%	36	636	11	647	1616
6	-20%	36	566	10	576	1519
7	-30%	36	495	8	503	1377

Table 21. Supply variation for 72 hour response time

Experiment #	Supply	Response Time	k1	k2	Supply Pre-positioned S(i,k)	Expected Number Repaired
13	Normal	72	762	17	779	1638
14	10%	72	706	12	718	1638
15	20%	72	706	12	718	1638
16	30%	72	706	12	718	1638
17	-10%	72	686	12	698	1638
18	-20%	72	610	12	622	1592
19	-30%	72	533	12	545	1465

Tables 22 and 23 give the relative value of the total supply available for each case which further proves that a decrease in supply has an effect on the total amount of items repaired. Table 24 shows the amount of ATONs damaged or repaired per region. Throughout each case we can see that the amount ATONs expected to be repaired and damaged for each region is the same. Based on Figures 13(a)-13(e) this proves true because all ATONs are repaired.

Table 22. Value of supply for 36 hour response time

Supply	Response Time	Value of Supply
base case(normal)	36	0
10%	36	0
20%	36	0
30%	36	0
-10%	36	.013
-20%	36	.072
-30%	36	.159

Table 23. Value of supply for 72 hour response time

Supply	Response Time	Value of supply
Normal	72	0
10%	72	0
20%	72	0
30%	72	0
-10%	72	0
-20%	72	.020
-30%	72	.105

Table 24. Expected number of damaged/repaired ATONs for base case per region (Experiment #1)

Base Case		
Region	Expected Number of ATONs Damaged	Expected Number of ATONs Repaired
Alabama	399	399
Florida	24	24
Louisiana	697	697
Mississippi	442	442
Mississippi/Louisiana	76	76
Total	1638	1638

The budget was varied three times through all experiments. The numbers used for the budget are half the cost of the United States Coast Guard Budget for ATONs and waterways; for the 2010 and 2011. The other budget is calculated using the cost within the model inflated by 10%. Table 25 gives a list of the budget and the amount of the budget actually used, determined from the model. The budget remains the same which results in no effect on the supply. The budget was not exceeded anytime because only the amount of commodities needed was purchased.

Table 25. Actual budget vs. Budget used

Experiment #	Actual Budget	Budget Used	% of budget used
1	$609,937	249,600	40.92%
8	$607,655	249,600	41.08%
9	$1,002,000	249,600	24.91%
13	$609,937	269,740	44.22%
20	$607,655	269,740	44.39%
21	$1,002,000	269,740	26.92%

7.4 Performance Measure

7.4.1 Response Ratio

To examine the impact of pre-positioning on the recovery phase the response ratios is considered. Table 26 shows the total expected number of ATONs and the total expected number of damaged ATONs used to determine the overall response ratio. The response ratio is 100% which shows that all ATONs are repaired and that teams are responding in a timely manner to each discrepancy. Tables 27 and 28 show the response ratio for the variation in supply. When the supply decreases the response ratio is reduced. When the supply is increased the response ratio is the same as the base case.

Table 26. Response ratio base case

Total Expected Repaired ATONs	Total Expected Number Damaged	Response Ratio
1638	1638	100%

Table 27. Response ratio based on supply variation with response time 36 hours

Experiment #	Supply	Response Time	Expected Number Repaired	Expected Number Damaged	Response Ratio
1	base case(normal)	36	1638	1638	100%
2	10%	36	1638	1638	100%
3	20%	36	1638	1638	100%
4	30%	36	1638	1638	100%
5	-10%	36	1616	1638	98%
6	-20%	36	1519	1638	93%
7	-30%	36	1377	1638	84%

Table 28. Response ratio based on supply variation with response time 72 hours

Experiment #	Supply	Response Time	Expected Number Repaired	Expected Number Damaged	Response Ratio
13	Normal	72	1638	1638	100%
14	10%	72	1638	1638	100%
15	20%	72	1638	1638	100%
16	30%	72	1638	1638	100%
17	-10%	72	1638	1638	100%
18	-20%	72	1592	1638	97%
19	-30%	72	1465	1638	90%

7.4.2 Value of Coordination

To understand the impact of coordination during the response phase the first stage pre-positioning constraints were removed from the model. All supplies are not accounted for until the second stage of the model. The same parameters from the base model were used except the supply acquisition time is used to reduce the response time.

Tables 29 and 31 are two cases that show the value of coordination. This coordination is measured by taking the difference between the expected number ATONs repaired without pre-positioning, within the response phase against the base model. The lack of coordination is considered when the time to acquire supplies is increased and no pre-positioning occurs. The supply acquisition reduces the amount of time it takes to respond and repair ATONs. Therefore, the number of ATONs repaired decreases as the supply acquisition time increases. In Tables 29 and 31, decreasing, the 36 hr. case by 48 hr. supply time is not considered for this test. For the 72 hr. response time the amount of

ATONs repaired remains the same when realistic data is used, since it allows more time to respond to ATONs.

Table 29 shows there is no value of coordination and the supply constrained model yields the same results as the base model since this is the best policy. This is because increasing the time and supply has no effect on the amount of ATONs repaired and shows the response ratio is unchanged. For the test case, the amount of teams was changed from (i.e. 50, 20, 30, and 25) to (i.e. 10, 15), from this some value of coordination is shown in Tables 31 and 32. For example, the 36 hr. case with a 24 hr. supply time results in a decrease in the response ratio by 17%. As the supply acquisition time increases the amount of ATONs repaired decreases (Table 31).

Table 29. Value of coordination for realistic data

Response Time	Base Case	12hrs.	24hrs.	48hrs.
36hrs.	1638	1638	1634	0
72hrs.	1638	1638	1638	1638

Table 30. Relative value for realistic data

Response Time	Base Case	12rs.	24hrs.	48hrs.
36hrs.	1638	0	0	0
72hrs.	1638	0	0	0

Table 31. Test case value of coordination

Response Time	Base Case	12hrs.	24hrs.	48hrs.
36hrs.	1126	1125	930	0
72hrs.	1126	1126	1126	1125

Table 32. Relative value for test case

Response Time	Base Case	12hrs.	24hrs.	48hrs.
36hrs.	1126	.0008	.174	0
72hrs.	1126	0	0	.174

CHAPTER 8

CONCLUSION

This research utilized a stochastic programming model to solve a real world problem involving emergency preparedness and response in relation to ports and ATONs. The findings of this research show that amount of repaired ATONs during the response decreases with variation of response time and supply acquisition time. The relationship between the available supply and worker response time affect the optimal solution of the amount of ATONs that are actually repaired. For some regions the Category one hurricane had more damaged ATONs than a Category five. This could be due to the amount of ATONs damaged for the particular experiment. The response ratio proved to be reasonable for the amount of ATONs that were repaired. These results show the motivation for researching the pre-positioning policy in relation to ports but further improvements can provide more insight.

Further research would include receiving more data from the Coast Guard of the damage acquired by ATONs due to a hurricane for each category type. This will help to build robust scenarios. Utilizing more hurricane paths will help to see the variation among damage within the scenarios at different levels; only one hurricane forecast was used for this model. Another improvement for this model is to consider the teams making multiple trips to the affected area during the response phase. This model only assumes one trip.

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APPENDIX 1.

NUMERICAL EXAMPLE DATA

Table 33. Light list/ cluster data (Louisiana)

Number	ATON Type	ATON Characteristics	Latitude	Longitude	Cluster
367	light	on research cage Fl Y 4s	29.9775	88.6050	5
370	buoy	red, horn, Q, R	29.5847	88.6828	5
397	buoy	white, Fl W 4s, lighted mooring buoy	28.1602	89.2633	5
400	buoy	white with orange bands, wreck buoy	29.1668	88.8836	5
402	buoy	Green , Q, Lighted horn buoy	29.2390	88.8837	5
405	buoy	red, lighted bell buoy , Fl R 6s	29.2380	88.9578	5
410	buoy	red, lighted bell buoy, Fl R 2.5s	29.1649	88.9423	5
414	buoy	white with blue bands,Q,W	29.1172	88.8583	5
416	buoy	white with orange bands, ocean energy buoy	28.9887	89.0818	2
417	buoy	red,lighted horn, Q,R	28.9881	89.0824	2
425	light	reef light, Fl Y 2.5s, NY on pile	30.2021	89.0811	5
430	light	Fl (5) W 60sskeleton tower, white below gallery, black above, Q,W	29.0152	89.1667	2
435	beacon	On texaco platform, Q,W, RACON	28.8661	89.2608	5
445	buoy	red, lighted bell buoy, Fl R 2.5s	28.9787	89.1087	2
455	light	tower on white dwelling on piles, Fl W 10s, Racon	28.9059	89.4286	5
460	beacon	on texaco platform A, Racon	28.8336	89.4534	5
465	buoy	red and white stripes with red spherical topmark, lighted whistle, Mo(A) W	28.8775	89.4319	5
467	buoy	white with orange bands lighted, Fl W 2.5s	28.8298	89.5265	5
468	buoy	white with orange bands lighted, Fl W 2.5s	28.8770	89.5357	5

Table 33. Light list/ cluster data (Louisiana) cont.

Number	ATON Type	ATON Characteristics	Latitude	Longitude	Cluster
470	buoy	white with orange bands lighted, Fl W 2.5s	28.7970	89.5583	5
481	buoy	red, private aid lighted, Q, R	28.9972	89.5283	5
482	beacon	on shell-WD-143-platform 1, Q, W , RACON	28.6617	89.5511	5
490	buoy	lighted bell, Fl G 4s, green	29.2238	89.6149	5
491	buoy	lighted Fl W 2.5s, white with orange bands, Exxon	28.9442	89.7111	5
493	buoy	lighted, Fl W 2.5s, white with orange bands,	28.9565	89.7520	5
495	buoy	LSU oceangraphic lighted, Fl Y4s, yellow	30.3843	86.7633	5
500	buoy	red and white stripes with red spherical topmark, lighted whistle, Mo(A) W	29.2328	89.9020	1
510	buoy	BP America lighted, Fl W 2.5s, white with orange bands	29.0314	89.8859	5
513	beacon	articulated beacon A , Fl Y 4s, ny on pillar buoy, (NIGHT) Fl Y 4s	29.1933	89.8833	4
513.1	beacon	Articulated beacon B, Fl Y 4s, ny on pillar buoy	29.1933	89.8950	4
513.2	beacon	articulated beacon C, Fl Y 4s, ny on pillar buoy	29.1850	89.8983	4
513.3	beacon	articulated beacon D, Fl Y 4s, ny on pillar buoy	29.1817	89.8883	4
513.4	beacon	Articulated beacon E, Fl Y 4s, ny on pillar buoy	29.1850	89.8800	4
530	light	Fl W 10s, on platform, RACON, Q, W, Horn	28.8850	90.0250	4
535	buoy	Lighted horn buoy, Fl G 6s, green	28.8100	89.9167	5
538	buoy	lighted buoy Fl W 2.5s, white with orange bands	28.6856	89.9592	5
540	buoy	lighted buoy Fl R 6s	28.8383	89.8983	5
545	buoy	lighted buoy Fl G 6s, green	28.8358	90.0400	4
550	buoy	lighted buoy, Fl R 6s, red	28.9144	89.9500	5
555	buoy	lighted mooring buoy, Q,W, white deck with yellow sides	28.8883	89.9997	4

Table 33. Light list/ cluster data (Louisiana) cont.

Number	ATON Type	ATON Characteristics	Latitude	Longitude	Cluster
560	buoy	lighted mooring buoy, Q,W, white deck with yellow sides	28.8711	90.0050	4
565	buoy	lighted mooring buoy,Q,W, white deck with yellow sides	28.8625	90.0233	4
570	buoy	lighted mooring buoy, Fl W 4s , white	28.8883	90.0200	4
575	buoy	lighted mooring buoy, Fl W 4s, white	28.8833	90.0333	4
580	buoy	lighted mooring buoy, Fl W 4s, white	28.8900	90.0453	4
590	buoy	lighted buoy, Fl Y 6s, yellow	28.8683	89.8783	5
595	buoy	lighted buoy, Fl Y 6s, yellow	28.9017	89.9433	5
597	buoy	lighted buoy, Fl W 2.5s, white with orange bands	28.7699	89.9721	5
600	light	Fl W 4s on pile, horn	29.1000	90.1133	4
605	light	Fl W 4s on pile,	29.1017	90.1150	4
615	buoy	lighted buoy, Fl W 2.5s, white with orange bands	28.4299	90.1348	5
625	buoy	lighted buoy, Q,W, red	28.6864	90.1528	5
630	buoy	Shell flare pipe buoy, white with orange bands	28.9750	90.1767	5
631	buoy	lighted buoy, Fl W 2.5s, white with orange bands	28.4432	90.1846	5
633	buoy	lighted buoy, Fl W 2.5s, white with orange bands	28.2799	90.2393	5
9477	light	NOAA shell beach tide monitoring platform light, Fl Y 2.5s,	29.8681	89.6732	3
9495	light	Fl W 6s, nb on dolphin, radar reflector	29.9463	89.7084	5
9500	light	Fl W 2.5s, nb on dolphin, radar reflector	30.0196	89.7199	5
9565	light	Fl R 6s , TR on dolphin, radar reflector	30.1610	89.6521	2
9570	light	Fl G 4s, SG on dolphin, radar reflector	30.1733	89.6888	2
9575	light	Fl R 4s, TR on dolphin	30.1669	89.7167	2
9577	buoy	LSU oceanographic lighted buoy, FL Y 4s, Yellow	30.1720	89.7300	2

Table 33. Light list/ cluster data (Louisiana) cont.

