



## **Technical Report: Louisiana Department of Natural Resources Fuel Demand Estimation Report**

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# 1. EXECUTIVE SUMMARY

The NIMSAT Institute at the University of Louisiana at Lafayette is currently involved in the research and development of a Fuel Demand Estimation model for the Louisiana's Department of Natural Resources. During hurricane evacuation, it is important for the emergency managers to understand the fuel demand along various evacuation routes. An understanding of fuel demand along evacuation routes would enable emergency managers to inform gas stations owners ahead of time and position refueling trucks along evacuation routes that are likely to have fuel deficit and conduct a smooth and effective evacuation.

The Evacuation Fuel Demand Model (EFDM) discussed in this report provides an overview of the methodology, analysis and preliminary results for estimating evacuation traffic and fuel demand. Among many different analysis required for developing this methodology to estimate fuel demand, the evacuation model is probably one of the most important components. The discussed approach brings together inputs on the hurricane track and intensity, the evacuation transportation network, evacuation population and their behavior, fuel demand estimation from evacuation traffic. A discussion on the results of expected fuel demand for the model and how it can be applied during an evacuation scenario is discussed through an example evacuation scenario for hurricane Gustav.

This report also discusses our investigations approaches to obtain situational awareness through real-time traffic monitoring from Automatic Traffic Recorders and video cameras.

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## 2. BACKGROUND

Evacuation is a means to move endangered people out of harm's way. One of the primary reasons for severe congestion during large-scale evacuations is the rapid depletion of fuel in the gas stations as people try to fill-up their fuel tanks to get out of harm's way. Unexpected fuel outages have caused hundreds of motorists to be stranded, despite a coordinated effort by state agencies and oil and natural gas partners [2]. In order to prepare and respond to issues related to fuel outages, emergency managers need estimations on the available fuel supply, and fuel demand along various evacuation routes, both prior to and during an event. This would enable the emergency managers to identify critical section of highways and inform the gas station owners on the anticipated fuel demand, send refueling trucks ahead of contraflow, and supply generators the gas stations that are in the critical evacuation paths in the event of a power outage.

Fuel demand to a large extent relies on the evacuation traffic. Evacuation traffic may be estimated from an evacuation planning models or tools that estimates evacuation traffic. The problem of evacuation is typically formulated as a transportation network problem that allocates traffic to evacuation highways based on how people load onto the evacuation highway network, where the destinations are and the shortest travel times to destinations. While there is a body of research in evacuation models and evacuation planning tools, estimating evacuation traffic remains a challenging problem owing to the uncertainty in the hurricane track, the behavior of peoples and the series of events that unfold during an event. Recent research sponsored by the National Science Foundation has revealed that most published evacuation transportation models rely on assumptions that are not consistent with findings of behavioral research on hurricane evacuations. Conversely, behavioral scientists have failed to collect data on various parameters that are important to evacuation traffic modelers.

In order to build upon and improve the existing state-of-the-art in research and development to develop this model for emergency fuel supply, we have brought a team of interdisciplinary researchers from social and behavioral sciences, transportation modelers, mathematics and emergency practitioners.

### **Explanation of Terms:**

**NIMSAT** – National Incident Management Systems and Advanced Technologies

**NOAA** - National Oceanic and Atmospheric Administration

**ATR** – Automatic Traffic Recorders

**DOTD** – Department of Transportation Division

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### 3. AN OVERVIEW OF LOUISIANA'S EVACUATION PROFILE

This chapter discusses some of the baseline information on the states evacuation plan. This includes a summary of evacuation population in Louisiana, evacuation zones, contraflow plans and a summary of gas stations.

#### 3.1 Evacuation Profile of Louisiana

According to Census 2000, the total population in Louisiana is 4,4M, out of which 2.2M live in coastal evacuation zones. Figure 1 shows an evacuation map of Louisiana. According to [1], areas in red are the areas that are south of intracoastal waterways and fall outside the levee protection system. These areas are vulnerable to Category 1 and 2 storms and evacuated 50 hours before the storm. Approximately 142K people live in the red area. Also, the areas in orange are considered phase II and lie within the levee protection system but are vulnerable to a slow moving Cat 3 or higher storm and evacuated 40 hours before the storm. There are 1.1M people living in orange areas. Areas in Green are considered Phase III and evacuated 30 hours before a hurricane. There are about 1M people living in zone 3.

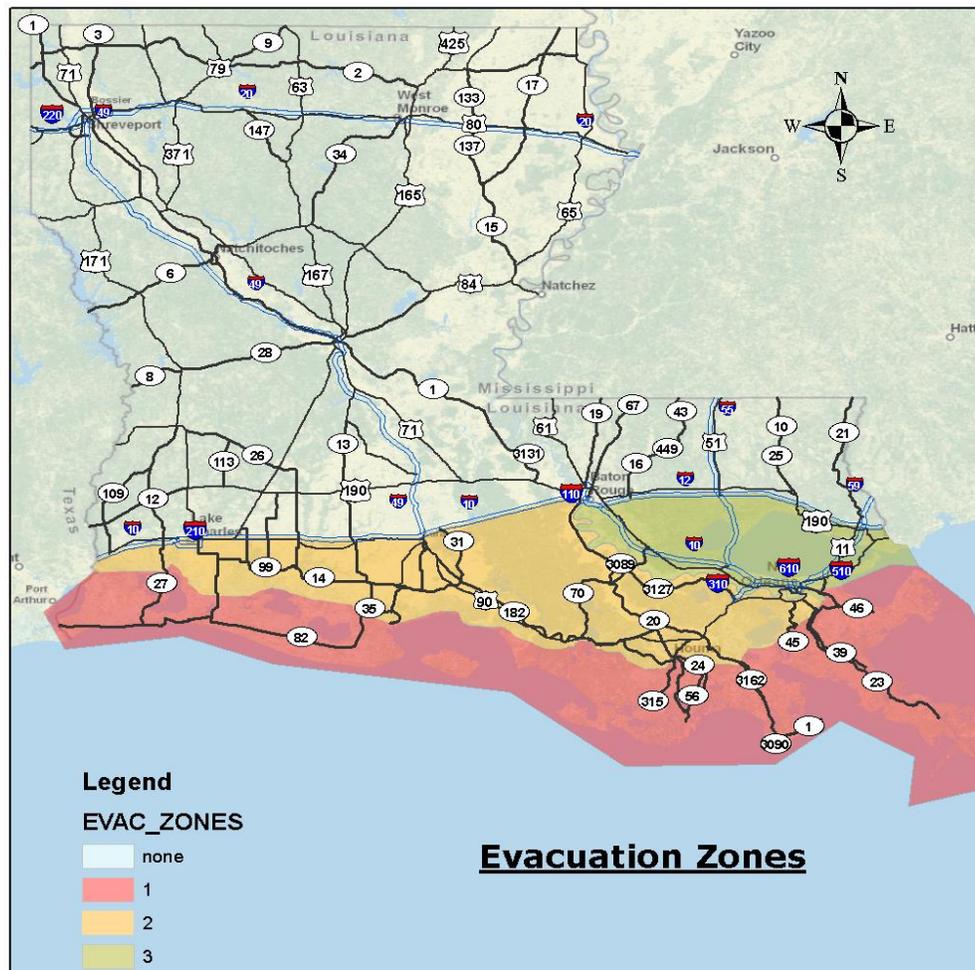
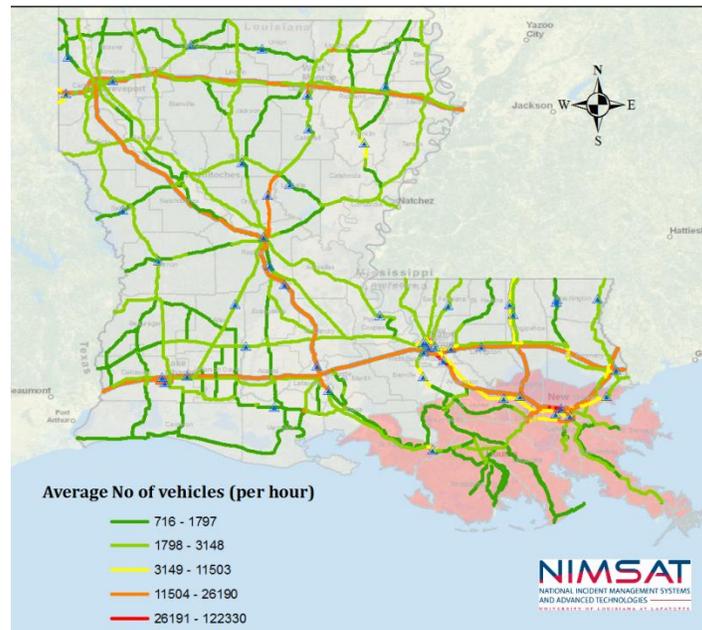