Number	ATON Type	ATON Characteristics	Latitude	Longitude	Cluster
9580	light	FI G 6s, SG on pile, radar reflector	30.1646	89.7360	2
9585	light	FI G 4s, SG on dolphin, radar reflector	30.1749	89.7431	2
9590	light	FI R 2.5s, TR on pile, radar reflector	30.1771	89.7546	2
9595	beacon	NW on pile worded Danger Rocks	30.1653	89.7492	2
9600	beacon	NW on pile worded Danger Rocks	30.1645	89.7492	2
9715	light	FI G 6s, green, SG on pile, radar reflector	30.1416	89.8588	5
9603	beacon	NW on pile worded Danger do not proceed	30.2292	89.7465	2
9810	light	Q, R, on concrete platform	30.1518	89.8964	5
9935	light	Q,W	30.0600	90.0300	5
9937	light	FI Y 4s, on pile	30.1644	90.0819	5
9992	light	FI (2)W 5s, on skeleton pole	30.0272	90.1132	5
10050	light	Q,W, on concrete slab.	30.3609	90.0940	3
10055	light	Q,W, on concrete slab.	30.3591	90.0949	3
10240	light	F R, on square platform	30.0317	90.1750	5
10281	light	FI Y 4s, on pile	30.0322	90.1955	5
10360	light	Q,W,on power line structure	30.0817	90.4017	5
10362	light	steel dolphins	30.0441	90.2369	5
10363	light	FI G 2.5s, steel dolphin	30.0333	90.2333	5
10365	light	Q,W, on power line structures	30.3831	90.1975	5
10367	light	Lumcon environmental monitoring station light,FI Y 2.5s, on platform	30.3146	90.2805	5
10426	beacon	NW on pile worded : Danger barricade ahead	30.3311	90.4117	2
10427	buoy	lighted buoy, white with orange bands and open face diamond	30.3314	90.4119	2
10428	beacon	NW on pile worded: Danger barricade ahead	30.3353	90.4125	1
10685	light	pipeline light, Q, G, SG on piles	29.5227	89.1687	4

Table 33. Light list/ cluster data (Louisiana) cont.

Number	ATON Type	ATON Characteristics	Latitude	Longitude	Cluster
10690	light	pipeline light, Q, R, TR on piles	29.5249	89.1662	4
10695	light	pipeline light, Q,R pile structure	29.5243	89.1713	4
10700	light	pipeline light, Q, R pile structure	29.5263	89.1695	4
10795	light	FI G 4s, SG on dolphin	29.6331	89.3262	2
10815	light	FI G 4s, SG on dolphin	29.6522	89.3536	2
10825	beacon	SG on pile	29.6567	89.3671	2
10830	beacon	TR on pile, radar reflector	29.6555	89.3656	2
10835	beacon	SG on pile	29.6589	89.3644	2
10840	beacon	TR on pile radar reflector	29.6584	89.3638	2
10860	light	Q R TR on pile, radar reflector	29.6779	89.3856	2
10880	light	FI R 4s, TR on pile	29.7071	89.4280	5
10980	light	Q,G, SG on pile	29.8401	89.6238	4
10985	light	Q, R, TR on pile radar reflector	29.8421	89.6230	4
10990	light	FI G 2.5s, SG on pile, radar reflector	29.8463	89.6458	4
10995	light	FI R 2.5s, TR on dolphin	29.8490	89.6453	4
11000	light	FI G 2.5s , SG on pile	29.8566	89.6804	3
11005	light	FI R 2.5s, TR on skeleton tower on piles	29.8585	89.6799	3
11010	light	Q,G, SG on skeleton tower on piles	29.8648	89.7091	3
11015	light	Q,R, TR on skeleton tower on plies	29.8667	89.7081	3
11020	light	FI G 2.5s, SG on pile	29.8748	89.7293	3
11025	light	FI R 2.5s, TR on dolphin	29.8767	89.7283	3
11030	light	FI G 4s SG on skeleton tower on piles.	29.8847	89.7490	3
11035	light	FI R 4s TR on pile, radar reflector	29.8864	89.7475	3
11040	light	FI G 2.5s, SG on pile	29.9030	89.7844	4
11045	light	FI R 2.5s,TR on skeleton tower on piles	29.9049	89.7835	4

Table 33. Light list/ cluster data (Louisiana) cont.

Number	ATON Type	ATON Characteristics	Latitude	Longitude	Cluster
11050	light	Q, G, SG on skeleton tower on piles	29.9162	89.8102	4
11055	light	Q, R, TR on skeleton tower on piles	29.9178	89.8087	4
11060	light	Fl G 2.5s, SG on pile	29.9416	89.8419	4
11065	light	Fl R 2.5s, TR on pile	29.9433	89.8401	4
11070	light	Fl G 6s, SG on pile	29.9553	89.8591	4
11075	light	Fl R 6s, TR on pile	29.9568	89.8568	4
11080	light	Fl G 4s, SG on dolphin, radar reflector	29.9733	89.8809	4
11085	light	Fl R 4s, TR on skeleton tower on piles	29.9748	89.8794	4
11090	light	Fl G 6s, SG on pile	29.9855	89.8965	4
11095	light	Fl Y 2.5s, nw on pile	29.9889	89.9011	4
11100	light	Fl R 6s, TR on pile	29.9871	89.8982	4
11105	light	Fl Y 2.5s, nw on pile	29.9908	89.8992	4
11110	light	Fl G 4s, SG on dolphin	30.0006	89.9149	4
11115	light	Fl R 4s, TR on skeleton tower on piles	30.0012	89.9119	4
11120	light	Fl G 2.5s, SG on dolphin	30.0054	89.9233	4
11125	light	Fl R 2.5s, TR on dolphin	30.0051	89.9172	4
11130	light	Fl (2+1) R 6s, JR-SY on skeleton tower on piles	30.0077	89.9217	4
11135	light	Fl G 4s, SG-SY on pile	30.0054	89.9317	4
11140	light	Fl R 2.5s	30.0067	89.9342	4
11145	light	Fl R 2.5s, on dolphin	30.0039	89.9497	4
11150	light	Fl R 2.5s, TR-TY on skeleton tower on piles	30.0029	89.9551	4
11152	light	Fl R 2.5s , on dolphins	29.9978	90.0097	5
15195	light	Fl G 2.5s , SG on dolphin	29.3728	89.6658	5
15200	light	Fl G 4s, SG on dolphin	29.3795	89.6413	5
15225	buoy	Fl G 4s, green	29.3716	89.6017	5
15323	buoy	Green Can	29.2412	89.9129	1
15325	buoy	Red nun	29.2430	89.9117	1
15328	buoy	Green Can	29.2472	89.9203	1
15330	buoy	Red nun	29.2489	89.9183	1
15338	Buoy	Green Can	29.2522	89.9266	1

Table 33. Light list/ cluster data (Louisiana) cont.

Number	ATON Type	ATON Characteristics	Latitude	Longitude	Cluster
15340	buoy	Fl R 6s , Red	29.2547	89.9251	1
15343	buoy	Green Can	29.2561	89.9316	1
15345	buoy	Red nun	29.2583	89.9303	1
15347	buoy	Green Can	29.2631	89.9391	1
15348	buoy	Red nun	29.2648	89.9372	1
15350	buoy	Green Can	29.2686	89.9453	1
15355.5	light	On pipe FL Y 2.5s	29.2728	89.9468	1
15356	beacon	nw on pile worded Danger rocks	29.2723	89.9435	1
15356.1	light	FL W 2.5s, nw on pile worded Danger rocks	29.2720	89.9439	1
15356.2	light	FL W 2.5s, nw on pile worded Danger rocks	29.2719	89.9451	1
15356.3	beacon	nw on piles worded Danger rocks	29.2727	89.9463	1
15356.4	beacon	nw on pile worded Danger rocks	29.2730	89.9464	1
15357	light	on four pile cluster	29.2712	89.9447	1
15360	light	FL W 3s end of fishing piers on pilings	29.2611	89.9500	1
15365	light	QR on pile structure	29.2624	89.9489	1
15366	beacon	NW on pile. Worded danger breakwater	29.2580	89.9483	1
15366.01	beacon	NW on pile. Worded danger breakwater	29.2562	89.9510	1
15485	light	FL Y 2.5s nw on pile do not anchor or dredge	29.2653	89.9719	1
15545	beacon	Shell Reef Daybeacon, NW on pile. Worded danger, radar reflector	29.3444	89.9408	1
15525	light	FL Y 4s nw on pile	29.3975	89.7958	2
15530	light	FL Y 4s nw on pile	29.3981	89.7961	2
15535	light	Q, W	29.3925	89.7933	2
15540	light	Q, R, on pile	29.3919	89.7981	2
15595	light	Q, W, nw on pile worded do not anchor or dredge	29.2767	89.9567	1
15600	light	Fl G 4s, SG on dolphin, radar reflector	29.2783	89.9586	1

Table 33. Light list/ cluster data (Louisiana) cont.

Number	ATON Type	ATON Characteristics	Latitude	Longitude	Cluster
15605	light	Q, R, TR on pile, radar reflector	29.2793	89.9575	1
15610	light	FI y 2.5s, nw on pile worded do no anchor or dredge	29.2801	89.9579	1
15615	light	FI Y 2.5s, nw on pile worded do not anchor or dredge	29.2783	89.9591	1
15620	Buoy	red nun	29.2805	89.9601	1
15625	beacon	SG on pile, radar reflector	29.2832	89.9653	1
15630	beacon	TR on pile, radar reflector	29.2842	89.9646	1
15635	beacon	Black diamond daymark on pile, FI W	29.2850	89.9650	1
15640	beacon	Black diamond daymark on pile,FI W	29.2917	89.9717	1
15650	beacon	Black diamond daymark on pile, FI W	29.2917	89.9733	1
15665	light	FI G 2.5s, SG on pile, radar reflector	29.2903	89.9741	1
15670	light	FI R 2.5s, TR on pile, radar reflector	29.2908	89.9728	1
15675	beacon	SG on pile, radar reflector	29.2987	89.9786	1
15680	beacon	TR on pile, radar reflector	29.2993	89.9774	1
15685	light	FI R 2.5s, TR on pile, radar reflector	29.3063	89.9810	1
15690	beacon	SG on pile, radar reflector	29.3060	89.9818	1
15695	beacon	TR on pile, radar reflector	29.3120	89.9835	1
15700	beacon	SG on pile, radar reflector	29.3112	89.9842	1
15705	light	FI G 4s, SG on pile, radar reflector	29.3188	89.9860	1
15710	light	FI R 4s, TR on pile, radar reflector	29.3188	89.9835	1
15715	light	FI G 6s, SG on pile, radar reflector	29.3329	89.9856	1
15720	beacon	TR on pile, radar reflector	29.3329	89.9846	1
15730	light	FI R 6s, Tr on pile, radar reflector	29.3489	89.9842	1
15735	light	FI G 2.5s, SG on pile, radar reflector	29.3639	89.9846	3
15740	light	FI R 2.5s, TR on pile, Radar reflector	29.3641	89.9834	3

Table 33. Light list/ cluster data (Louisiana) cont.

Number	ATON Type	ATON Characteristics	Latitude	Longitude	Cluster
15745	beacon	SG on pile, radar reflector	29.3689	89.9851	3
15750	beacon	TR on pile, radar reflector	29.3696	89.9838	3
15755	beacon	SG on pile, radar reflector	29.3761	89.9861	3
15760	light	FI R 4s, TR on pile, radar reflector	29.3751	89.9844	3
15765	light	FI G 4s, SG on pile, radar reflector	29.3830	89.9869	3
15770	beacon	TR on pile, radar reflector	29.3828	89.9855	3
15775	beacon	SG on pile, radar reflector	29.3889	89.9876	3
15780	light	FO R 2.5s, TR on pile, radar reflector	29.3890	89.9865	3
15825	beacon	SG on pile, radar reflector	29.3955	89.9886	3
15830	beacon	TR on pile, radar reflector	29.3957	89.9876	3
15835	light	FI G 6s, SG on pile, radar reflector	29.4059	89.9902	3
15840	light	FI R 6s, Tr on pile, radar reflector	29.4059	89.9891	3
15845	beacon	SG on pile, radar reflector	29.4163	89.9918	3
15850	beacon	TR on pile, radar reflector	29.4209	89.9916	3
15855	beacon	SG on pile, radar reflector	29.4271	89.9936	3
15860	light	Q, G, SG on pile, radar reflector	29.4250	89.9999	3
15865	light	FI R 4s, TR on pile, radar reflector	29.4378	89.9942	3
15870	beacon	SG on pile, radar reflector	29.4416	89.9960	3
15875	beacon	TR on pile, radar reflector	29.4534	89.9970	3
15880	light	Q, G, SG on pile, radar reflector	29.4668	90.0004	2
15885	light	Q, R, TR on pile, radar reflector	29.4674	89.9998	2
15890	buoy	Green Can	29.4716	90.0038	2
15895	buoy	Red nun	29.4715	90.0027	2
15900	light	FI G 2.5s, SG on pile, Radar reflector	29.4753	90.0073	2
15905	light	FI R 2.5s, TR on pile, radar reflector	29.4761	90.0061	2
15910	beacon	TR on pile, radar reflector	29.4806	90.0111	2
15915	beacon	SG on pile, radar reflector	29.4882	90.0171	2

Table 33. Light list/ cluster data (Louisiana) cont.

Number	ATON Type	ATON Characteristics	Latitude	Longitude	Cluster
15920	buoy	red nun	29.4922	90.0170	2
15925	light	FI R 4s, TR on pile, radar reflector	29.4949	90.0184	2
15930	light	FI G 4s , SG on pile, radar reflector	29.4989	90.0214	2
15933	light	FI Y 2.5s, NW on dolphin worded Danger	29.4528	90.0325	2
15934	light	FI Y 2.5s, NB on dolphin worded danger submerged pipeline	29.4517	90.0400	2
15935	light	on dolphin	29.5533	90.0433	2
15936	light	on dolphin	29.5533	90.0450	2
15938	light	FL Y 2.5s nw on dolphin worded danger submerged pipeline	29.5819	90.0618	2
15939	light	FL Y 2.5s nw on dolphin worded danger submerged pipeline	29.5819	90.0607	2
15940	light	FL Y 2.5s on dolphin	29.5831	90.0611	2
15945	light	FL Y 2.5s on dolphin	29.5833	90.0597	2
15948	light	FL G 4s SG on pile, radar reflector	29.5779	90.0592	2
15949	light	FL R 4s TR on pile, radar reflector	29.5877	90.0640	2
15950	light	FL G 2.5s SG on pile, radar reflector	29.6009	90.0728	2
15955	light	FL R 2.5s TR on pile, radar reflector	29.6012	90.0720	2
15960	beacon	SG on pile, radar reflector	29.6112	90.0790	2
15965	beacon	TR on pile radar reflector	29.6115	90.0780	2
15970	light	FL G 4s SG on pile, radar reflector	29.6232	90.0859	2
15975	light	FL R 4s TR on pile, radar reflector	29.6237	90.0847	2
15980	light	FL R 2.5s TR on pile, radar reflector	29.6457	90.0980	2
15985	light	FL G 4s SG on pile, radar reflector	29.6663	90.1120	2
15990	light	FL R 4s TR on pile, radar reflector	29.6670	90.1122	2

Table 33. Light list/ cluster data (Louisiana) cont.

Number	ATON Type	ATON Characteristics	Latitude	Longitude	Cluster
16205	light	Q, R, on dolphin	29.1991	90.0411	5
16210	light	FI Y 2.5s, NW on dolphin worded Do not anchor or dredge	29.2094	90.0433	5
16217	beacon	NW on pile worded danger submerged oyster reef	29.3506	90.1318	5
16218	beacon	white with orange band worded danger barricade ahead	29.3551	90.0893	5
16220	light	Q, W , SG on pile	29.5325	90.1642	4
16225	light	Q,W, SG on pile	29.5325	90.1600	4
16230	light	Q,W, SG on pile	29.5322	90.1550	4
16235	ligh	Q,W,SG on pile	29.5472	90.1664	4
16240	light	Q,W, TR on pile	29.5467	90.1608	4
16245	light	FI W 4s TR on pile	29.0711	90.1797	3
16515	buoy	lighted bell buoy, Q, R, Red	29.5172	90.2279	4
16530	buoy	Q,G, Green	29.0717	90.2314	3
16535	light	Q, G, KRW on platform	29.0986	90.2232	3
16535.01	light	Iso G 6s, KRW on platform	29.1234	90.2176	3
16540	light	FI G 2.5s, SG on pile, Radar reflector	29.0794	90.2294	3
16547	light	FI R 2.5s, TR on pile, radar reflector	29.0789	90.2257	3
16550	light	FI R 4s TR on pile, radar reflector	29.0845	90.2253	3
16555	light	FI R 6s , TR on pile, radar reflector	29.0910	90.2241	3
16560	light	Q,W on pile	29.0863	90.5571	1
16570	light	Q,W, on pile	29.1001	90.5296	1
16575	light	Q,W, SG on pile	29.0964	90.5283	1
16580	beacon	SG on pile	29.0961	90.5283	1
16585	beacon	SG on pile	29.0942	90.5281	1
16590	beacon	SG on pile	29.0922	90.5278	1
16595	beacon	SG on pile	29.0908	90.5272	1
16600	beacon	SG on pile	29.0894	90.5267	1
16605	beacon	SG on pile	29.0886	90.5267	1
16610	beacon	SG on pile	29.0881	90.5264	1

Table 33. Light list/ cluster data (Louisiana) cont.

Number	ATON Type	ATON Characteristics	Latitude	Longitude	Cluster
16615	light	Q,W on pile	29.1078	90.5055	1
16620	light	Q,W on pile	29.1121	90.4970	1
16625	light	Q,W on pile	29.1116	90.4856	1
16630	light	Q,W on pile	29.1115	90.4846	1
16635	beacon	TR on pile	29.0922	90.4964	1
16640	beacon	TR on pile	29.0917	90.4950	1
16645	beacon	TR on pile	29.0911	90.4933	1
16650	beacon	TR on pile	29.0903	90.4917	1
16655	light	TR on pile	29.0747	90.4700	1
16660	beacon	TR on pile	29.0733	90.4706	1
16665	beacon	TR on pile	29.0719	90.4708	1
16670	beacon	TR on pile	29.0706	90.4714	1
16675	beacon	TR on pile	29.0697	90.1797	3
16684	light	On wooden structure FL 2.5s Y	29.1273	90.5142	1
16684.01	light	Q,Q, TR on four pile platform	29.0789	90.4556	1
16685	beacon	TR on piles	29.0706	90.4542	1
16690	beacon	TR on piles	29.0694	90.4539	1
16695	beacon	TR on piles	29.0681	90.4539	1
16696.01	beacon	SG on pile, radar reflector	29.1656	90.5818	5
16696.03	light	Fl G 4s, SG on pile	29.1651	90.5637	5
16696.07	light	Fl G 6s, SG on pile	29.1642	90.5275	5
16696.11	light	Fl G 4s SG on pile	29.1632	90.4914	5
16696.15	light	Fl G 6s , SG on pile	29.1623	90.4552	5
16696.19	light	Fl G 4s, SG on pile	29.1613	90.4190	5
16696.23	light	Fl G 6s , SG on pile	29.1604	90.3828	5
16696.27	light	Q, G, SG on pile, radar reflector	29.1594	90.3467	5
16696.29	beacon	SG on pile, radar reflector	29.1507	90.3322	5
16696.31	light	Fl G 4s, SG on pile	29.1418	90.3178	5
16696.33	beacon	SG on pile, radar reflector	29.1328	90.3034	5
16696.36	light	Q, R, TR on pile, radar reflector	29.1233	90.2892	5
16696.38	light	Fl R 4s, TR on pile, radar reflector	29.1278	90.2760	5

Table 33. Light list/ cluster data (Louisiana) cont.

Number	ATON Type	ATON Characteristics	Latitude	Longitude	Cluster
16696.4	light	Fl R 6s, Tr on pile, radar reflector	29.1324	90.2630	5
16696.42	light	Q, R, TR on pile, radar reflector	29.1370	90.2494	5
16699	buoy	Fl(2+1)R 6s Red with green band	29.1652	90.6000	5
16780	light	Fl G 4s SG on dolphin	29.1939	90.3496	5
16785	light	Fl R 4s TR on dolphin	29.1864	90.4186	5
16790	light	Fl W 4s, SG on dolphin	29.2025	90.2689	3
16795	light	Fl W 4s, SG on dolphin	29.2275	90.3000	3
16800	buoy	Green Can	29.2289	90.2989	3
16805	buoy	Green Can	29.2306	90.2978	3
16810	buoy	Green Can	29.2319	90.2964	3
16815	buoy	Green Can	29.2333	90.2953	3
16820	buoy	Green Can	29.2350	90.2942	3
16825	buoy	Green Can	29.2364	90.2931	3
16830	buoy	Green Can	29.2378	90.2919	3
16835	buoy	Green Can	29.2394	90.2908	3
16840	buoy	Green Can	29.2411	90.2903	3
16845	light	Fl W 4s, SG on piles	29.2464	90.2825	3
16850	buoy	Green Can	29.2464	90.2806	3
16855	buoy	Green Can	29.2461	90.2786	3
16860	buoy	Green Can	29.2458	90.2767	3
16865	buoy	Green Can	29.2458	90.2744	3
16870	buoy	Green Can	29.2456	90.2725	3
16875	buoy	Green Can	29.2453	90.2706	3
16880	buoy	Green Can	29.2450	90.2683	3
16885	buoy	Green Can	29.2450	90.2664	3
16890	buoy	Green Can	29.2447	90.2644	3
16895	buoy	Green Can	29.2444	90.2622	3
16900	buoy	Green Can	29.2444	90.2603	3
16905	buoy	Green Can	29.2442	90.2583	3
16910	buoy	Green Can	29.2439	90.2439	3
16915	light	Q, R, on pile	29.2393	90.1797	5
16920	beacon	SG on pile	29.2910	90.3512	4

Table 33. Light list/ cluster data (Louisiana) cont.

Number	ATON Type	ATON Characteristics	Latitude	Longitude	Cluster
16925	beacon	SG on pile	29.2943	90.3475	4
16930	beacon	SG on pile	29.2949	90.3453	4
16935	beacon	SG on pile	29.2949	90.3407	4
16940	beacon	SG on pile	29.2958	90.3375	4
16945	beacon	SG on pile	29.2984	90.3348	4
16950	beacon	SG on pile	29.3008	90.3346	4
16955	beacon	SG on pile	29.3030	90.3352	4
16960	beacon	SG on pile	29.3055	90.3382	4
16965	beacon	SG on pile	29.3076	90.3404	4
16967	light	SG on pile	29.5435	90.4002	5
16990	light	Fl G 4s, SG on dolphin, radar reflector	29.2727	90.4753	5
16995	light	Fl R 4s, TR on pile, radar reflector	29.3204	90.4376	5
17000	light	Fl G 4s, SG on pile, radar reflector	29.1821	90.5835	5
17005	light	Fl R 2.5s, TR on dolphin, radar reflector	29.2072	90.5806	5
17010	light	Fl R 4s, TR on dolphin, radar reflector	29.2250	90.5961	5
17015	light	Fl G 6s, SG on dolphin, radar reflector	29.2324	90.6032	5
17020	light	Fl G 4s, SG on dolphin, radar reflector	29.2439	90.5914	5
17025	light	Fl G 2.5s, SG on dolphin, radar reflector	29.2489	90.5777	5
17030	light	Fl W 4s, NB on pile, radar reflector	29.2887	90.5407	5

Table 34. Damaged aids to navigation for Hurricane Katrina (Alabama)

LLNR	Latitude	Longitude	Region	Discrepancy Summary
6190	30.47667	88.01197	Alabama	Missing
6030	30.25461	88.05721	Alabama	Temporarily Replaced by Unlighted Buoy
5770	30.37023	88.85473	Alabama	LT EXT
5440	30.63964	88.03333	Alabama	LT EXT
6025	30.2537	88.0563	Alabama	TRUB
6050	30.25359	88.0619	Alabama	DBN DEST
6055	30.25257	88.06353	Alabama	TRUB/DBD DES
6075	30.25226	88.07207	Alabama	DBN DEST
6080	30.25201	88.07577	Alabama	DBN DEST
6095	30.24993	88.07333	Alabama	TRUB/LT EXT/DBD DEST
6100	30.25009	88.06828	Alabama	TRLB
6160	30.45393	88.1039	Alabama	LT EXT
6167	30.45064	88.10864	Alabama	DBN DEST
6180	30.44398	88.1123	Alabama	DBN DEST
6185	30.44436	88.11333	Alabama	DBN DEST
5295	30.47742	88.01902	Alabama	DBN DEST
6220	30.48727	88.03249	Alabama	TRLB/LT EXT/DBD DEST
6230	30.49487	88.04551	Alabama	TRLB/LT EXT/DBD DEST
6235	30.49652	88.0442	Alabama	TRLB/LT EXT/DBD DEST
6245	30.50458	88.05858	Alabama	TRLB
6250	30.51023	88.07252	Alabama	TRLB/LT EXT/DBD DEST
6260	30.51497	88.08136	Alabama	TRLB/LT EXT/DBD DEST
6275	30.51908	88.0836	Alabama	DBN DEST
6280	30.51943	88.08858	Alabama	TRUB/DBD DEST
6295	30.52353	88.09213	Alabama	TRLB/LT EXT/DBD DEST
6460	30.54597	88.02684	Alabama	MISSING/TRUB
6465	30.54695	88.02762	Alabama	DBN DEST
6470	30.55501	88.04118	Alabama	LT EXT/DBD DEST
6475	30.5554	88.04089	Alabama	DBN DEST
6480	30.56379	88.05555	Alabama	DBN DEST
6490	30.56635	88.07023	Alabama	MISSING/TRUB
6495	30.56676	88.07019	Alabama	LT EXT
6505	30.56644	88.07348	Alabama	DBN DEST
6510	30.56698	88.07336	Alabama	DBN DEST

Table 34. Damaged aids to navigation for Hurricane Katrina (Alabama) cont.

LLNR	Latitude	Longitude	Region	Discrepancy Summary
6515	30.56678	88.07649	Alabama	LT EXT/DBD DEST
6520	30.5672	88.07651	Alabama	DBN DEST
6530	30.56641	88.08163	Alabama	DBN DEST
6535	30.56487	88.08451	Alabama	LT EXT/DBD DEST
6540	30.56564	88.08469	Alabama	DBN DEST
6640	30.30246	88.26683	Alabama	MISSING
6643	30.30497	88.27405	Alabama	MISSING
6648	30.25936	88.4278	Alabama	MISSING/TRUB
32684	30.24773	88.42565	Alabama	MISSING/TRUB
32682	30.2546	88.34594	Alabama	MISSING/TRUB
6660	30.27473	88.31618	Alabama	MISSING
6666	30.29789	88.30712	Alabama	MISSING
6670	30.31285	88.30058	Alabama	MISSING
6695	30.37218	88.27526	Alabama	LT EXT
6255	30.51245	88.07248	Alabama	TRLB/LT EXT/DBD DEST
6674	30.32891	88.29407	Alabama	MISSING
6678	30.34436	88.28757	Alabama	MISSING
6225	30.48873	88.03095	Alabama	TRLB/LT EXT/DBD DEST
6285	30.52151	88.08798	Alabama	TRLB/LT EXT/DBD DEST
6485	30.56595	88.05734	Alabama	LT EXT
6525	30.56588	88.08158	Alabama	DBD DMGD/ DBD DEST
6040	30.25412	88.05974	Alabama	TRUB
6060	30.25333	88.06379	Alabama	TRUB
6065	30.25218	88.06703	Alabama	TRUB
6070	30.25286	88.06706	Alabama	TRUB
6035	30.25279	88.05932	Alabama	TRUB/ DBN DEST
5110	30.21587	88.04426	Alabama	LT EXT
5260	30.43996	88.01217	Alabama	MISSING/TRLT
5265	30.45796	88.00957	Alabama	LT EXT/DBD DEST
5267	30.45796	88.00957	Alabama	LT EXT/DBD DEST
5237	30.41132	88.00971	Alabama	MISSING
5236	30.41132	88.00971	Alabama	MISSING
5415	30.6076	88.03332	Alabama	MISSING/TRLT
5417	30.6076	88.03332	Alabama	MISSING
5075	30.26221	88.04227	Alabama	MISSING
4950	30.205	88.03411	Alabama	TRLT/LT IMCH

Table 34. Damaged aids to navigation for Hurricane Katrina (Alabama) cont.