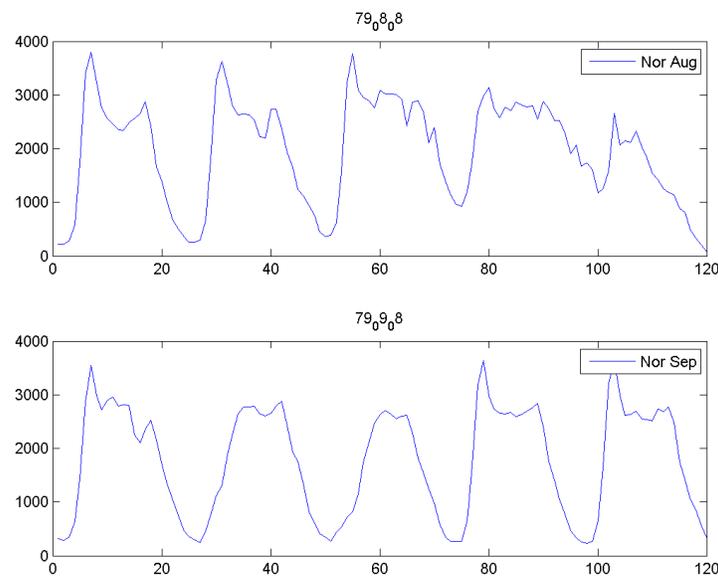
Figure 1 Evacuation Zones of Louisiana

### 3.2 Normal day Traffic

Figure 2 shows the normal daily traffic in average number of vehicles per hour along the evacuation routes. Red color indicates highest traffic volume. We can observe that there is maximum traffic in the Baton Rouge and New Orleans area. Figure 3 shows the normal daily traffic pattern along I-10 at the Pecue Overpass in Baton Rouge. Normal day traffic follows a clear trend on weekdays and weekends with some variation in long weekends. The observed evacuation traffic pattern was obtained from ATR's deployed by LA-DOTD.



**Figure 2 Normal Daily Traffic along various Evacuation Routes**



**Figure 3 Normal Daily Traffic Distribution over a 5-day period**

### 3.3 Traffic Analysis Zones

The graphic in Figure 3 shows the traffic analysis zones that would be analyzed for evacuation. We are considering 8 major cities in Louisiana namely Alexandria, Baton Rouge, Houma, Lafayette, Lake Charles, Monroe, New Orleans and Shreveport.

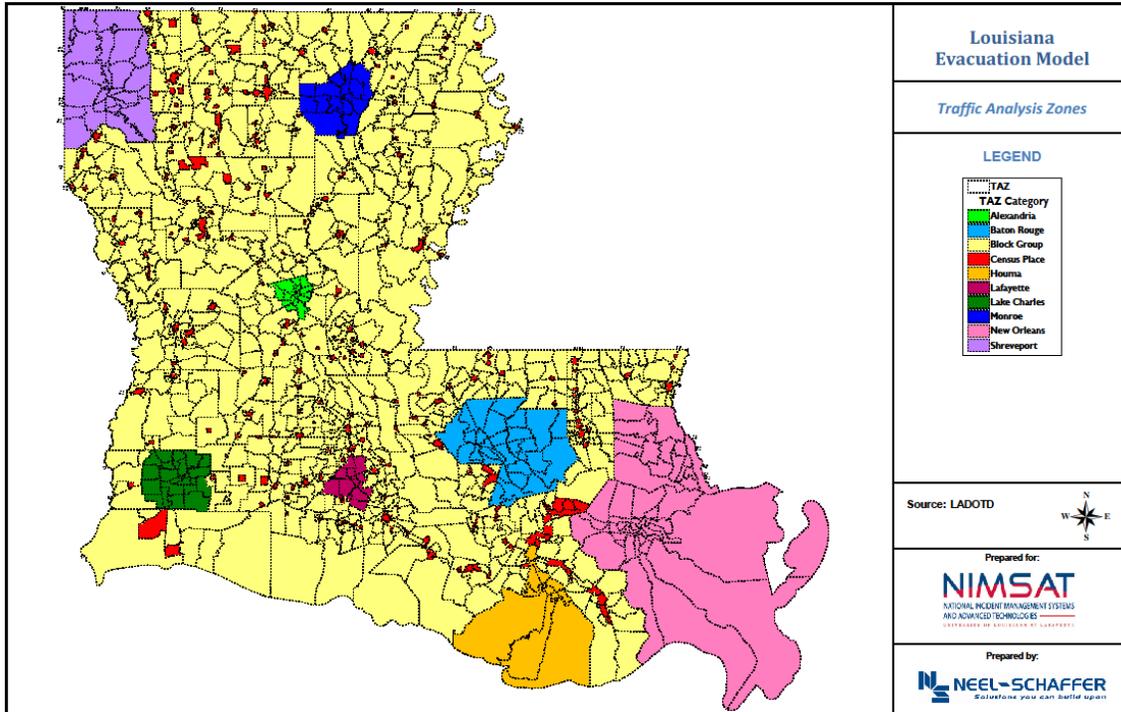


Figure 3 Traffic Analysis Zones in Louisiana

### 3.4 Contra flow Plans

Figure 4 shows the contraflow plans for the south east portion of the state of Louisiana. The large arrows indicate the direction of flow of traffic with contraflow enforcement. The contraflow map is provided by LA DOTD [1].