LLNR	Latitude	Longitude	Region	Discrepancy Summary
4953	30.205	88.03411	Alabama	TRLT/REDUCED INT
5070	30.25723	88.04128	Alabama	MISSING
5433	30.63018	88.03423	Alabama	MISSING
5420	30.59385	88.0338	Alabama	MISSING/TRLT
5423	30.59385	88.0338	Alabama	MISSING
5430	30.63018	88.03423	Alabama	MISSING
6195	30.46906	87.99875	Alabama	MISSING
4970	30.14132	88.06333	Alabama	MISSING
4975	30.14037	88.06049	Alabama	OFF STA
4980	30.14823	88.06022	Alabama	OFF STA
4985	30.14739	88.05772	Alabama	OFF STA
5030	30.20022	88.04363	Alabama	OFF STA
5035	30.19982	88.0413	Alabama	OFF STA
5065	30.21361	88.03759	Alabama	MISSING
5085	30.22418	88.03747	Alabama	OFF STA
5095	30.23824	88.03875	Alabama	OFF STA
5100	30.23895	88.03622	Alabama	OFF STA
5155	30.30696	88.03291	Alabama	MISSING
4990	30.15722	88.05627	Alabama	MISSING
4995	30.15646	88.05397	Alabama	OFF STA
5000	30.16507	88.05325	Alabama	OFF STA
5005	30.16421	88.05069	Alabama	OFF STA
5010	30.17257	88.05095	Alabama	OFF STA
5015	30.17234	88.06519	Alabama	OFF STA
5025	30.18332	88.04564	Alabama	OFF STA
5160	30.30662	88.04644	Alabama	MISSING
5165	30.32247	88.03068	Alabama	DBD DMGD/LT EXT
5170	30.32213	88.02754	Alabama	DBD DMGD/LT EXT
5175	30.33811	88.02841	Alabama	DBD DMGD/LT EXT
5180	30.33786	88.02528	Alabama	MISSING
5185	30.34348	88.02447	Alabama	MISSING
5190	30.36023	88.02525	Alabama	MISSING
5195	30.35989	88.02191	Alabama	MISSING
5200	30.04551	88.02257	Alabama	MISSING
5205	30.04517	88.01942	Alabama	MISSING
5210	30.39296	88.02064	Alabama	MISSING

Table 34. Damaged aids to navigation for Hurricane Katrina (Alabama) cont.

LLNR	Latitude	Longitude	Region	Discrepancy Summary
5215	30.3926	88.01739	Alabama	MISSING
5220	30.40995	88.01809	Alabama	MISSING
5225	30.40961	88.01494	Alabama	MISSING
5240	30.42921	88.01531	Alabama	DBD DMGD/LT EXT
5245	30.42902	88.01247	Alabama	MISSING
5250	30.43746	88.01522	Alabama	MISSING
5270	30.44562	88.01512	Alabama	MISSING
5275	30.44574	88.01237	Alabama	DBD DMGD/LT EXT
5280	30.46452	88.01693	Alabama	DBD DMGD/LT EXT
5285	30.46473	88.0144	Alabama	MISSING
5290	30.47704	88.01566	Alabama	DBD DMGD/LT EXT
5305	30.48288	88.01992	Alabama	TRLB/LT EXT/DBD DEST
5310	30.48953	88.01958	Alabama	MISSING
5320	30.50447	88.0214	Alabama	TRLB
5325	30.50468	88.01887	Alabama	DBD DMGD/LT EXT
5330	30.52235	88.02348	Alabama	DBD DMGD
5340	30.52247	88.02081	Alabama	MISSING
5345	30.53902	88.02527	Alabama	MISSING
5350	30.53923	88.02275	Alabama	MISSING
5355	30.55491	88.02706	Alabama	DBD DMGD/LT EXT
5360	30.55512	88.02453	Alabama	DBD DMGD/LT EXT
5365	30.57399	88.0292	Alabama	MISSING
5370	30.5742	88.02667	Alabama	DBD DMGD
5375	30.58995	88.03099	Alabama	DBD DMGD/LT EXT
5380	30.59016	88.02846	Alabama	MISSING
5385	30.60572	88.03276	Alabama	MISSING
5390	30.60594	88.03023	Alabama	MISSING
5400	30.61844	88.03419	Alabama	HAZ NAV/LT EXT/DBD DMGD
5405	30.61847	88.03129	Alabama	DBD DMGD/LT EXT
5425	30.62928	88.03124	Alabama	DBD DMGD/LT EXT
5455	30.64967	88.03049	Alabama	MISSING
6555	30.64279	88.03703	Alabama	TRLB
6595	30.64814	88.05456	Alabama	DBD DMGD
32655	30.2635	88.25394	Alabama	TRUB/DBD DEST
32665	30.2623	88.26723	Alabama	TRLB/LT EXT/DBD DEST
32645	30.26464	88.23931	Alabama	MISSING

Table 34. Damaged aids to navigation for Hurricane Katrina (Alabama) cont.

LLNR	Latitude	Longitude	Region	Discrepancy Summary
32637	30.26441	88.22424	Alabama	MISSING
32627	30.2657	88.20955	Alabama	MISSING
32625	30.26704	88.20959	Alabama	TRUB/DBD DEST
32605	30.271	88.14992	Alabama	MISSING
32520	30.25912	88.1156	Alabama	LT EXT/DBD DEST
32515	30.25952	88.11531	Alabama	DBD DEST
32510	30.26246	88.12298	Alabama	LT EXT/DBD DEST
32500	30.26552	88.12962	Alabama	DBD DEST
32495	30.26606	88.12947	Alabama	DBD DEST
32490	30.26922	88.13618	Alabama	MISSING/TRUB
32485	30.27145	88.14243	Alabama	DBD DEST
32480	30.27507	88.14873	Alabama	DBD DEST
32475	30.27854	88.155	Alabama	DBD DEST
32450	30.25823	88.21316	Alabama	LT EXT/DBD DEST
32445	30.26656	88.19041	Alabama	DBD DEST
32377	30.29389	88.12141	Alabama	DBD DMGD/LT EXT
6215	30.48172	88.02301	Alabama	TRLB/LT EXT/DBD DEST
6655	30.27054	88.32127	Alabama	MISSING/TRUB
6750	30.37608	88.24147	Alabama	DBD DEST
6710	30.37626	88.26265	Alabama	LT EXT/DBD DEST
32600	30.26881	88.17745	Alabama	TRLB/LT EXT/DBD DEST
32635	30.26587	88.22404	Alabama	TRUB
5120	30.25251	88.03798	Alabama	OFF STA
5125	30.26293	88.03855	Alabama	OFF STA
5445	30.6413	88.031	Alabama	TRLB/DBD DMGD/LT EXT
255	30.12527	88.06867	Alabama	MISSING
6197	30.46906	87.99875	Alabama	MISSING
5155	30.30696	88.03291	Alabama	LIGHT EXTINGUISHED
6590	30.64783	88.04991	Alabama	TRUB/DBN DEST
31140	30.39975	86.75904	Alabama	OFF STATION
6575	30.64519	88.04451	Alabama	MISSING/TRLB
6610	30.65006	88.05917	Alabama	LIGHT EXTINGUISHED
5585	30.28398	87.75642	Alabama	TRLB
5280	30.46452	87.01693	Alabama	TRLB
5700	30.30328	87.72714	Alabama	TRUB
6560	30.64372	88.03671	Alabama	MISSING
6580	30.64623	88.04464	Alabama	DBN DEST

Table 35. Damaged aids to navigation Hurricane Katrina (Florida)

LLNR	Latitude	Longitude	Region	Discrepancy Summary
3265	30.14492	85.66659	Florida	LT EXT
3795	30.38923	86.51369	Florida	OFF STA
3805	30.39106	86.51552	Florida	OFF STA
165	30.37075	86.515	Florida	OFF STA
3755	30.37501	86.51401	Florida	OFF STA
1608	30.11537	84.20377	Florida	OFF STA
1610	30.11771	84.20239	Florida	BUOY DMGD
1595	30.11093	84.20308	Florida	OFF STA
1470	30.07137	84.19115	Florida	BUOY DMGD
1695	30.13959	84.20781	Florida	MISSING
205	30.25854	87.55676	Florida	OFF STA
3955	30.29476	87.31195	Florida	OFF STA
185	30.27103	87.29247	Florida	OFF STA
3965	30.30111	87.30113	Florida	OFF STA
31625	30.33355	87.31746	Florida	OFF STA
30050	30.38371	86.11861	Florida	OFF STA
3200	30.11366	85.73988	Florida	OFF STA
3210	30.12097	85.72909	Florida	MISSING
3351	30.17216	85.72475	Florida	LT EXT/DBN DMGD
29280	29.8172	85.16936	Florida	DBD DMGD/LT EXT
29120	29.73189	84.98144	Florida	MISSING
28910	29.68003	84.90077	Florida	MISSING
28880	29.68423	84.87927	Florida	MISSING
28875	29.68534	84.87136	Florida	MISSING
28765	29.7156	84.81401	Florida	MISSING
3195	30.11485	85.74094	Florida	OFF STA
4175	30.40711	87.19321	Florida	MISSING
31627	30.33276	87.32031	Florida	OFF STA
3215	30.12431	85.72421	Florida	OFF STATION
3220	30.12852	85.7207	Florida	OFF STATION
31165	30.39697	86.79433	Florida	MISSING/TRLB
4705	30.49969	87.51055	Florida	DBD DMGD
4700	30.4884	87.13408	Florida	MISSING/TRLB

Table 35. Damaged aids to navigation Hurricane Katrina (Florida) cont.

LLNR	Latitude	Longitude	Region	Discrepancy Summary
4710	30.50009	87.13819	Florida	DBD DEST
3760	30.375	86.51279	Florida	OFF STATION
30930	30.40258	86.65316	Florida	LIGHT EXTINGUISHED
30945	30.40626	86.65926	Florida	LIGHT EXTINGUISHED
31180	30.39712	86.83181	Florida	REDUCED INT

Table 36. Damaged aids to navigation Hurricane Katrina (Louisiana)

LLNR	Latitude	Longitude	Region	Discrepancy Summary
4810	30.26978	87.55806	Louisiana	TRLT
14705	30.29508	91.23364	Louisiana	LT EXT/DBD DEST
12955	29.1742	89.25701	Louisiana	LT EXT/DBD DEST
12990	29.20202	89.27146	Louisiana	TRLT
13415	29.7782	90.02512	Louisiana	MISSING
13430	29.83846	89.98412	Louisiana	MISSING
13460	29.87345	89.97142	Louisiana	MISSING
13780	29.94599	90.16637	Louisiana	MISSING
13815	29.92168	90.21319	Louisiana	MISSING
13825	29.97224	90.24555	Louisiana	MISSING
13900	29.93096	90.32953	Louisiana	MISSING
13935	29.94195	90.37252	Louisiana	MISSING
14180	30.04589	90.66976	Louisiana	MISSING
14400	30.10138	90.91341	Louisiana	MISSING
12915	29.16475	89.25246	Louisiana	LT EXT/DBD DEST
12980	29.1924	89.26433	Louisiana	LT EXT/DBD DEST
12995	29.2401	89.29842	Louisiana	MISSING
13000	29.24671	89.3173	Louisiana	LT EXT/DBD DEST
13045	29.34596	89.40276	Louisiana	LT EXT/DBD DEST
13050	29.36227	89.43204	Louisiana	LT EXT/DBD DEST
13070	29.36673	89.45114	Louisiana	LT EXT/DBD DEST
13075	29.36345	89.46125	Louisiana	LT EXT/DBD DEST
13085	29.33995	89.48237	Louisiana	LT EXT/DBD DEST
13100	29.35906	89.50997	Louisiana	LT EXT/DBD DEST
13125	29.37227	89.57162	Louisiana	LT EXT/DBD DEST

Table 36. Damaged aids to navigation Hurricane Katrina (Louisiana) cont.

LLNR	Latitude	Longitude	Region	Discrepancy Summary
13145	29.41861	89.60239	Louisiana	LT IMCH/DBD DEST
13155	29.43831	89.60263	Louisiana	MISSING
13160	29.44248	89.59549	Louisiana	LT EXT/DBD DEST
13170	29.448	89.59727	Louisiana	LT EXT/DBD DEST
13175	29.45599	89.60898	Louisiana	LT EXT/DBD DEST
13185	29.45666	89.65375	Louisiana	LT EXT/DBD DEST
13190	29.46644	89.66179	Louisiana	LT EXT/DBD DEST
13255	29.61194	89.89501	Louisiana	LT EXT/DBD DEST
13365	29.6817	89.96037	Louisiana	DBD DMGD
13405	29.72636	89.99619	Louisiana	LT EXT/DBD DEST
13470	29.88413	89.96863	Louisiana	DBD DMGD
13475	29.87803	89.96026	Louisiana	DBD DMGD
13490	29.86446	89.90986	Louisiana	DBD DMGD
13500	29.92392	89.92442	Louisiana	DBD DMGD
13807	29.92544	90.20401	Louisiana	DBD DMGD
13958	29.96463	90.3922	Louisiana	DBD DMGD
14035	30.00632	90.47018	Louisiana	DBD DMGD
14050	30.04707	90.4743	Louisiana	DBD DMGD
14225	30.0182	90.75685	Louisiana	DBD DMGD
14240	30.01603	90.77833	Louisiana	DBD DMGD
14430	30.13958	90.93331	Louisiana	DBD DMGD
14480	30.11401	90.96673	Louisiana	DBD DMGD
14770	30.34728	91.16299	Louisiana	DBD DMGD
635	29.0711	90.22787	Louisiana	OFF STA
16530	29.07168	90.2314	Louisiana	TRLB
16550	29.08445	90.22534	Louisiana	MISSING
16555	29.09097	90.22407	Louisiana	TRLB
13515	29.91998	89.96739	Louisiana	DBD DMGD
11150	30.0029	89.95506	Louisiana	DBD DMGD
13633	29.95525	90.0553	Louisiana	DBD DMGD
11040	29.90299	89.7844	Louisiana	MISSING
11045	29.90495	89.78348	Louisiana	MISSING
11060	29.94159	89.84187	Louisiana	MISSING
11065	29.94326	89.84006	Louisiana	MISSING
11070	29.95525	89.85906	Louisiana	MISSING
11075	29.95678	89.85684	Louisiana	MISSING

Table 36. Damaged aids to navigation Hurricane Katrina (Louisiana) cont.

LLNR	Latitude	Longitude	Region	Discrepancy Summary
11080	29.97326	89.8809	Louisiana	MISSING
11085	29.97481	89.87938	Louisiana	MISSING
11090	29.98548	89.89653	Louisiana	MISSING
11100	29.98709	89.89449	Louisiana	MISSING
11110	30.00064	89.91487	Louisiana	MISSING
11115	30.00118	89.91188	Louisiana	MISSING
11120	30.00535	89.92327	Louisiana	DBD DMGD/LT EXT
11125	30.00509	89.91721	Louisiana	LT EXT/DBN DMGD
12355	29.40463	89.30798	Louisiana	LT EXT/DBN DMGD
12360	29.40455	89.30944	Louisiana	LT EXT/DBN DMGD
12365	29.39924	89.30724	Louisiana	LT EXT/DBN DMGD
12370	29.39591	89.30837	Louisiana	DBN DMGD
12375	29.39321	89.3065	Louisiana	LT EXT/DBD DEST
12380	29.38936	89.30723	Louisiana	LT EXT/DBD DEST
12385	29.38418	89.30502	Louisiana	LT EXT/DBD DEST
12390	29.38432	89.30663	Louisiana	DBN DMGD
12400	29.37833	89.3056	Louisiana	DBD DMGD/LT EXT
12405	29.37484	89.30367	Louisiana	DBN DMGD
12410	29.37298	89.30467	Louisiana	DBN DMGD
12425	29.36248	89.30159	Louisiana	DBN DMGD
12430	29.3627	89.30305	Louisiana	LT EXT/DBN DMGD
12440	29.35976	89.30257	Louisiana	LT EXT/DBD DEST
12445	29.32076	89.31529	Louisiana	DBN DMGD
12447	29.31421	89.31993	Louisiana	DBN DMGD
12415	29.36787	89.30247	Louisiana	LT EXT/DBD DEST
12420	29.36761	89.30385	Louisiana	LT EXT/DBN DMGD
33090	30.14765	89.62921	Louisiana	MISSING
33085	30.14591	89.62943	Louisiana	MISSING
33045	30.14575	89.55981	Louisiana	MISSING
9140	30.1558	89.52487	Louisiana	MISSING
15165	29.22854	89.34847	Louisiana	TRLB
15160	29.22411	89.34955	Louisiana	TRUB
15157	29.22002	89.35074	Louisiana	MISSING
15156	29.21524	89.35064	Louisiana	MISSING
15155	29.21535	89.34987	Louisiana	TRLB
15150	29.21292	89.35099	Louisiana	TRUB

Table 36. Damaged aids to navigation Hurricane Katrina (Louisiana) cont.

LLNR	Latitude	Longitude	Region	Discrepancy Summary
15147	29.20982	89.35184	Louisiana	MISSING
15145	29.20555	89.35313	Louisiana	TRUB
15140	29.20575	89.35404	Louisiana	MISSING
15135	29.19817	89.35613	Louisiana	MISSING
15130	29.19866	89.35673	Louisiana	TRUB
15125	29.19489	89.35837	Louisiana	TRLB
15120	29.19527	89.35939	Louisiana	MISSING
15110	29.19116	89.3612	Louisiana	MISSING
15100	29.18806	89.36332	Louisiana	MISSING
15095	29.18386	89.36326	Louisiana	MISSING
15090	29.18199	89.36479	Louisiana	MISSING
15085	29.17805	89.36445	Louisiana	MISSING
15080	29.17826	89.36533	Louisiana	MISSING
15070	29.17437	89.36708	Louisiana	MISSING
15060	29.17169	89.3692	Louisiana	MISSING
15055	29.16709	89.37442	Louisiana	MISSING
15050	29.16857	89.37403	Louisiana	MISSING
15045	29.17948	89.37905	Louisiana	MISSING
15040	29.16344	89.37975	Louisiana	MISSING
15035	29.15767	89.38886	Louisiana	MISSING
15030	29.15848	89.38903	Louisiana	MISSING
15027	29.15513	89.39256	Louisiana	MISSING
15025	29.15408	89.39536	Louisiana	MISSING
15020	29.15226	89.39654	Louisiana	MISSING
15015	29.15276	89.39877	Louisiana	MISSING
15013	29.15183	89.40069	Louisiana	MISSING
15010	29.15057	89.40712	Louisiana	MISSING
15005	29.15142	89.4069	Louisiana	MISSING
15002	29.14807	89.41297	Louisiana	MISSING
15000	29.14523	89.41533	Louisiana	MISSING
14995	29.14481	89.41814	Louisiana	MISSING
14990	29.14225	89.42196	Louisiana	MISSING
14985	29.14339	89.42185	Louisiana	MISSING
14980	29.1411	89.42445	Louisiana	MISSING
14975	29.14211	89.42491	Louisiana	MISSING
14970	29.13884	89.42977	Louisiana	MISSING

Table 36. Damaged aids to navigation Hurricane Katrina (Louisiana) cont.

LLNR	Latitude	Longitude	Region	Discrepancy Summary
14965	29.13978	89.43033	Louisiana	MISSING
14950	29.13603	89.44171	Louisiana	MISSING
14945	29.13808	89.44236	Louisiana	MISSING
14395	30.09949	90.91293	Louisiana	MISSING
14390	30.09647	90.91221	Louisiana	MISSING
14380	30.0963	90.91481	Louisiana	MISSING
13005	29.25239	89.31191	Louisiana	LT EXT/DBD DEST
13840	29.9752	90.26674	Louisiana	DBD DMGD
14040	30.03276	90.46921	Louisiana	DBD DMGD
11055	29.91784	89.80865	Louisiana	MISSING
11135	30.00539	89.93166	Louisiana	DBD DMGD
11050	30.91617	89.81019	Louisiana	MISSING
11130	30.00766	89.92167	Louisiana	MISSING
13225	29.52115	89.72923	Louisiana	LT EXT/DBD DEST
13940	30.94355	90.37578	Louisiana	MISSING
13945	30.94415	89.3775	Louisiana	MISSING
15167	30.23516	89.35767	Louisiana	MISSING
15065	30.17125	88.36828	Louisiana	MISSING
15075	30.174	88.36609	Louisiana	MISSING
15105	30.18767	88.36238	Louisiana	MISSING
15115	30.19012	88.36069	Louisiana	TRUB
14935	30.13859	88.45134	Louisiana	MISSING
14940	30.13637	88.45166	Louisiana	MISSING
14955	30.13818	88.43631	Louisiana	MISSING
14960	30.13682	88.43602	Louisiana	MISSING
12395	30.37844	88.30415	Louisiana	LT EXT/DBD DEST
12435	30.35972	88.30102	Louisiana	LT EXT/DBD DEST
14805	30.34821	91.24644	Louisiana	LT EXT
17330	29.30149	90.71376	Louisiana	DBD DEST
17320	29.21692	90.64907	Louisiana	DBD DEST
17315	29.20905	90.63826	Louisiana	DBD DEST
17297	29.17998	90.59972	Louisiana	LT EXT/DBD DEST
17295	29.17998	90.59972	Louisiana	DBD DMGD/LT EXT
17250	29.17075	90.6049	Louisiana	DBD DEST
17190	29.10598	90.57925	Louisiana	MISSING
17185	29.09962	90.57554	Louisiana	MISSING

Table 36. Damaged aids to navigation Hurricane Katrina (Louisiana) cont.

LLNR	Latitude	Longitude	Region	Discrepancy Summary
17180	29.09913	90.57754	Louisiana	MISSING
14150	30.04119	90.62999	Louisiana	LT EXT
14145	30.03638	90.62212	Louisiana	LT EXT
14140	30.02915	90.61889	Louisiana	LT EXT
14095	30.05085	90.5433	Louisiana	DBD DEST
13850	29.97242	90.28156	Louisiana	LT EXT
33445	29.62244	91.05228	Louisiana	MISSING
33345	29.68155	90.19335	Louisiana	MISSING
33335	29.73903	90.14285	Louisiana	MISSING
14890	30.44129	91.19645	Louisiana	MISSING
14885	30.43762	91.1966	Louisiana	MISSING
14190	30.04348	90.67498	Louisiana	MISSING
14185	30.04403	90.67381	Louisiana	MISSING
13805	29.94332	90.16575	Louisiana	MISSING
13790	29.94268	90.16997	Louisiana	MISSING
13785	29.94491	90.16763	Louisiana	MISSING
12950	29.17291	89.26106	Louisiana	LT EXT
12550	28.98657	89.133	Louisiana	OFF STA
12547	28.98147	89.12199	Louisiana	OFF STA
16535.01	29.12343	90.21761	Louisiana	DBD DEST
12910	29.16675	89.25361	Louisiana	LT EXT/DBD DEST
13890	29.93166	90.32254	Louisiana	DBD DMGD
13855	29.97378	90.2802	Louisiana	LT EXT/DBD DEST
14229	30.01934	90.76519	Louisiana	LT EXT/DBD DEST
14238	30.0185	90.76874	Louisiana	LT EXT/DBD DEST
12935	29.17302	89.25343	Louisiana	LT EXT/DBD DEST
12940	29.16986	89.25517	Louisiana	LT EXT/DBD DEST
12945	29.17327	89.25496	Louisiana	LT EXT/DBD DEST
12705	28.91787	89.41773	Louisiana	LT EXT/DBD DEST
12710	28.91971	89.41583	Louisiana	LT EXT/DBD DEST
12695	28.917	89.4193	Louisiana	LT EXT/DBD DEST
12697	28.91584	89.42051	Louisiana	LT EXT/DBD DEST
12700	28.92027	89.41585	Louisiana	LT EXT/DBD DEST
12715	28.91839	89.41849	Louisiana	LT EXT/DBD DEST
12720	28.92025	89.41651	Louisiana	LT EXT/DBD DEST
12661	28.91385	89.43143	Louisiana	LT EXT/DBD DEST

Table 36. Damaged aids to navigation Hurricane Katrina (Louisiana) cont.

LLNR	Latitude	Longitude	Region	Discrepancy Summary
12670	28.91299	89.43246	Louisiana	LT EXT/DBD DEST
12870	29.13232	89.25683	Louisiana	LT EXT/DBD DEST
12873	29.13189	89.25672	Louisiana	LT EXT/DBD DEST
12645	28.91273	89.26531	Louisiana	LT EXT/DBD DEST
12925	29.171	89.25448	Louisiana	LT EXT/DBD DEST
10860	29.67787	89.38559	Louisiana	MISSING
10880	29.70709	89.42803	Louisiana	MISSING
10980	29.84006	89.62385	Louisiana	MISSING
10995	29.84895	89.6453	Louisiana	MISSING
11005	29.85854	89.6799	Louisiana	MISSING
11010	29.86476	89.70915	Louisiana	MISSING
11020	29.87479	89.72932	Louisiana	LIGHT EXTINGUSIHED/DBD DEST
11030	29.88465	89.74897	Louisiana	LIGHT EXTINGUISHED/DBD DESET
11035	29.88643	89.74756	Louisiana	LIGHT EXTINGUISHED/DBD DEST
12650	28.89479	89.43349	Louisiana	MISSING
12725	28.93643	89.41024	Louisiana	LIGHT EXTINGUISHED/DBD DEST
12730	28.9379	89.40347	Louisiana	LIGHT EXTINGUISHED/DBD DEST
12735	28.94748	89.40265	Louisiana	LIGHT EXTINGUISHED/DBD DEST
12740	28.95156	89.39389	Louisiana	LIGHT EXTINGUISHED/DBD DEST
12745	28.96586	89.38821	Louisiana	TRLT
12755	28.98115	89.37529	Louisiana	LIGHT EXTINGUISHED/DBD DEST
12760	28.99112	89.36081	Louisiana	DBD DMGD
12770	29.00225	89.3514	Louisiana	LIGHT EXTINGUISHED/DBD DEST
12785	29.02327	89.33504	Louisiana	LIGHT EXTINGUISHED/DBD DEST
12830	29.06157	89.31093	Louisiana	LIGHT EXTINGUISHED/DBD DEST
12840	29.08578	89.28638	Louisiana	LIGHT EXTINGUISHED/DBD DEST

Table 36. Damaged aids to navigation Hurricane Katrina (Louisiana) cont.