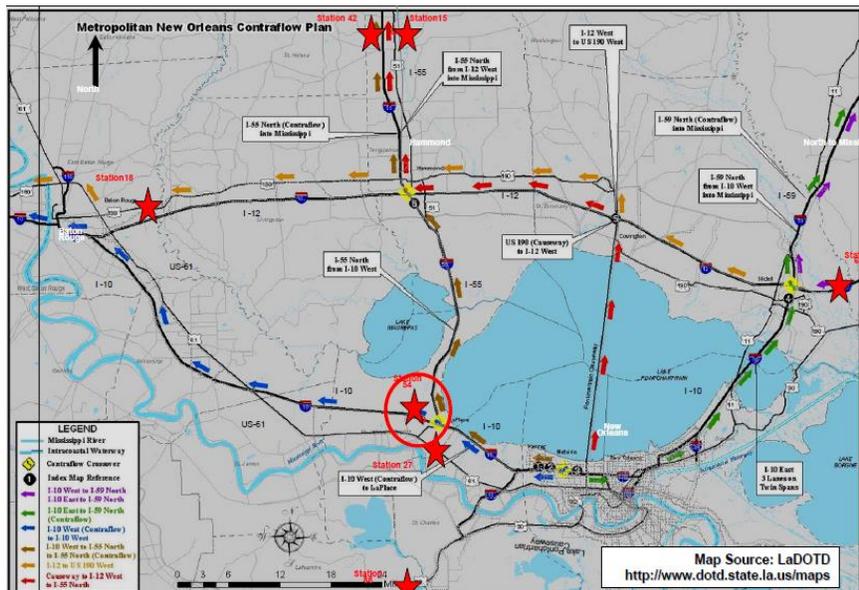
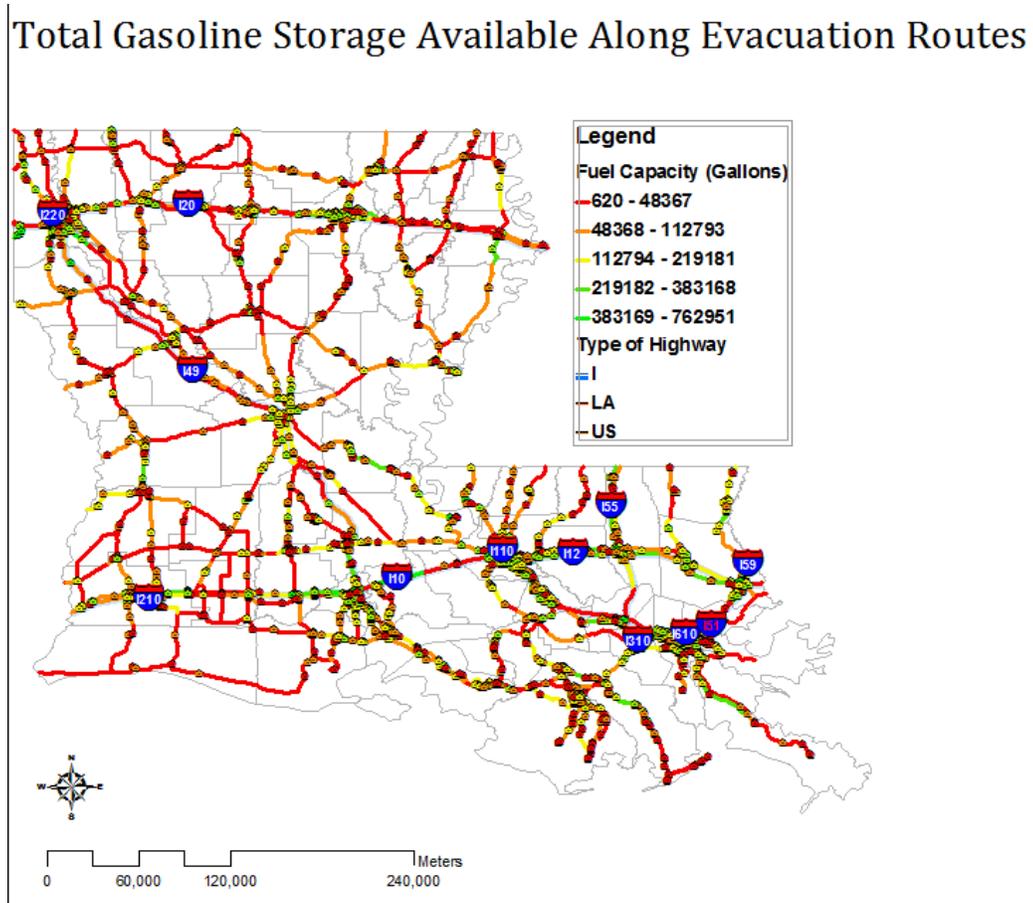


Figure 4 Contra flow Plans for Southeast Louisiana

### 3.5 Gas Stations

The total numbers of gas stations that are within one mile of the evacuation routes are 2670, out of which 813 are there on the interstates and 1857 are there on the LA and US highways. Below is a map of all the gas stations. The dots represent the gas stations, with the legend showing the total storage capacity of gas stations along each segment of the evacuation route.



**Figure 5 Available gas stations along the evacuation routes**

## 4. EVACUATION MODELING METHODOLOGY AND FRAMEWORK

The demand for fuel along the evacuation a highway primarily depends on the amount of traffic that is likely to travel on any given evacuation highway segment. Estimating the evacuation traffic and fuel demand is a multidisciplinary problem that involves analyzing the evacuation behavior, modeling the evacuation network analyzing possible evacuation scenarios to estimate evacuation traffic. In this chapter we discuss the variables that affect fuel demand and discuss the approach we are using to estimate evacuation traffic and fuel demand.

### 5.1 Variables that affect Fuel Demand

There are several variables that affect fuel demand. Out of which the most important ones are the hurricane track, category, projected landfall, when and what type of evacuation orders, if it is mandatory or voluntary. Also, given the evacuation order how many people are likely to evacuate, where people will go, how they would travel.

Figure 6 shows the dependency of Expected fuel on various variables. The main objective is to estimate the fuel demand at any given segment of road during a future time. At the high-level is the fuel demand, which is the main objective of interest. Fuel-demand is dependent on 'the number of vehicles that will stop for gas and 'the number of gallons that will be filled by a vehicle. The vehicles that will stop would depend on both the expected traffic at that particular segment and the length of the evacuation segment. The expected traffic depends on the number of people evacuated, the time they evacuated, the destination choices of the evacuees, the transportation mode of the evacuees (bus, plane, car, etc) and the number of vehicles that evacuees will take. The evacuees depend on the number of actual evacuees and the travelers or the shadow evacuees.

The evacuation time of people depends on the evacuation order (Mandatory/Voluntary/Recommended), the hurricane intensity (category, track, storm surge, wind speeds) and individual preferences (work day vs holiday, past experiences). The routes people will take depend on the hurricane track, the destination choice (hotel/relatives/shelters ) and the road factors (contraflow, congestion).

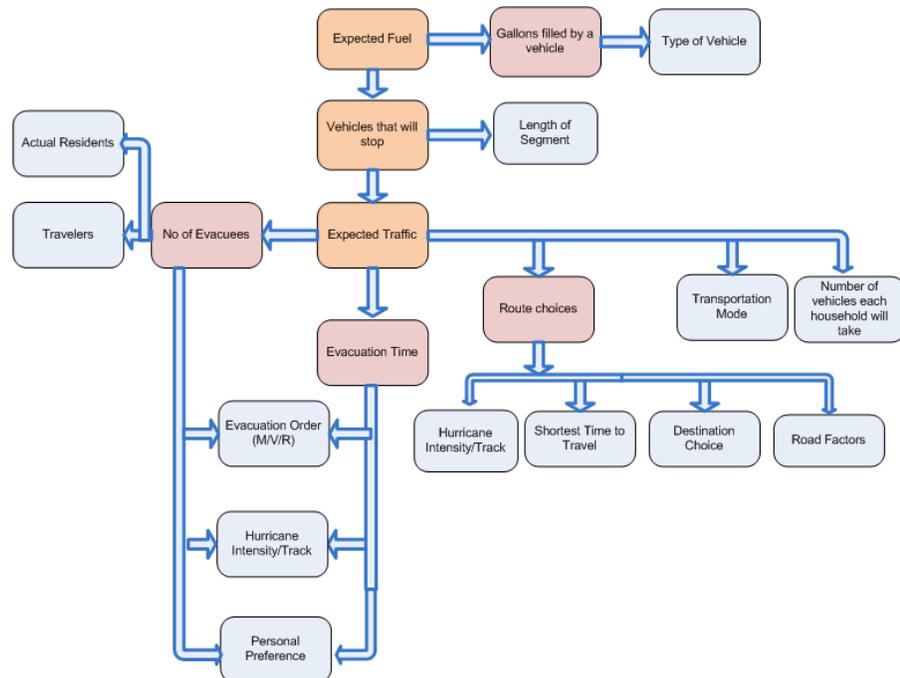


Figure 6 Variables that affect Fuel Demand

## 5.2 Methodology to estimate Fuel Demand

The following methodology is used to estimate fuel demand.

### Methodology

- i. *For a given hurricane track and intensity identify the likely area of impact and estimate the percentage of population that will evacuate for a given parish*
- ii. *Estimate the time (day-1, day-2 or day-3), population in a given parish will evacuate*
- iii. *Identify the closest evacuation route for the evacuation population*
- iv. *Identify the likely destinations of evacuees and setup the Louisiana's evacuation transportation network as a directed graph  $G(N,E)$ , where  $N$  nodes represent the occupancy of people and  $E$  edges represents the road between any two nodes.*
- v. *Run the transportation network evacuation model that estimates evacuation traffic volume along various highways, based on the O-D matrices, the highway capacity, the network configuration and capacity (take into account contraflow and road closures) for a 3 day period.*
- vi. *Estimate the volume of traffic by hour from the total volume along each segment based on historical patterns of evacuation traffic*
- vii. *Estimate the expected number of vehicles that will get off the highway*
- viii. *Estimate the expected gallons of fuel needed for the vehicles that get off the highway*

The following are the list of tasks we performed in order to estimate fuel demand.

1. Understanding Evacuee Behavior
2. Generate Origin Destination Matrices for evacuation network
3. Estimate Evacuation traffic volume
4. Estimating Fuel Demand
5. Identify areas that are likely to have fuel deficit

### **Task 1 : Understanding Evacuee Behavior**

Human behavior and decision making process under hurricane risk is a complex issue influenced by various factors. There has been a lot of research in understanding human behavior before and during an event through studies on factors influencing human behavior during an event. There have also been various attempts to model the decision-making process by conceptualizing the reasoning process on the perception of hurricane risk based on demographic and socioeconomic profiles for a given geographical region. There are also studies done by FEMA across the nation to study evacuee behavior that are incorporated into HURREVAC, an evacuation modeling tool. But we have not found any studies or data that we could use for our evacuation model. Hence we have taken up this study.

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We have conducted a behavioral survey was to obtain data on household evacuation response and understand how people have evacuated in the past and how they filled up their tanks during these events. The survey was conducted by the NIMSAT Institute in collaboration with the department of Sociology at the University of Louisiana at Lafayette. As part of this study, we have collected data via telephone interviews with coastal Louisiana residents. The data was collected for 14 previous storm tracks and 27447 people were surveyed out of which we received 4298 responses. Out of the 14 tracks, only four tracks have a reasonable sample size, namely hurricane Katrina, Gustav, Rita and Ike.

The survey provided the following information that would be used by the transportation network model.

1. The percentage of household that evacuated for various hurricane tracks
2. How long before the storm did the household evacuate
3. What was their destination choice
4. How many vehicles did the evacuees take
5. What highways did they use
6. How many gallons of fuel they filled up

A more detailed description of the survey and the results were discussed as part of a separate report titled Evacuation Behavior Survey Report that will be submitted to LA DNR.

## **Task 2 :       Generate Origin Destination Matrices**

The evacuation scenario is formulated as a transportation problem with fixed Origins and Destinations (O-D). That is any transportation models need the O-D data as a model input. To prepare O-D data, the network of interest first needs to be defined with zones. A typical travel demand models defined traffic analysis zones (TAZ), in which the intensity of travel activities are estimated based on the number of households or land use patterns inside each zone. We have chosen to apply parishes as the zonal definition for the studied network.

In order to obtain the O-D matrices, we leverage the survey data we have done in Task 1 and have used the loading patterns of people that were well discussed in literature and are observed to follow a Weibull distribution. The data on the *percentage of households that evacuated* and *how long before the storm the households evacuated* combined with evacuation loading curves and trip distribution models translates to O-D matrices for different intervals time.

## **Task 3 :       Estimate Evacuation traffic volume**

The traffic volume is estimated by using a traffic assignment model used for conducting transportation network analysis. TransCAD is a widely accepted transportation model that is also being used by the state of Louisiana's DOTD for traffic planning and evacuation network configuration. Dr. Gottumukkala worked with Neel-Schaeffer a local transportation modeling company and Dr. Xiaoduan Sun a transportation modeling researcher and to perform the following tasks in order to develop an evacuation network model to estimate the traffic volume.

1. Develop the network loading model
  2. Model the evacuation network setup for 3 hurricane evacuation scenarios. This includes establishing the study area boundaries and traffic zones, development of trip generation, trip distribution and trip assignment.
-

3. Model validation
4. Sensitivity Analysis

We believe that the evacuation volume produced by this approach will be a realistic representation of evacuation traffic

**Task 4 : Estimating Fuel Demand**

We have developed a statistical model to estimate the number of vehicles that will stop along a given segment of highway, and have translated that into Fuel Demand. We assume that on average every vehicle will stop for  $d$  miles by assuming that each vehicle will stop for gas every  $s$  miles. The model is formulated based on an exponential distribution.

$$F = X * \left[ N * e^{-\left(\frac{d}{s}\right)} \left(\frac{d}{s}\right)^k \right]$$

Where  $X$  is the average gallons of fuel filled by a vehicle,  $N$  is the total number of vehicles passing through a given stretch of road with length ' $d$ ' miles and ' $s$ ' is the average miles a vehicle will travel between stops.

As also assume that a vehicle will fill 12 gallons of fuel at every gas station and translate the number of vehicles that will stop to the total amount of gallons of fuel they will fill up.

**Task 5 : Identify areas with Fuel Deficit**

LA DNR is in the process of collecting information on gas stations that includes the location of these gas stations, the storage tank capacities of these gas stations, number of fuel pumps etc. Understanding the supply chain of fuel supply in terms of the frequency of supply of fuel to various gas stations, we will develop a methodology to estimate the fuel supply during the course of an event.

We would look at the GIS data on projected fuel supply; the expected demands of fuel based on the evacuation traffic and subtract the demand from the supply to estimate the fuel surplus and deficit.

## **5. FUEL DEMAND ESTIMATION REPORT**

In this chapter we discuss the work product that would be given to LA DNR and along with a proposed timeline of evacuation traffic estimation and fuel demand prediction.

### **5.1 Work products for LA DNR**

#### **a. Evacuation Summary Report**

- (i) The summary report provides a brief description of the hurricane scenario and a snapshot of fuel demand along the evacuation routes. The summary report would contain the following items
- (ii) Hurricane Evacuation Summary including the total evacuation population and the number of vehicles that will get on the road.
- (iii) Parishes that are in consideration for evacuation
- (iv) Major destinations and number of people that will get off the road at these destinations
- (v) Total number of available gas stations along the evacuation routes
- (vi) Total gasoline capacity available for gas stations that are within one mile of evacuation

The report will also list the important assumptions made for estimating the fuel demand. These include, but are not limited to the following

- (i) Number of vehicles from base population
- (ii) Evacuation network
- (iii) Average number of gallons filled by a vehicle
- (iv) Number of vehicles that will stop for gas
- (v) Assumptions on network model

#### **b. A GIS Map**

A GIS map in the form of a shape file with the following items:

- (i) Projected hurricane track from the most recent NOAA advisory
  - (ii) Evacuating parishes
  - (iii) Evacuation Highways (Primary and secondary)
  - (iv) Fuel demand (in gallons) and evacuation traffic along the evacuation highways for 24 hour interval for H-72, H-48, H-24
-

## 5.2 Timeline and responsibilities

### a. H96

- i. NIMSAT and LA-DNR
  1. Monitor the projected path and strength of the hurricane from NOAA
- ii. LA-DNR
  1. If category -2 or above, LA-DNR indicates possible need of fuel demand model
- iii. NIMSAT team
  1. Identifies closest evacuation scenario
  2. Delivers a preliminary fuel demand product based on the closest evacuation scenario prior to H96
- iv. NIMSAT team
  1. Initiates communication with GOHSEP to identify possible parishes under evacuation for the next scenario
- v. LA-DNR
  1. Requests NIMSAT to develop alternate scenarios for the model with a 6 hour lead time

### b. H96 to H72

- i. NIMSAT team
  1. Obtains input data for the model, including identifying the evacuation zones, possible destinations, evacuation times from GOHSEP
  2. Identifies closest evacuation scenario and requests approval from DNR on the scenario
- ii. LA-DNR
  1. Approves the second scenario required
- iii. NIMSAT team
  1. Delivers a more detailed second fuel demand product based on the closest evacuation scenario prior to H72
- iv. LA-DNR
  1. Requests NIMSAT to develop alternate scenarios based on the available information with a 6 hour lead time