LLNR	Latitude	Longitude	Region	Discrepancy Summary
12845	29.0856	89.28061	Louisiana	LIGHT EXTINGUISHED/DBD DEST
12860	29.10742	89.26856	Louisiana	LIGHT EXTINGUISHED/DBD DEST
12865	29.11973	89.26695	Louisiana	LIGHT EXTINGUISHED/DBD DEST
12677	28.89975	89.43766	Louisiana	DBD DMGD/LIGHT EXTINGUISHED
12780	29.02208	89.34156	Louisiana	LIGHT EXTINGUISHED/DBD DEST
12810	29.04695	89.31954	Louisiana	LIGHT EXTINGUISHED/DBD DEST
11025	29.87666	89.72833	Louisiana	LIGHT EXTINGUISHED/DBD DEST
11015	29.86674	89.70814	Louisiana	MISSING
11000	29.8566	89.68043	Louisiana	MISSING
10990	29.84635	89.64585	Louisiana	MISSING
10985	29.84213	89.62297	Louisiana	MISSING
465	28.87753	89.43194	Louisiana	OFF STATION
12750	28.97653	89.37323	Louisiana	LIGHT EXTINGUISHED/DBD DEST
9645	30.19597	89.80067	Louisiana	MISSING
9640	30.196	89.79378	Louisiana	DBN DEST
9635	30.19596	89.78529	Louisiana	DBN DEST
9630	30.19588	89.77712	Louisiana	DBN DEST
9620	30.18517	89.76474	Louisiana	DBN DEST
9615	30.1809	89.7607	Louisiana	MISSING
9585	30.17487	89.74305	Louisiana	MISSING
9575	30.16686	89.71673	Louisiana	MISSING
9570	30.17329	89.68882	Louisiana	DBD DMGD/ LIGHT EXTINGUISHED
9565	30.16103	89.65206	Louisiana	MISSING
9460	30.16116	89.6495	Louisiana	MISSING
9290	30.20964	89.5895	Louisiana	MISSING
9285	30.20717	89.59284	Louisiana	MISSING
9280	30.20015	89.58979	Louisiana	MISSING
9275	30.19506	89.58592	Louisiana	DBN DEST
9272	30.19445	89.58847	Louisiana	MISSING

Table 36. Damaged aids to navigation Hurricane Katrina (Louisiana) cont.

LLNR	Latitude	Longitude	Region	Discrepancy Summary
9265	30.18477	89.58016	Louisiana	DBN DEST
9260	30.18436	89.58076	Louisiana	MISSING
9255	30.18165	89.58211	Louisiana	TMK DMGD
9250	30.18106	89.586	Louisiana	DBN DEST
9245	30.18367	89.5858	Louisiana	MISSING
9240	30.1785	89.59513	Louisiana	DBD DEST
9235	30.17964	89.59561	Louisiana	MISSING
9215	30.17676	89.60125	Louisiana	DBD DEST
9210	30.17068	89.60978	Louisiana	DBD DEST
9195	30.16273	89.62617	Louisiana	DBD DEST
9190	30.16192	89.62496	Louisiana	MISSING
9185	30.16081	89.62804	Louisiana	DBN DEST
9180	30.15839	89.62792	Louisiana	MISSING
9175	30.15995	89.63037	Louisiana	MISSING
9160	30.18343	89.5245	Louisiana	DBD DMGD/LIGHT EXTINGUISHED
9155	30.17236	89.52391	Louisiana	MISSING/TRUB
9150	30.16473	89.52453	Louisiana	MISSING/TRUB
9220	30.17816	89.60061	Louisiana	TMK DMGD
9225	30.17776	89.60685	Louisiana	DBN DEST
9590	30.17711	89.75457	Louisiana	MISSING
9157	30.18285	89.52749	Louisiana	MISSING
9465	30.16189	89.64806	Louisiana	MISSING
9145	30.16034	89.52471	Louisiana	MISSING/TRUB
16540	29.07936	90.22943	Louisiana	TRLB
16535	29.09859	90.22316	Louisiana	LT MICH
16535.02	29.12343	90.21761	Louisiana	LT MICH
410	29.16495	88.94226	Louisiana	OFF STATION
445	28.97865	89.10868	Louisiana	OFF STATION
405	29.238	88.95782	Louisiana	OFF STATION/LIGHT EXTINGUISHED
17330	29.30149	90.71376	Louisiana	DBD DEST
17320	29.21692	90.64907	Louisiana	DBD DEST
17317	29.21164	90.64486	Louisiana	MISSING
17315	29.20904	90.63826	Louisiana	DBD DEST
17305	29.20023	90.62675	Louisiana	MISSING
17280	29.18654	90.61239	Louisiana	DBD DEST

Table 36. Damaged aids to navigation Hurricane Katrina (Louisiana) cont.

LLNR	Latitude	Longitude	Region	Discrepancy Summary
17290	29.187	90.60933	Louisiana	MISSING
17230	29.14479	90.59393	Louisiana	MISSING
17210	29.11847	90.58292	Louisiana	TRLB
17175	29.09129	90.57977	Louisiana	OFF STATION
17115	29.01918	90.56815	Louisiana	OFF STATION
15410	29.26718	89.95977	Louisiana	MISSING
15375	29.27505	89.95604	Louisiana	OFF STATION
15380	29.27076	89.95738	Louisiana	MISSING
15390	29.26999	89.96034	Louisiana	MISSING
15385	29.26858	89.95915	Louisiana	MISSING
15435	29.26601	89.96098	Louisiana	TRLB
15445	29.26504	89.96155	Louisiana	MISSING/TRLB
15440	29.26447	89.97936	Louisiana	DBD DEST
15460	29.25158	89.99754	Louisiana	DBD DEST
15465	29.24673	89.97142	Louisiana	DBD DEST
15670	29.29079	89.97279	Louisiana	DBD DEST
15665	29.29029	89.97405	Louisiana	DBD DEST
15675	29.29874	89.99525	Louisiana	DBD DEST
15695	29.31195	89.98345	Louisiana	DBD DEST
15720	29.33294	89.98461	Louisiana	DBD DEST
15730	29.34887	89.98419	Louisiana	DBD DEST
15750	29.36959	89.98382	Louisiana	DBD DEST
15765	29.38296	89.98691	Louisiana	MISSING
15780	29.38897	89.98649	Louisiana	TRLB
10010	30.34696	90.0627	Louisiana	MISSING/TRLB
15710	29.3188	89.98491	Louisiana	DBD DEST
15700	29.31119	89.98415	Louisiana	DBD DEST
17215	29.1254	90.58455	Louisiana	OFF STATION
15405	29.26728	89.95938	Louisiana	MISSING
15470	29.24162	89.99852	Louisiana	DBD DEST
15475	29.24029	90.00375	Louisiana	DBD DEST
15770	29.38285	89.98553	Louisiana	DBN DEST
4815	30.26962	87.55675	Louisiana	TRLT
9230	30.17858	89.61077	Louisiana	DBD DEST

Table 37. Damaged aids to navigation Hurricane Katrina (Mississippi)

LLNR	Latitude	Longitude	Region	Discrepancy Summary
6933	30.216	88.5043	Mississippi	Missing
33000	30.1583	89.4729	Mississippi	MISSING/TRUB
32997	30.1722	89.453	Mississippi	MISSING/TRUB
32995	30.1846	89.426	Mississippi	MISSING
335	30.2126	88.9664	Mississippi	MISSING
340	30.1194	88.8777	Mississippi	MISSING
32755	30.2754	89.0205	Mississippi	LT EXT/DBD DEST
32750	30.2755	89.0182	Mississippi	LT EXT/DBD DEST
32765	30.2843	89.028	Mississippi	LT EXT/DBD DEST
32760	30.2843	89.0257	Mississippi	LT EXT/DBD DEST
32971	30.1797	89.3772	Mississippi	DBN DMGD/DBD DEST
32970	30.1797	89.3649	Mississippi	DBD DMGD/LT EXT
32959	30.1796	89.352	Mississippi	DBN DMGD/DBD DEST
32935	30.2046	89.3553	Mississippi	DBD DMGD/LT EXT
32930	30.2296	89.2841	Mississippi	DBD DMGD/LT EXT
32926	30.233	89.2689	Mississippi	DBD DMGD/TMK DMGD
32916	30.2359	89.2505	Mississippi	DBD DMGD/DBN DMGD
32906	30.2399	89.2487	Mississippi	DBD DMGD/DBN DMGD
32901	30.2385	89.245	Mississippi	DBD DMGD/TMK DMGD
32897	30.2412	89.2456	Mississippi	DBD DMGD/DBN DMGD
32896	30.2419	89.245	Mississippi	DBN DMGD/DBD DEST
32891	30.2412	89.2431	Mississippi	DBN DMGD/DBD DEST
32886	30.2438	89.2445	Mississippi	DBN DMGD/DBD DEST
32881	30.2455	89.2372	Mississippi	DBN DMGD/DBD DEST
32875	30.2588	89.2165	Mississippi	DBN DMGD/DBD DEST
32871	30.2631	89.2039	Mississippi	MISSING
32860	30.1903	89.2882	Mississippi	MISSING
32855	30.1967	89.2745	Mississippi	MISSING
32850	30.1978	89.2755	Mississippi	MISSING
32840	30.2023	89.2675	Mississippi	MISSING
32835	30.2053	89.2591	Mississippi	MISSING
32825	30.2094	89.2518	Mississippi	MISSING
32815	30.2148	89.2462	Mississippi	MISSING
32812	30.2236	89.2315	Mississippi	MISSING/TRUB

Table 37. Damaged aids to navigation Hurricane Katrina (Mississippi) cont.

LLNR	Latitude	Longitude	Region	Discrepancy Summary
32810	30.2219	89.23	Mississippi	MISSING
32805	30.2335	89.2164	Mississippi	TRUB
32800	30.2376	89.2085	Mississippi	MISSING
32990	30.1792	89.4023	Mississippi	DBD DMGD/LT EXT
32979	30.1796	89.3901	Mississippi	DBD DMGD/LT EXT
32955	30.1797	89.3348	Mississippi	LT EXT/DBD DEST
32940	30.1797	89.3036	Mississippi	DBD DMGD/LT EXT
32830	30.2065	89.2597	Mississippi	MISSING
7357	30.3357	88.5127	Mississippi	DBD DMGD
7435	30.3523	88.5061	Mississippi	LT EXT/DBD DEST
7370	30.2631	88.513	Mississippi	LT EXT/DBD DEST
7372	30.2627	88.513	Mississippi	LT EXT/DBD DEST
6955	30.2992	88.5145	Mississippi	LT EXT/DBD DEST
6960	30.3129	88.5162	Mississippi	LT EXT/DBD DEST
7073	30.271	88.4981	Mississippi	LT EXT/DBD DEST
6935	30.2118	88.5038	Mississippi	LT EXT/DBD DEST
7440	30.3593	88.5042	Mississippi	LT EXT/TMK DMGD
7365	30.2738	88.5129	Mississippi	LT EXT/DBD DEST
6930	30.216	88.5043	Mississippi	DBD DMGD
7070	30.271	88.4981	Mississippi	LT EXT/DBD DEST
7065	30.2824	88.5092	Mississippi	LT EXT/DBD DEST
7360	30.3434	88.5127	Mississippi	DBD DMGD
7470	30.3155	88.5162	Mississippi	LT EXT/DBD DEST
7465	30.3221	88.5144	Mississippi	LT EXT/DBD DEST
6925	30.2217	88.5077	Mississippi	OFF STA
6975	30.2411	88.5083	Mississippi	LT EXT/DBD DEST
7085	30.295	88.5227	Mississippi	TRLB
7090	30.2962	88.5212	Mississippi	LT EXT/DBD DEST
7100	30.3052	88.53	Mississippi	LT EXT/DBD DEST
7145	30.3133	88.5378	Mississippi	LT EXT/DBD DEST
7150	30.3213	88.5483	Mississippi	LT EXT/DBD DEST
7155	30.3225	88.5468	Mississippi	LT EXT/DBD DEST
7165	30.3311	88.5553	Mississippi	LT EXT/DBD DEST
7170	30.3387	88.5655	Mississippi	LT EXT/DBD DEST
7175	30.34	88.5638	Mississippi	LT EXT/DBD DEST

Table 37. Damaged aids to navigation Hurricane Katrina (Mississippi) cont.

LLNR	Latitude	Longitude	Region	Discrepancy Summary
7190	30.3437	88.5659	Mississippi	LT EXT/DBD DEST
7380	30.2955	88.5118	Mississippi	LT EXT/DBD DEST
7385	30.3037	88.5139	Mississippi	LT EXT/DBD DEST
7390	30.3037	88.5118	Mississippi	LT EXT/DBD DEST
7405	30.3122	88.5138	Mississippi	LT EXT/DBD DEST
7410	30.3122	88.5118	Mississippi	LT EXT/DBD DEST
7415	30.32	88.5138	Mississippi	LT EXT/DBD DEST
7425	30.3229	88.5119	Mississippi	LT EXT/DBD DEST
7427	30.3299	88.511	Mississippi	LT EXT/DBD DEST
7430	30.3276	88.5137	Mississippi	LT EXT/DBD DEST
7432	30.333	88.515	Mississippi	LT EXT/DBD DEST
7433	30.3346	88.5146	Mississippi	LT EXT/DBD DEST
7442	30.3524	95.4983	Mississippi	LT EXT/DBD DEST
7140	30.3121	88.5395	Mississippi	LT EXT/DBD DEST
7420	30.3159	88.5119	Mississippi	LT EXT
7045	30.2848	88.5137	Mississippi	LT EXT
7375	30.2956	88.514	Mississippi	LT EXT/DBD DEST
32715	30.2803	88.6358	Mississippi	MISSING/TRLB
32705	30.2553	88.6041	Mississippi	MISSING/TRLB
32700	30.2532	88.5791	Mississippi	LT EXT
8506.2	30.2428	89.0332	Mississippi	DBD DMGD/LT EXT
7340	30.4186	88.5247	Mississippi	DBD DEST/TMK MISSING
7330	30.4212	88.5326	Mississippi	DBD DEST
7315	30.4259	88.5411	Mississippi	DBD DEST
7310	30.423	88.5528	Mississippi	MISSING/TRUB
7305	30.4228	88.5587	Mississippi	MISSING/TRUB
7300	30.4205	88.5668	Mississippi	MISSING/TRUB
7295	30.4194	88.5728	Mississippi	MISSING/TRUB
7485	30.4123	88.5832	Mississippi	MISSING/TRUB
7280	30.4055	88.5845	Mississippi	DBD DEST
7275	30.4024	88.5825	Mississippi	DBD DEST
7270	30.3984	88.5778	Mississippi	MISSING/TRUB
7265	30.3936	88.5758	Mississippi	DBD DEST
7260	30.3887	88.5641	Mississippi	DBD DEST
7255	30.3829	88.5688	Mississippi	MISSING/TRUB

Table 37. Damaged aids to navigation Hurricane Katrina (Mississippi) cont.