### c. H48 to H24

- v. NIMSAT team
    1. Continues to obtain input data for the model, including identifying the evacuation zones, possible destinations, evacuation times from GOHSEP
    2. Identifies closest evacuation scenario and requests approval from DNR on the scenario
  - vi. LA-DNR
    2. Approves the second scenario required
  - vii. NIMSAT team
    1. Delivers a more detailed second fuel demand product based on the closest evacuation scenario prior to H72
-

## 6. HURRICANE GUSTAV: AN EXAMPLE FUEL DEMAND PREDICTION

### 1. Evacuation Summary: Hurricane Gustav

Hurricane Gustav made landfall on August 31 2008 as a category 2 hurricane along Louisiana coast. The actual track of Gustav along with evacuation zones is shown in Figure 1

#### Evacuation Summary

- a. Total Population in Louisiana: 4,492,076
- b. Total population evacuated:1,858,119
- c. Total Number of Vehicles for evacuating parishes:1,032,324

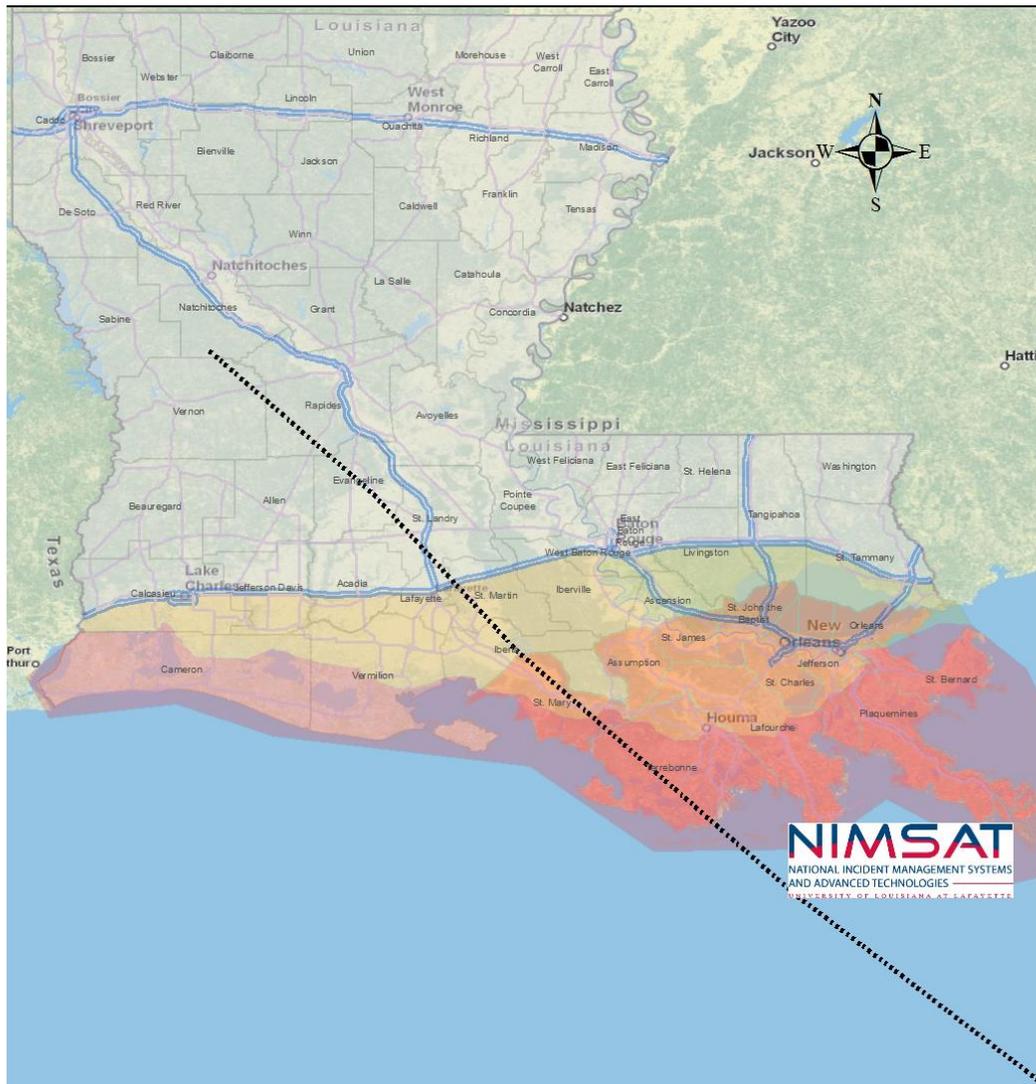


Figure 7 Evacuation Zones and project hurricane track of Gustav

## 2. Parishes considered for evacuation

The following parishes were issued mandatory and voluntary evacuation orders.

### a. Mandatory

Assumption  
 Calcasieu  
 Cameron  
 Iberia  
 Jefferson  
 Lafourche  
 Orleans  
 Plaquemines  
 St. Bernard  
 St. Charles  
 St. John the Baptist  
 St. Martin  
 St. Mary  
 St. Tammany  
 Tangipahoa  
 Terrebonne  
 Vermilion

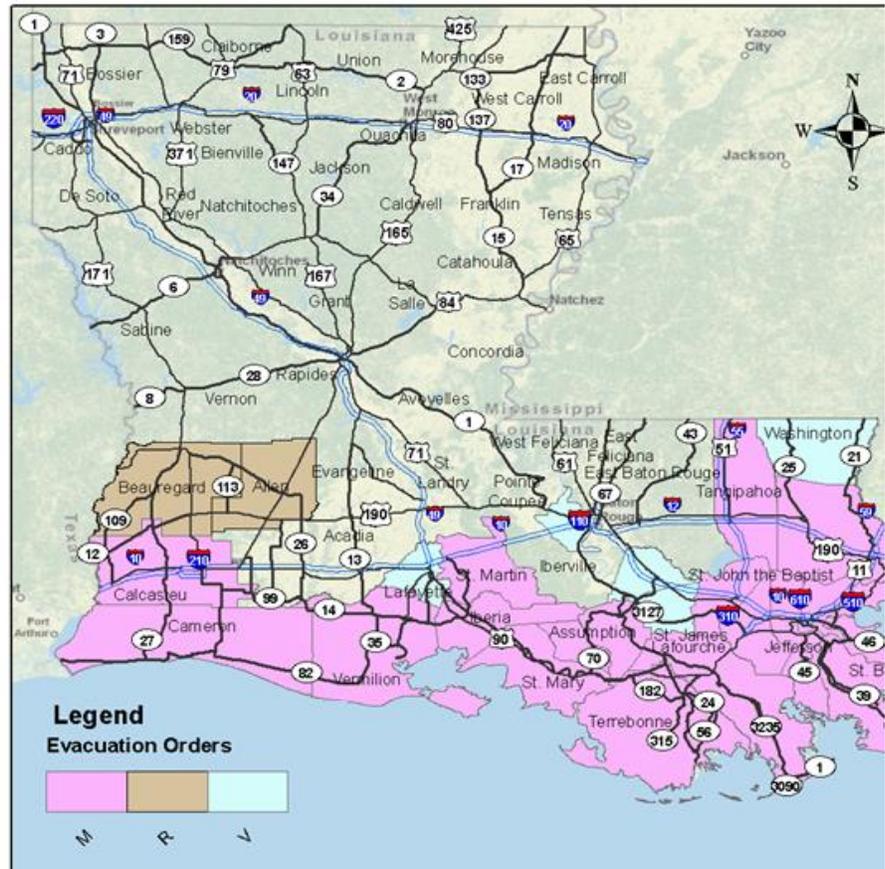


Figure 8 Evacuation Orders for various parishes

### b. Voluntary

Ascension  
 Lafayette  
 St. James  
 Washington  
 West Baton Rouge

## 3. Major Destinations

The following are the major destinations, and we assume that these cities can absorb 20% of their capacity (including hotels, relatives/friends and shelters).