LLNR	Latitude	Longitude	Region	Discrepancy Summary
7250	30.3796	88.5667	Mississippi	DBD DEST
7000	30.2569	88.5084	Mississippi	BUOY DMGD
6895	30.2152	88.5108	Mississippi	OFF STA
6900	30.216	88.5078	Mississippi	OFF STA
32710	30.2518	88.6118	Mississippi	MISSING/TRLB
32720	30.2803	88.6356	Mississippi	MISSING
32725	30.2849	88.6848	Mississippi	MISSING
32730	30.2872	88.7451	Mississippi	MISSING
32740	30.2853	88.8859	Mississippi	MISSING
32745	30.2836	88.9532	Mississippi	MISSING
7042	30.2808	88.5189	Mississippi	MISSING
6890	30.2125	88.5096	Mississippi	LT EXT
6980	30.2413	88.5065	Mississippi	OFF STA
6950	30.2242	88.5069	Mississippi	LT EXT
8485	30.2663	89.0072	Mississippi	LT EXT
8490	30.3018	89.0156	Mississippi	LT EXT/DBD DEST
8493	30.3018	89.0156	Mississippi	LT EXT/DBD DEST
8565	30.2308	88.9816	Mississippi	LT EXT/DBD DEST
8570	30.2126	88.9663	Mississippi	LT IMCH
8650	30.3645	89.0949	Mississippi	MISSING
8395	30.1195	88.897	Mississippi	OFF STA
8400	30.1169	88.9123	Mississippi	OFF STA
8405	30.119	88.9124	Mississippi	OFF STA
8410	30.1185	88.9277	Mississippi	OFF STA
8415	30.1168	88.9306	Mississippi	OFF STA
8420	30.1206	88.9315	Mississippi	OFF STA
8425	30.1304	88.9419	Mississippi	OFF STA
8430	30.1314	88.9404	Mississippi	OFF STA
8435	30.1413	88.9508	Mississippi	OFF STATION
8440	30.1422	88.9493	Mississippi	OFF STATION
8445	30.1521	88.9599	Mississippi	OFF STATION
8450	30.1531	88.9582	Mississippi	OFF STATION
8455	30.163	88.9687	Mississippi	OFF STATION
8460	30.1639	88.9671	Mississippi	OFF STATION
8465	30.1738	88.9776	Mississippi	OFF STATION

Table 37. Damaged aids to navigation Hurricane Katrina (Mississippi) cont.

LLNR	Latitude	Longitude	Region	Discrepancy Summary
8470	30.1748	88.976	Mississippi	OFF STATION
8475	30.1857	88.985	Mississippi	OFF STATION
8480	30.1888	88.9899	Mississippi	OFF STATION
8505	30.2037	88.9915	Mississippi	OFF STATION
8506	30.2026	88.0001	Mississippi	LIGHT EXTINGUISHED
8506.1	30.2428	88.0332	Mississippi	LT MICH
8510	30.2227	88.9978	Mississippi	MISSING
8515	30.223	88.9961	Mississippi	MISSING
8520	30.2309	88.9997	Mississippi	MISSING
8525	30.2312	88.998	Mississippi	MISSING
8540	30.2391	89.0017	Mississippi	MISSING
8545	30.2394	89.9998	Mississippi	MISSING
8550	30.2473	89.0037	Mississippi	MISSING
8555	30.2476	89.0017	Mississippi	MISSING
8560	30.2555	89.0055	Mississippi	MISSING
8562	30.2342	89.9833	Mississippi	LIGHT EXTINGUISHED/DBD DMGD/DEST
8580	30.2613	89.0084	Mississippi	MISSING
8585	30.2679	89.014	Mississippi	MISSING
8590	30.2689	89.0125	Mississippi	MISSING
8615	30.2901	89.033	Mississippi	MISSING
8620	30.2911	89.0314	Mississippi	MISSING
8575	30.2597	89.0045	Mississippi	MISSING/DAYBOARD DESTROYED
8625	30.2969	89.0387	Mississippi	MISSING/DAYBOARD DESTROYED
8495	30.1941	89.9892	Mississippi	OFF STATION
8500	30.2034	89.9933	Mississippi	OFF STATION
8630	30.2978	89.0372	Mississippi	MISSING
8635	30.3036	89.0444	Mississippi	MISSING
8640	30.3046	89.0429	Mississippi	MISSING
8645	30.3534	89.0854	Mississippi	TRLT
8655	30.3103	89.0501	Mississippi	MISSING
8660	30.311	89.0484	Mississippi	MISSING
8670	30.3169	89.0557	Mississippi	MISSING
8675	30.318	89.0543	Mississippi	MISSING
8690	30.3248	89.06	Mississippi	MISSING

Table 37. Damaged aids to navigation Hurricane Katrina (Mississippi) cont.

LLNR	Latitude	Longitude	Region	Discrepancy Summary
8695	30.3305	89.0672	Mississippi	MISSING
8700	30.3315	89.0657	Mississippi	MISSING
8705	30.3372	89.073	Mississippi	MISSING
8710	30.3385	89.0717	Mississippi	MISSING
8715	30.344	89.0787	Mississippi	MISSING
8720	30.345	89.0771	Mississippi	MISSING
8725	30.3484	89.0824	Mississippi	MISSING
9079	30.2636	89.327	Mississippi	TRLB
9079.05	30.2666	89.3159	Mississippi	TRLB
9080	30.2732	89.3329	Mississippi	TRLB
8680	30.3227	89.0551	Mississippi	MISSING
8685	30.3237	89.0614	Mississippi	MISSING
9120	30.2383	89.4245	Mississippi	MISSING
7920	30.3935	88.8317	Mississippi	MISSING
7885	30.3881	88.8641	Mississippi	MISSING
7875	30.39	88.8707	Mississippi	MISSING
7870	30.3895	88.8768	Mississippi	MISSING
7830	30.3894	88.8991	Mississippi	MISSING
7810	30.3765	88.9016	Mississippi	MISSING
7805	30.3771	88.9028	Mississippi	MISSING
7800	30.3687	88.9018	Mississippi	MISSING
7795	30.3599	88.9021	Mississippi	MISSING
7790	30.3597	88.9037	Mississippi	MISSING
6810.1	30.1542	88.5667	Mississippi	OFF STATION
6810.2	30.153	88.5651	Mississippi	OFF STATION
6810.3	30.166	88.5548	Mississippi	OFF STATION
6810.4	30.1649	88.5532	Mississippi	OFF STATION
6810.5	30.1779	88.5429	Mississippi	OFF STATION
6810.6	30.1767	88.5413	Mississippi	OFF STATION
6855	30.1968	88.5237	Mississippi	OFF STATION
6865	30.2033	88.5173	Mississippi	OFF STATION
6870	30.2022	88.5159	Mississippi	OFF STATION
7080	30.3545	88.5793	Mississippi	TRLT/LIGHT EXTINGUISHED
7075	30.3458	88.5709	Mississippi	LIGHT EXTINGUISHED
7355	30.3357	88.5127	Mississippi	LIGHT EXTINGUISHED
7178	30.3421	88.5681	Mississippi	LIGHT EXTINGUISHED

Table 38. Damaged aids to navigation Hurricane Katrina (Mississippi/Louisiana)

LLNR	Latitude	Longitude	Region	Discrepancy Summary
9270	30.1884	89.5846	Mississippi/Louisiana	DBD DMGD
9435	30.3284	89.633	Mississippi/Louisiana	DBN DGMD
9430	30.3253	89.6308	Mississippi/Louisiana	DBN DEST
9420	30.3197	89.6311	Mississippi/Louisiana	MISSING
9415	30.3183	89.6309	Mississippi/Louisiana	DBN DEST
9405	30.3092	89.6327	Mississippi/Louisiana	DBN DEST
9400	30.3078	89.6364	Mississippi/Louisiana	DBN DEST
9375	30.288	89.6375	Mississippi/Louisiana	DBN DEST
9370	30.2856	89.6384	Mississippi/Louisiana	MISSING
9365	30.2785	89.63	Mississippi/Louisiana	MISSING
9360	30.2688	89.6331	Mississippi/Louisiana	MISSING
9355	30.2662	89.626	Mississippi/Louisiana	DBN DEST
9350	30.2617	89.632	Mississippi/Louisiana	TRUB
9340	30.2485	89.6226	Mississippi/Louisiana	DBN DGMD
9335	30.2469	89.6149	Mississippi/Louisiana	DBN DGMD
9330	30.226	89.6164	Mississippi/Louisiana	TRUB
9325	30.2223	89.6154	Mississippi/Louisiana	TRUB
9320	30.2208	89.6151	Mississippi/Louisiana	TRLB
9315	30.2181	89.6105	Mississippi/Louisiana	TRUB
9310	30.215	89.6014	Mississippi/Louisiana	MISSING
9295	30.2155	89.5869	Mississippi/Louisiana	MISSING
9385	30.2922	89.6473	Mississippi/Louisiana	MISSING/TRUB

APPENDIX 2.

CODE

Numerical Example

Sets

l set of supply locations /l1*l3/

i set of safe locations /i1*i3/

k set of commodities used in repair activity /k1*k3/

v set of possible Aids to Navigation repair types /v1*v3/

j set of demand areas affected by the storm path /j1*j4/

o set of scenarios /o1*o3/;

Parameters

w(k) weight associated with commodity k (lbs)

/k1 1

k2 1

k3 1/

N(l) number of teams based at location l

/l1 50

l2 20

l3 30/

alpha(v) criticality weight associted with aton repair of type v

/v1 3

v2 2

v3 1/

        c(k) per unit cost associated with pre-positioning commodity k

            /k1 40

            k2 120

            k3 190/

        p(o) scenario specific probabilties

            /o1 0.6

            o2 0.3

            o3 0.1/;

Scalar

*M is the weight associated with commodities

*B is the maximum allowable cost associated with prepositioned commodities

        M /200/

        B/609937/;

Table

a(v,k) amount of commodity k used in repair of type v

     k1   k2   k3

v1   1   0   0

v2   1   0   0

v3   1   0   0 ;

Table

D(j,v,o) amount of ATONs in need of repair of type v in region j under scenario w

	v1.o1	v1.o2	v1.o3	v2.o1	v2.o2	v2.o3	v3.o1	v3.o2	v3.o3
j1	20	55	70	15	75	30	50	45	50
j2	35	40	90	40	15	80	25	30	35
j3	25	15	60	15	45	80	75	20	30
j4	55	65	15	70	95	45	60	50	25;

Table

t(v,o) Repair time for ATONs

	o1	o2	o3
v1	2	1	0.75
v2	2	1	0.75
v3	2	1	0.75 ;

Table

e(i,j) travel time

	j1	j2	j3	j4
i1	2	2	3	1
i2	2	1	3	1
i3	2	2	4	3 ;

Variables

    x(i) the number of teams assigned to safe location

    s(i,k) the number of supplies of commodity type k assigned to safe location

    y(l,i) the number of teams transferred from supply location l to safe location i

    z(i,j,o) the number of teams assigned from location i to demand region j in scenario w

    h(i,j,k,o) the number of commodities of type k transferred from location i to affected
area j in scenario w

    u(i,j,v,o) Unrepaired ATONs of type v in region j in scenario w

    r(i,j,v,o) Repaired atons of type v region j in scenario w ;

positive variable y,s,h,u,r;

integer variable x,z;

free variable q;

Equations

    repaireditems objective function

    con1 Flow balance pre-position constraint

    con2 Flow balance pre-position constraint

    con3 Number of supplies stored at safe location i cannot exceed more than what
teams can carry

    con4 Total items prepositioned cannot exceed budget constraint

    con5 The number of teams dispatched per location per scenario cannot exceed
available team supply per location

    con6 Time to repair items at demand region per scenario cannot exceed daily
operating time of teams allocated to affected area j

116

con7 Inventory balance contraint

con8 Relationship between repaired ATONs and pre-positioned supplies

con9 Amount of supplies sent into affected areas cannot exceed available supply

con10 Commodities can only be allocated to an affected area if there are teams allocated to that area;

repaireditems.. q =e= sum(v,sum(j,sum(o,(p(o)*alpha(v)*sum(i,r(i,j,v,o))))));

con1(i).. sum(l,y(l,i)) =e= x(i);

con2(l).. sum(i,y(l,i)) =l= N(l);

con3(i)..sum(k,w(k)*s(i,k)) =l= M*x(i);

con4.. sum(k,sum(i,c(k)*s(i,k))) =l= B;

con5(i,o).. sum(j,z(i,j,o)) =l= x(i);

con6(j,o).. sum(v,sum(i,t(v,o)*r(i,j,v,o))) =l= sum(i,z(i,j,o)*(36-e(i,j)));

con7(j,v,o).. sum(i,r(i,j,v,o)+ u(i,j,v,o)) =e= D(j,v,o);

con8(i,j,k,o).. sum(v,a(v,k)*r(i,j,v,o)) =l= h(i,j,k,o);

con9(i,k,o).. sum(j,h(i,j,k,o)) =l= s(i,k);

con10(i,j,o).. sum(k,h(i,j,k,o)) =l= M*z(i,j,o);

Model ThesisModel1 /all/;

Solve ThesisModel1 using mip maximizing q;

Display x.l, s.l, y.l, z.l, h.l, r.l, u.l;

Model with prepositioning and unconstrained supply

Sets

    l set of supply locations /l1*l4/

    i set of safe locations /i1*i4/

    k set of commodities used in repair activity /k1*k3/

    v set of possible Aids to Navigation repair types /v1*v3/

    j set of demand areas affected by the storm path /j1*j5/

    o set of scenarios /o1*o5/;

Parameters

    w(k) weight associated with commodity k (lbs)