	City	Population	No of Evacuees flowing into the city
1	Shreveport	200145	22238
2	Lafayette	110257	22051
3	Bossier City	56461	11292
4	Monroe	53107	10621
5	Alexandria	46342	9268

We also assume that the remaining part of the majority of the population will flow out of the state to Texas, MS and a small portion to Alabama

#### 4. Gas station summary

The Total numbers of gas stations on evacuation routes are **2670** out of which 813 are there on the interstates and 1857 are there on the LA and US highways. Below is a map of all the gas stations.

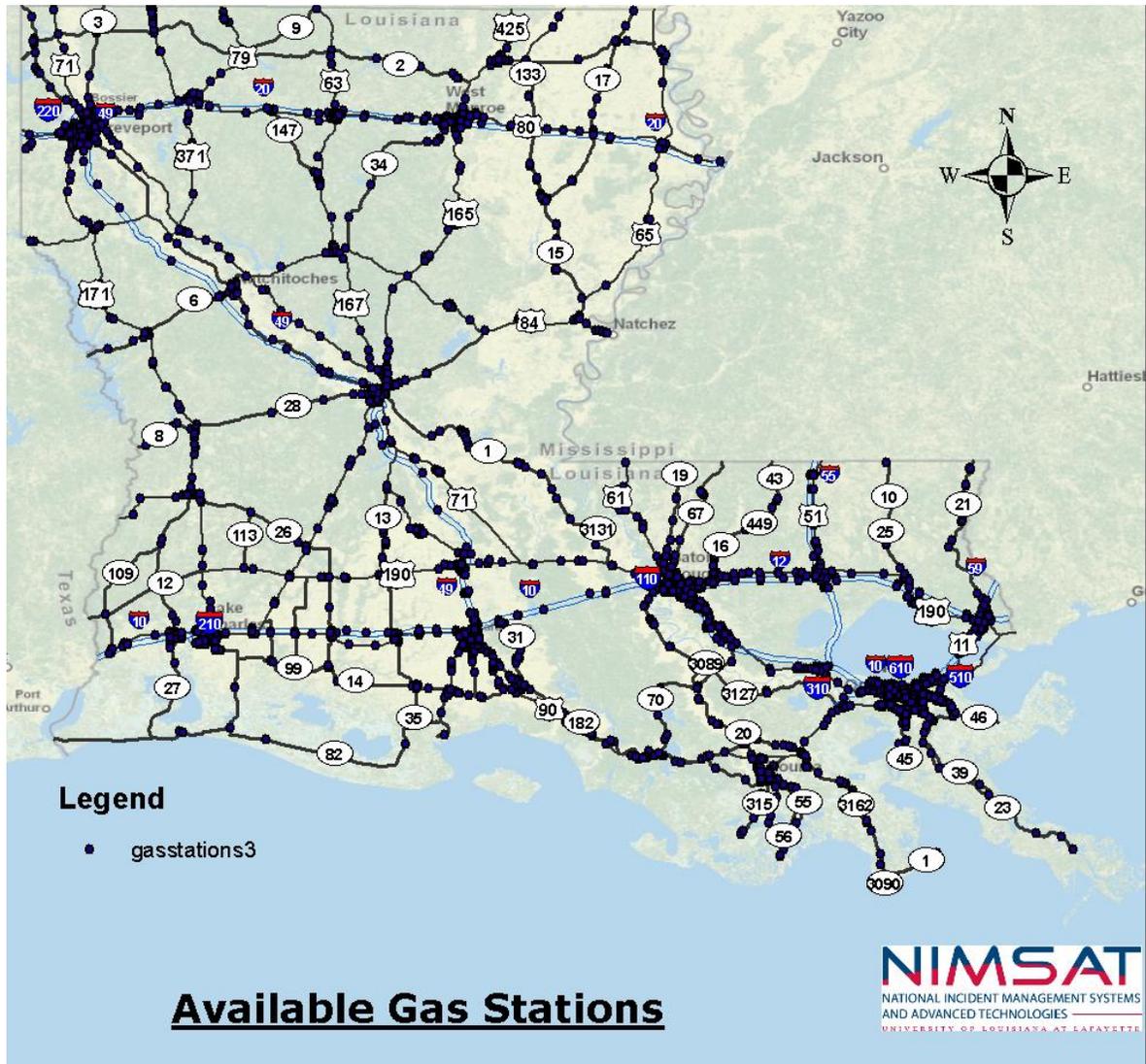


Figure 9 Available Gas Stations on evacuation routes

For the initial model we assume that 10% of vehicles stop at any given stretch of road and on the average a vehicle fills up to 12 gallons of fuel.

## 5. Available Fuel Capacity

The total numbers of gas stations that are within one mile of the evacuation routes are 2670, out of which 813 are there on the interstates and 1857 are there on the LA and US highways. Below is a map of all the gas stations. The dots represent the gas stations, with the legend showing the total storage capacity of gas stations along each segment of the evacuation route.

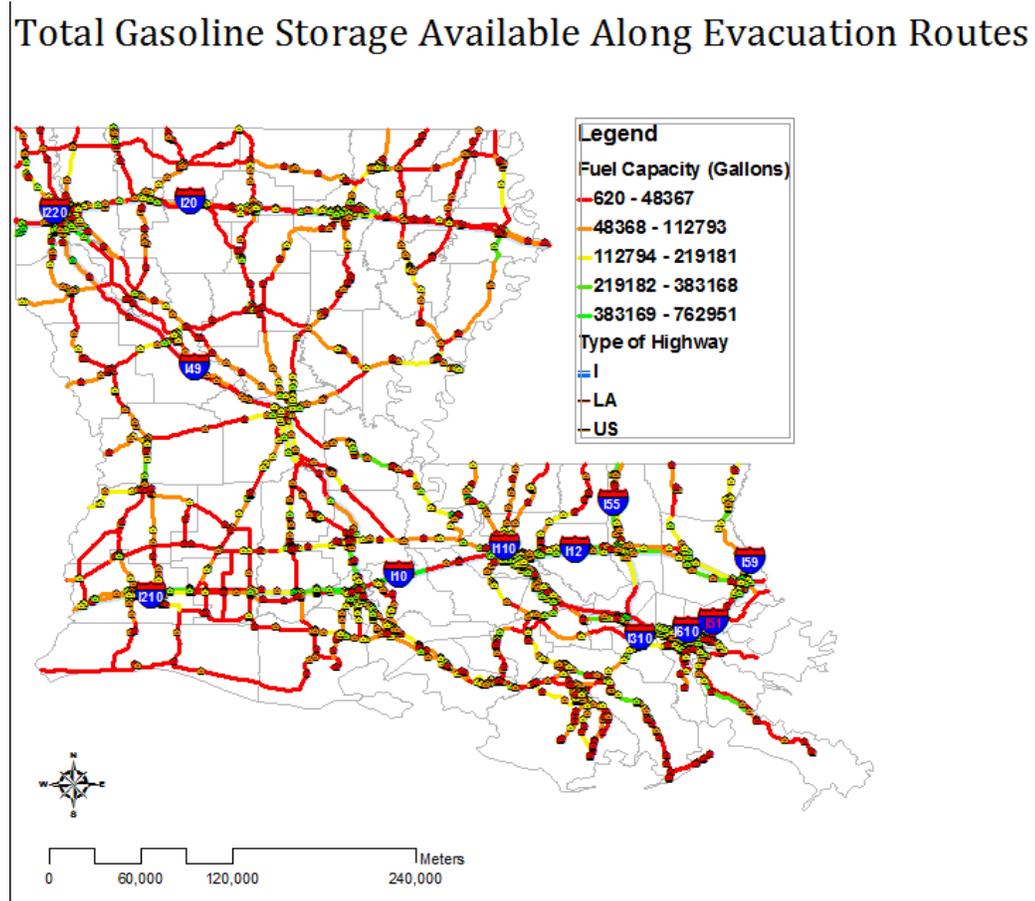


Figure 10 Available gas stations along the evacuation routes

## 6. Evacuation Traffic (number of Vehicles)

Assuming that one vehicle takes 1.8 people, the below graphic shows the total evacuation traffic for hurricane Gustav for August 30<sup>th</sup> for a 24 hour period.

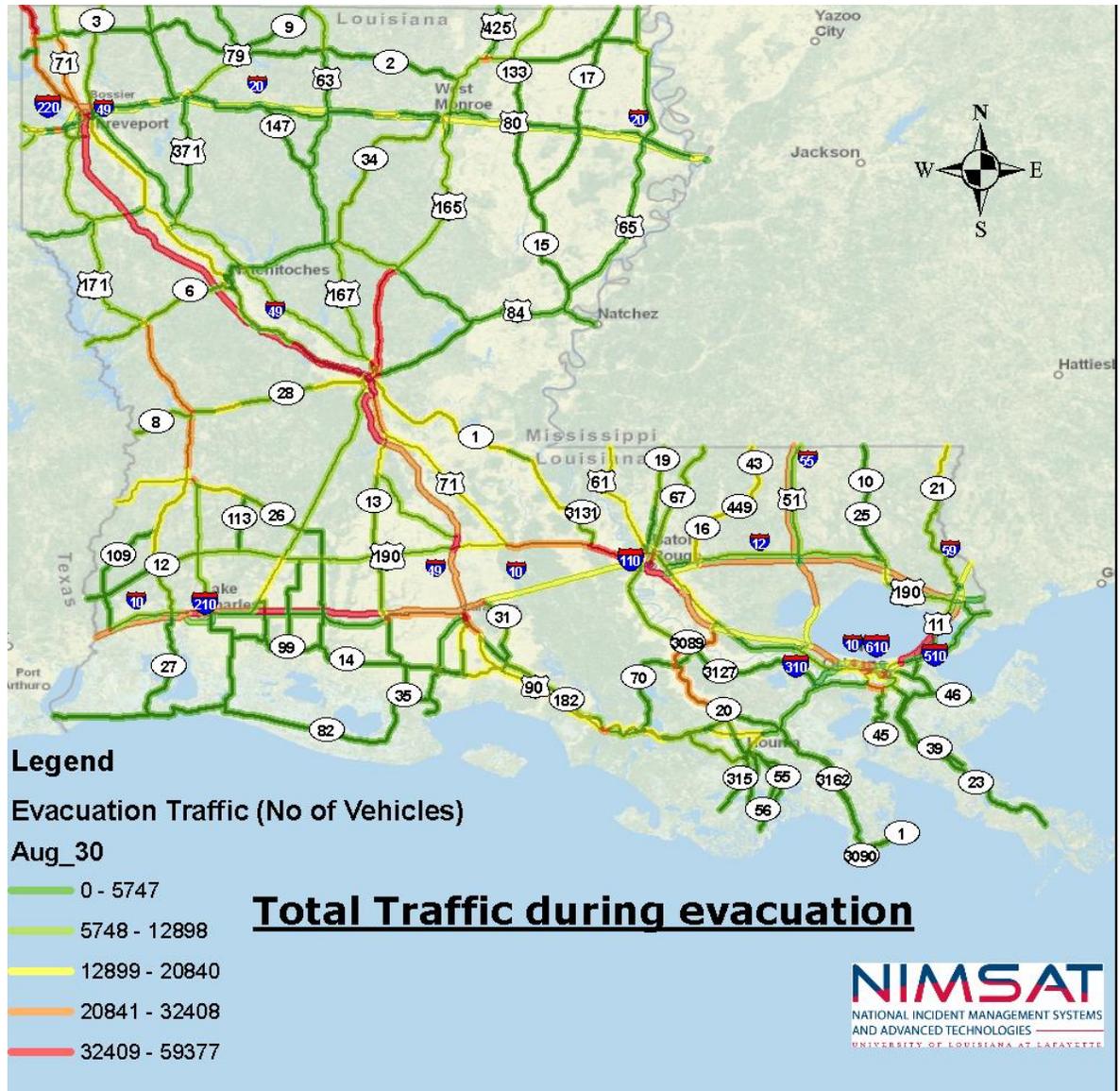


Figure 11 Estimated Evacuation Traffic (In no of vehicles)

The graphic in Figure 12 shows a zoomed in version of the evacuation traffic, and a graph shows the comparison of the observed evacuation traffic and predicted evacuation traffic. For Aug 29 2008 for hurricane Gustav

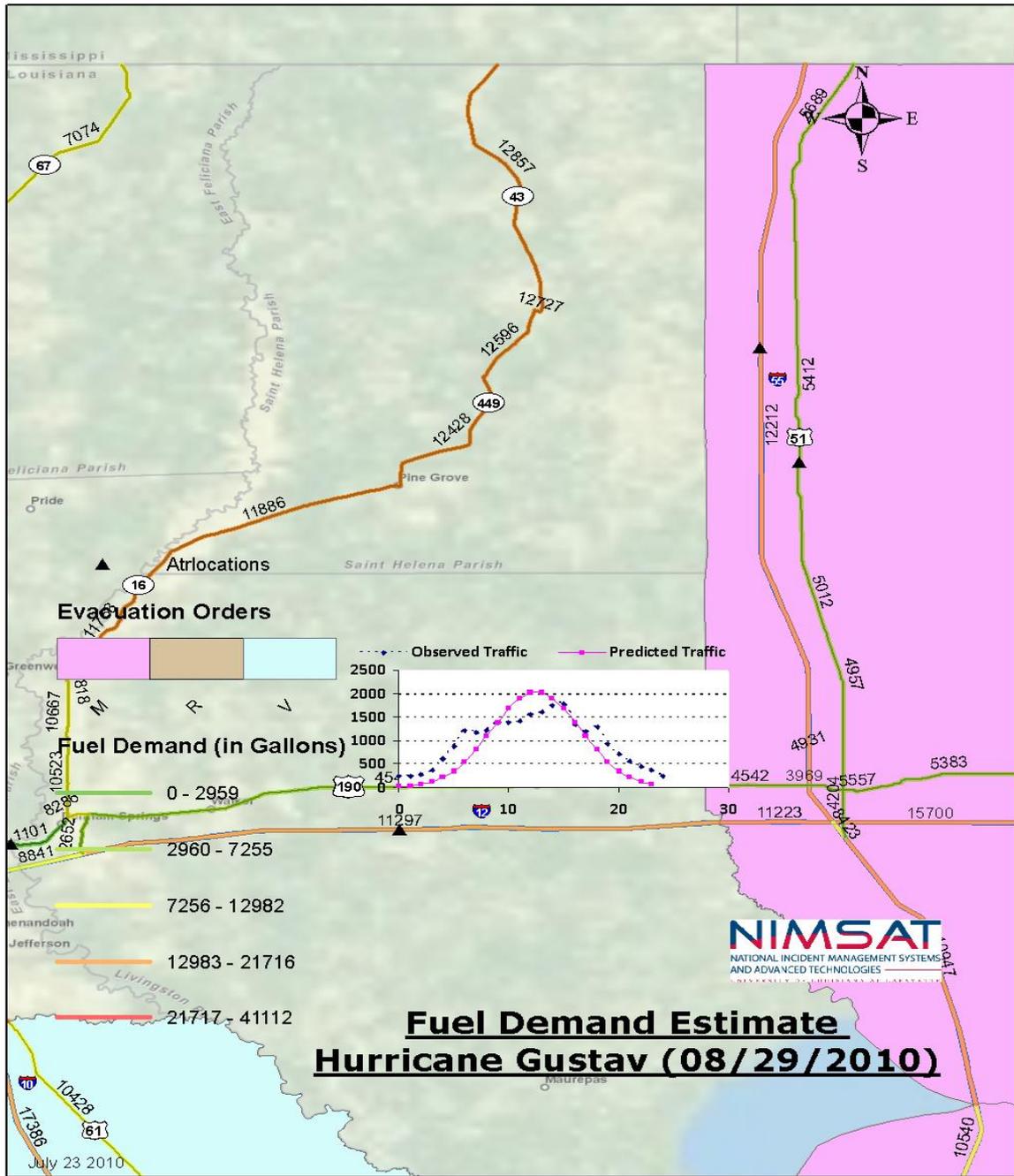


Figure 12 Estimated Evacuation Traffic (In no of vehicles)

The below image shows the zoomed in version of the actual traffic numbers along the levee district in NO in number of vehicles



Figure 13 Estimated Evacuation Traffic in NO region

## 7. Fuel Demand (In Gallons)

The below figure shows the fuel demand estimate generated by the model for a 24 hour period during Gustav on 08/30/2008.