        /k1 190

         k2 1

         k3 6/

    N(l) number of teams based at location l

        /l1 50

         l2 20

         l3 30

         l4 25/

    alpha(v) criticality weight associted with aton repair of type v

        /v1 3

         v2 2

         v3 1/

c(k) per unit cost associated with pre-positioning commodity k

/k1 350

k2 179

k3 139/

p(o) scenario specific probabilties

/o1 0.05

o2 0.15

o3 0.25

o4 0.25

o5 0.30/;

Scalar

*M is the weight associated with commodities

*B is the maximum allowable cost associated with prepositioned commodities

M /1500/

B/1002000/;

Table

a(v,k) amount of commodity k used in repair of type v

	k1	k2	k3
v1	1	0	0
v2	0	1	0
v3	0	0	1 ;

Table

D(j,v,o) amount of ATONs in need of repair of type v in region j under scenario w

	v1.o1	v1.o2	v1.o3	v1.o4	v1.o5	v2.o1	v2.o2	v2.o3	v2.o4	v2.o5	v3.o1	v3.o2	v3.o3	v3.o4	v3.o5
j1	0	120	140	162	172	0	3	3	2	1	0	0	0	0	0
j2	0	6	9	9	10	0	1	0	0	0	0	0	0	0	0
j3	0	195	229	285	319	0	7	6	4	1	0	0	0	0	0
j4	0	17	188	200	208	0	0	1	0	0	0	0	0	0	0
j5	0	94	12	17	18	0	2	1	1	0	0	0	0	0	0;

Table

t(v,o) Repair time for ATONs

	o1	o2	o3	o4	o5
v1	0	1	1	2	2
v2	0	1	1	2	2
v3	0	1	1	2	2 ;

Table

e(i,j) travel time

	j1	j2	j3	j4	j5
i1	2	3	1	1	1
i2	1	3	2	1	1
i3	2	3	2	1	1
i4	3	1	3	3	3;

Variables

   x(i) the number of teams assigned to safe location

   s(i,k) the number of supplies of commodity type k assigned to safe location

   y(l,i) the number of teams transferred from supply location l to safe location i

   gamma(k) available supply for each commoditiy

   z(i,j,o) the number of teams assigned from location i to demand region j in scenario w

   h(i,j,k,o) the number of commodities of type k transferred from location i to affected
area j in scenario w

   u(i,j,v,o) Unrepaired ATONs of type v in region j in scenario w by teams from
location i

   r(i,j,v,o) Repaired atons of type v region j in scenario w by teams from location i;

positive variable s,u,r,gamma;

integer variable z,x,y,h;

free variable q;

Equations

      repaireditems objective function

      con1 Flow balance pre-position constraint

      con2 Flow balance pre-position constraint

      con3 flow balance supply constraint

      con4 number of supplies stored at safe location i cannot exceed more thatn what
teams can carry

      con5 Total items prepositioned cannot exceed budget constraint

con6 The number of teams dispatched per location per scenario cannot exceed available team supply per location

con7 Time to repair items at demand region per scenario cannot exceed daily operating time of teams allocated to affected area j

con8 Inventory balance contraint

con9 Relationship between repaired ATONs and pre-positioned supplies

con10 Amount of supplies sent into affected areas cannot exceed available supply

con11 Commodities can only be allocated to an affected area if there are teams allocated to that area;

repaireditems.. q =e= sum(v,sum(j,sum(o,(p(o)*alpha(v)*sum(i,r(i,j,v,o))))));

con1(i).. sum(l,y(l,i)) =e= x(i);

con2(l).. sum(i,y(l,i)) =l= N(l);

con3(k).. sum(i,s(i,k)) =l= gamma(k);

con4(i)..sum(k,w(k)*s(i,k)) =l= M*x(i);

con5.. sum(k,sum(i,c(k)*s(i,k))) =l= B;

con6(i,o).. sum(j,z(i,j,o)) =l= x(i);

con7(i,j,o).. sum(v,t(v,o)*r(i,j,v,o)) =l= z(i,j,o)*(120-e(i,j));

con8(j,v,o).. sum(i,r(i,j,v,o)+ u(i,j,v,o)) =e= D(j,v,o);

con9(i,j,k,o).. sum(v,a(v,k)*r(i,j,v,o)) =l= h(i,j,k,o);

con10(i,k,o).. sum(j,h(i,j,k,o)) =l= s(i,k);

con11(i,j,o).. sum(k,w(k)*h(i,j,k,o)) =l= z(i,j,o)*M;

Model ThesisModel1 /all/;

Solve ThesisModel1 using mip maximizing q;

Display x.l, s.l, y.l, z.l, h.l, r.l, u.l, gamma.l;

Model without pre-positioning

Sets

    l set of supply locations /l1*l4/

    i set of safe locations /i1*i4/

    k set of commodities used in repair activity /k1*k3/

    v set of possible Aids to Navigation repair types /v1*v3/

    j set of demand areas affected by the storm path /j1*j5/

    o set of scenarios /o1*o5/;

Parameters

    w(k) weight associated with commodity k (lbs)

        /k1 190

         k2 1

         k3 6/

    N(l) number of teams based at location l

        /l1 50

         l2 20

         l3 30

         l4 25/

    alpha(v) criticality weight associted with aton repair of type v

        /v1 3

         v2 2

         v3 1/

c(k) per unit cost associated with pre-positioning commodity k

    /k1 350

    k2 179

    k3 139/

p(o) scenario specific probabilties

    /o1 0.05

    o2 0.15

    o3 0.25

    o4 0.25

    o5 0.30/;

Scalar

*M is the weight associated with commodities

*B is the maximum allowable cost associated with prepositioned commodities

    M /1500/

    B/1002000/;

Table

a(v,k) amount of commodity k used in repair of type v

	k1	k2	k3
v1	1	0	0
v2	0	1	0
v3	0	0	1 ;

Table

D(j,v,o) amount of ATONs in need of repair of type v in region j under scenario w

	v1.o1	v1.o2	v1.o3	v1.o4	v1.o5	v2.o1	v2.o2	v2.o3	v2.o4	v2.o5	v3.o1	v3.o2	v3.o3	v3.o4	v3.o5
j1	0	109	127	147	156	0	3	3	2	1	0	0	0	0	0
j2	0	5	8	8	9	0	1	0	0	0	0	0	0	0	0
j3	0	177	208	259	290	0	6	5	4	1	0	0	0	0	0
j4	0	15	171	182	189	0	0	1	0	0	0	0	0	0	0
j5	0	90	11	15	16	0	2	1	1	0	0	0	0	0	0;

Table

t(v,o) Repair time for ATONs

	o1	o2	o3	o4	o5
v1	0	1	1	2	2
v2	0	1	1	2	2
v3	0	1	1	2	2 ;

Table

e(i,j) travel time

	j1	j2	j3	j4	j5
i1	3	5	2	2	2
i2	2	4	3	2	2
i3	3	5	5	2	2
i4	4	2	6	4	4;

Variables

    x(i) the number of teams assigned to safe location

    y(l,i) the number of teams transferred from supply location l to safe location i

    z(i,j,o) the number of teams assigned from location i to demand region j in scenario w

    h(i,j,k,o) the number of commodities of type k transferred from location i to affected area j in scenario w

    u(i,j,v,o) Unrepaired ATONs of type v in region j in scenario w by teams from location i

    r(i,j,v,o) Repaired atons of type v region j in scenario w by teams from location i;

positive variable u,r;

integer variable z,x,y,h;

free variable q;

Equations

      repaireditems objective function

      con1 Flow balance pre-position constraint

      con2 Flow balance pre-position constraint

      con5 Total items prepositioned cannot exceed budget constraint

      con6 The number of teams dispatched per location per scenario cannot exceed available team supply per location

      con7 Time to repair items at demand region per scenario cannot exceed daily operating time of teams allocated to affected area j

      con8 Inventory balance contraint

      con9 Relationship between repaired ATONs and pre-positioned supplies

con11 Commodities can only be allocated to an affected area if there are teams allocated to that area;

repaireditems.. q =e= sum(v,sum(j,sum(o,(p(o)*alpha(v)*sum(i,r(i,j,v,o))))));

con1(i).. sum(l,y(l,i)) =e= x(i);

con2(l).. sum(i,y(l,i)) =l= N(l);

con5(o).. sum(k,sum(i,sum(j,c(k)*h(i,j,k,o)))) =l= B;

con6(i,o).. sum(j,z(i,j,o)) =l= x(i);

con7(i,j,o).. sum(v,t(v,o)*r(i,j,v,o)) =l= z(i,j,o)*(120-e(i,j));

con8(j,v,o).. sum(i,r(i,j,v,o)+ u(i,j,v,o)) =e= D(j,v,o);

con9(i,j,k,o).. sum(v,a(v,k)*r(i,j,v,o)) =l= h(i,j,k,o);

con11(i,j,o).. sum(k,w(k)*h(i,j,k,o)) =l= z(i,j,o)*M;

Model ThesisModel1 /all/;

Solve ThesisModel1 using mip maximizing q;

Display x.l, y.l, z.l, h.l, r.l, u.l;

Supply Constrained Model

Sets

    l set of supply locations /l1*l4/

    i set of safe locations /i1*i4/

    k set of commodities used in repair activity /k1*k3/

    v set of possible Aids to Navigation repair types /v1*v3/

    j set of demand areas affected by the storm path /j1*j5/

    o set of scenarios /o1*o5/;

Parameters

    w(k) weight associated with commodity k (lbs)

        /k1 190

         k2 1

         k3 6/

    N(l) number of teams based at location l

        /l1 50

         l2 20

         l3 30

         l4 25/

    gamma(k) available supply

    / k1 533

     k2 12

     k3 0/

alpha(v) criticality weight associted with aton repair of type v

    /v1 3

    v2 2

    v3 1/

c(k) per unit cost associated with pre-positioning commodity k

    /k1 350

     k2 179

     k3 139/

p(o) scenario specific probabilities

    /o1 0.05

     o2 0.15

     o3 0.25

     o4 0.25

     o5 0.30/;

Scalar

*M is the weight associated with commodities

*B is the maximum allowable cost associated with prepositioned commodities

    M /1500/

    B/609937/;

Table

a(v,k) amount of commodity k used in repair of type v

	k1	k2	k3
v1	1	0	0
v2	0	1	0
v3	0	0	1 ;

Table

D(j,v,o) amount of ATONs in need of repair of type v in region j under scenario w

	v1.o1	v1.o2	v1.o3	v1.o4	v1.o5	v2.o1	v2.o2	v2.o3	v2.o4	v2.o5	v3.o1	v3.o2	v3.o3	v3.o4	v3.o5
j1	0	109	127	147	156	0	3	3	2	1	0	0	0	0	0
j2	0	5	8	8	9	0	1	0	0	0	0	0	0	0	0
j3	0	177	208	259	290	0	6	5	4	1	0	0	0	0	0
j4	0	15	171	182	189	0	0	1	0	0	0	0	0	0	0
j5	0	90	11	15	16	0	2	1	1	0	0	0	0	0	0;

Table

t(v,o) Repair time for ATONs

	o1	o2	o3	o4	o5
v1	0	1	1	2	2
v2	0	1	1	2	2
v3	0	1	1	2	2 ;

Table

e(i,j) travel time

	j1	j2	j3	j4	j5
i1	2	3	1	1	1
i2	1	3	2	1	1
i3	2	3	2	1	1
i4	3	1	3	3	3;

Variables

x(i) the number of teams assigned to safe location

s(i,k) the number of supplies of commodity type k assigned to safe location

y(l,i) the number of teams transferred from supply location l to safe location i

z(i,j,o) the number of teams assigned from location i to demand region j in scenario w

h(i,j,k,o) the number of commodities of type k transferred from location i to affected area j in scenario w

u(i,j,v,o) Unrepaired ATONs of type v in region j in scenario w by teams from location i

r(i,j,v,o) Repaired atons of type v region j in scenario w by teams from location i;

positive variable s,u,r;

integer variable z,x,y,h;

free variable q;

Equations

     repaireditems objective function

     con1 Flow balance pre-position constraint

     con2 Flow balance pre-position constraint

     con3 flow balance supply constraint

     con4 number of supplies stored at safe location i cannot exceed more than what teams can carry

     con5 Total items prepositioned cannot exceed budget constraint

     con6 The number of teams dispatched per location per scenario cannot exceed available team supply per location

     con7 Time to repair items at demand region per scenario cannot exceed daily operating time of teams allocated to affected area j

     con8 Inventory balance constraint

     con9 Relationship between repaired ATONs and pre-positioned supplies

     con10 Amount of supplies sent into affected areas cannot exceed available supply

     con11 Commodities can only be allocated to an affected area if there are teams allocated to that area;

repaireditems.. q =e= sum(v,sum(j,sum(o,(p(o)*alpha(v)*sum(i,r(i,j,v,o))))));

con1(i).. sum(l,y(l,i)) =e= x(i);

con2(l).. sum(i,y(l,i)) =l= N(l);

con3(k).. sum(i,s(i,k)) =l= gamma(k);

con4(i)..sum(k,w(k)*s(i,k)) =l= M*x(i);

con5.. sum(k,sum(i,c(k)*s(i,k))) =l= B;

con6(i,o).. sum(j,z(i,j,o)) =l= x(i);

con7(i,j,o).. sum(v,t(v,o)*r(i,j,v,o)) =l= z(i,j,o)*(72-e(i,j));

con8(j,v,o).. sum(i,r(i,j,v,o)+ u(i,j,v,o)) =e= D(j,v,o);

con9(i,j,k,o).. sum(v,a(v,k)*r(i,j,v,o)) =l= h(i,j,k,o);

con10(i,k,o).. sum(j,h(i,j,k,o)) =l= s(i,k);

con11(i,j,o).. sum(k,w(k)*h(i,j,k,o)) =l= z(i,j,o)*M;

Model ThesisModel1 /all/;

Solve ThesisModel1 using mip maximizing q;

Display x.l, s.l, y.l, z.l, h.l, r.l, u.l;