Figure 14 Estimated Fuel Demand



## 7. OPTIMIZATION OF TRAFFIC MONITORING DEVICE PLACEMENT PLAN

### 7.1 Introduction

Evacuation is typically modeled as a network optimization problem that aims at selecting optimal routes from a set of candidate roads within an existing evacuation network. The selection of optimal routes involves determining the potential evacuation routes based on the location of origin and destination points, the capacity of highways and the evacuee traffic patterns on how, when, where people would evacuate to minimize the overall evacuation time. One of the biggest limitations in existing evacuation models is the inability to incorporate real-time situational awareness information constraints into the evacuation model. Models are typically initialized with data that is available from surveys on historical hurricanes and stated preferences. This prompts emergency managers to use preplanned evacuation plans provided by transportation engineers and any change of course during an event prompts emergency managers to make ad hoc decisions based on the best available information.

#### Real-time Traffic Information

In order to investigate the possibility of obtaining real-time traffic information, we have investigated two approaches to obtain better situational awareness through a traffic monitoring plan. One is a network of Automated Traffic Recorders (ATR)'s placed by DOTD and the other is through a series of video cameras placed by DOTD. Below we discuss the advantages and disadvantages of both the approaches.

### 7.2 Automated Traffic Recorders

The LA DOTD Office of Planning and Programming as part of their statewide traffic data collection program, collects traffic data through a network of 67 permanent ATR's located across the state of Louisiana. These are arranged to provide a representative sample of traffic on all road classifications and across rural and urbanized regions. Sixteen of these stations are located on the Interstate, 22 are installed on US Highways and the remaining 29 are placed along the Louisiana State Highway system.

At present, the ATR's are the most accurate means of obtaining real-time traffic information. While these 67 ATR's provide a representative sample of traffic along Louisiana's highways, they do not provide a reliable estimation of traffic patterns. For example, the following are some of the critical segments of evacuation highways that do not have ATR sensors

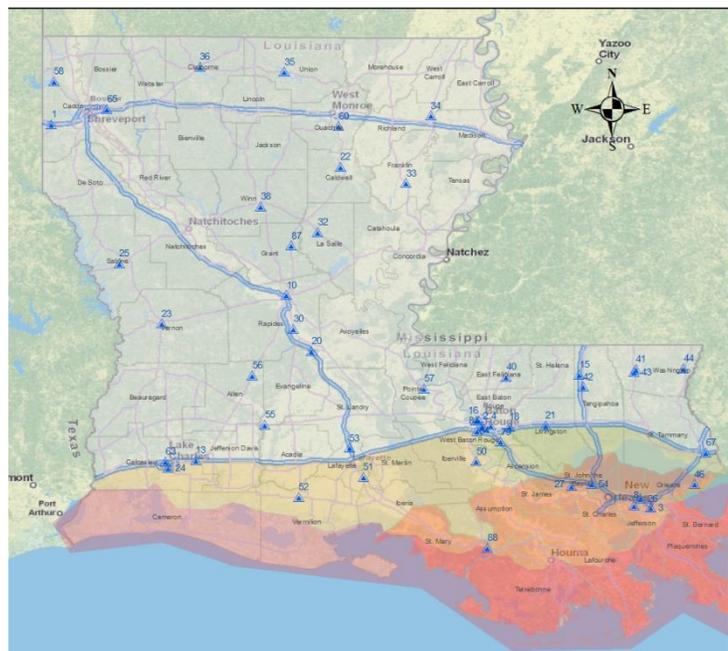


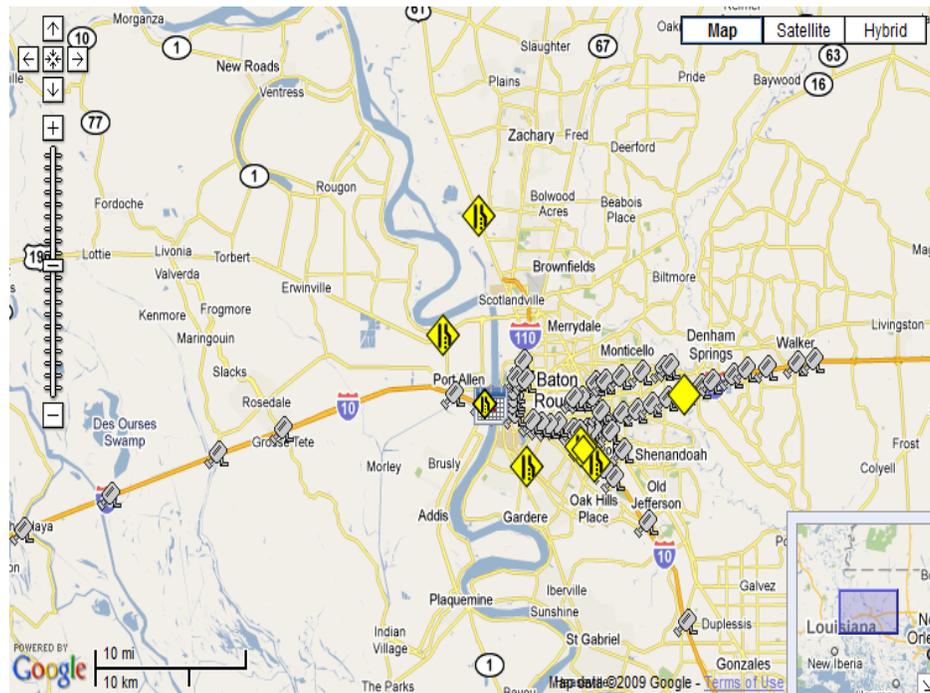
Figure 16 Locations of ATR Sensors in Louisiana

1. The I-59 segment that goes to Mississippi after the I-12 and I-10 Merger, so we do not have a good understanding of how many evacuees are going to Mississippi or coming from Mississippi to Louisiana.
2. The I-12 segment from I-55 to I-59. This is important to both understand how many people are leaving from St Tammany parish during evacuation
3. US-90 where it merges with I-310. A lot of population south to New Orleans uses this route to get onto the interstates. Considering that this is one of the most frequently evacuated coastal zones, it is important to have at least one ATR sensor to monitor traffic.
4. I-20 on either side of Lafayette to understand how much traffic is flowing in and out of Lafayette
5. I-49 North between Alexandria and Shreveport

The above are just some of the most critical locations that need ATR's to get a representative evacuation traffic. In order to obtain a reliable estimation of evacuation traffic, we would need several hundreds of sensors which would be very expensive. We plan to investigate and develop a methodology to estimate minimum number of sensors required to get a reliable estimate of evacuation traffic as a research project.

### 7.3 Video Cameras

DOTD has deployed several hundreds of video cameras across the state, primarily in urban areas. While traffic cameras are a cheaper option to count traffic, there are several research challenges to perform a video analysis to extract traffic information. The primary challenges are that the image is typically collected from a far-field, the video-quality may be degraded due to light conditions or bad weather conditions. We have been working with a computer vision researcher, Dr. Henry Chu at the Center for Advanced Computer Studies to solve this research problem.



**Figure 17 Locations of video cameras in the Baton Rouge Areas**

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