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Integrating demand and traffic simulation modeling to evaluate adaptive evacuation plans

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INTEGRATING DEMAND AND TRAFFIC SIMULATION MODELING TO EVALUATE ADAPTIVE EVACUATION PLANS

A Thesis

Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering

in

The Department of Civil and Environmental Engineering

By

Thomas J. Montz, Jr.
B.S., Louisiana State University, 2009
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Abstract

Significant efforts are currently being made by transportation officials to improve the planning and preparation of mass evacuations. The idea of adaptive evacuation plans is an avenue of research that could help improve future evacuation processes. Adaptive evacuation plans stem from the observation that different disaster threat scenarios require different evacuation responses. While adaptive evacuation planning can be generalized to any form of evacuation planning, this project focused on adaptive planning in the context of a hurricane evacuation.

This project was the first to adapt the demand models of Fu, et al, and Cheng, et al, into a regional-scale traffic simulation model. The conclusion of this component of research was that the use of household-level evacuation decision models to generate traffic demand in a simulation model can accurately produce cumulative evacuation volumes. The results showed $R^2$ correlations to observed cumulative evacuation volumes with values of at least 0.7. A qualitative and quantitative assessment of the traffic impacts of using adaptive evacuation plans was also performed in the study. Overall, the results showed that the average travel time across the entire simulated region was reduced by 14.8 percent when adaptive evacuation plans were employed.

The significance of these results lies in their applicability in effectively moving more people out of danger when faced with a threat. The main argument behind this study was that to effectively transport evacuees, something must be known about how they will react to any given threat. A single, static evacuation plan does not tailor to the broad range of response that could come from evacuees. Evacuation plans that have been adapted to suit a range of likely evacuation responses have been shown in this study to better serve evacuees by reducing travel
time and other costs associated with evacuation. The general results should be enormously important to all researchers in the evacuation field as well as emergency managers.
Chapter 1. Introduction

Transportation system deficiencies associated with the evacuations for Hurricane Floyd in Florida, Georgia, and South Carolina in 1999; Hurricane Ivan in Louisiana and Mississippi in 2004; and Hurricane Rita in Texas in 2005 have led to significant efforts by transportation experts to help better prepare for mass evacuations. One idea that has been suggested is the development of adaptive, or flexible, evacuation plans which can change based on the scenario. This idea stems from past observation which appears to suggest that different threat scenarios will require different evacuation responses. An illustration of adaptive evacuation planning can be seen in California, where a basic template of action exists for wildfire evacuations. In those areas, formal evacuation plans do not exist because wildfires move at high speeds of 90 miles per hour (mph) or more with variable direction based on wind conditions. Therefore, the evacuation template only identifies major routes leading away from populated areas. A formal evacuation route is developed after evaluating the speed and forecasted movement of the fire (Wolshon, 2009). Similar to California wildfire evacuation planning, the first step toward adaptive evacuation planning should begin with a framework that identifies the major routes available for the evacuation and allocates the available capacity of these routes to evacuees based on the nature of the threat.

1.1 Study Scope and Background

While it is believed that adaptive evacuation planning could be applied to evacuation planning for any type of hazard, this study focused on adaptive planning in the context of a hurricane evacuation. In fact, this idea has been suggested specifically for use in hurricane evacuation planning (Wolshon, 2001); (Urbina and Wolshon, 2003). This suggestion is based on the recognition that there is currently limited ability to forecast hurricane movement with
sufficient levels of accuracy prior to the issuance of evacuation orders, and there is variability in the evacuation decision process. When contrasting between wildfire evacuation and hurricane evacuation, a significant difference is noticed: portions of road network are often closed during wildfire evacuation (especially for roads that are in the path of the fire), while this usually is not the case during hurricanes. Even without restriction, it can generally be observed that evacuees favor familiar routes, freeways, or routes parallel with freeways, all of which provide quicker access to their desired destinations (Wolshon and McArdle 2009). Since evacuee destination choice is influenced by the hurricane’s path, it is important to understand how these changing dynamics affect evacuee response. This topic has been studied by both transportation and behavioral researchers (Fu, Wilmot, & Baker, 2006); (Cheng, Wilmot, & Baker, 2008). Behavioral models for evacuation departure time and destination choice is of interest to transportation experts because the output from these models can be used to generate evacuation trips in a traffic simulation model.

Computer modeling of hurricane evacuation is growing in popularity due to the ever-increasing processing power of computers. Research using computer simulation of corridors and small-scale networks has led to improvements in contraflow crossover design (Theodoulou and Wolshon, 2004). Today, the simulation of larger, regional networks is becoming the new standard for general transportation planning. Regional modeling is also useful for hurricane evacuation planning because these evacuations can generate traffic volumes that extend over periods of up to several days, cover areas of thousands of square miles, and involve millions of vehicles. For these reasons, evacuation simulation is also moving toward a standard of regional-scale models (Wolshon and McArdle, 2009); a feat that was not possible with the computing capabilities available only a few years ago.
Historically, there has been a disconnect between travel demand models and traffic simulation models in the context of emergency evacuation, although they are well integrated for normal-day transportation planning. It is hypothesized that a more streamlined approach that connects these areas in the evacuation context could be used to develop the idea of adaptive evacuation planning. Since the development of adaptive evacuation plans is tied to the ability to reliably predict evacuation traffic and then route and simulate this traffic on a regional-scale network, the approach must first be tested. Once this combination approach has been validated, adaptive hurricane evacuation plans that channel traffic to a desired destination can be compared to existing “static” evacuation plans.

1.2 Research Goal and Components

The overall goal of this study was to compare adaptive evacuation plans to an existing “static” evacuation plan. To meet this goal, the study incorporated two primary components. The first was the development of a new method that linked evacuation travel demand modeling with evacuation traffic flow modeling. The second was to test and evaluate the traffic effects of employing an adaptive evacuation framework compared to static evacuation plans for various storm scenarios.

The first research component required the combination of several existing models. Evacuation demand models were adapted from research by Fu, Wilmot, and Baker (2006) who modeled evacuation departure time and Cheng, Wilmot, and Baker (2008) who modeled destination choice. These models were selected because of their ability to alter evacuation demand based on differing hurricane scenarios. Parameters such as the hurricane wind speed, distance to landfall, and evacuation order all altered the predicted evacuation response. The models were integrated into an existing TRANSIMS simulation model of New Orleans developed by Wolshon, et al (2009). This simulation model was calibrated and validated with
observed evacuation data, and one of the first to model evacuation at a regional-scale. The combined models were then used to simulate a storm scenario that was based on the Katrina evacuation event. The simulated traffic output was compared to data recorded during the 2005 evacuation for Hurricane Katrina to validate the combination of the models.

The second research component involved comparing adaptive evacuation response to existing “static” plans over several hurricane scenarios. Four storms scenarios were created which affected both temporal and spatial evacuation demand. The hypothetical evacuation traffic generated by each storm scenario was then simulated in the TRANSIMS model, under both existing contraflow plans and an alternate plan developed for each storm scenario. The alternate plan was a modified version of the existing contraflow plan that catered to traffic moving toward the predominate destination identified by the logit models.

The research goal was completed as part of six primary tasks, including:

1. Applying household decision models to New Orleans region based on Hurricane Katrina scenario.
2. Routing and Simulating traffic in TRANSIMS under existing evacuation plans, comparing results to observed Katrina traffic to evaluate use of logit models.
3. Developing four worst-case storm scenarios.
4. Routing and Simulating traffic in TRANSIMS for each storm under existing plan.
5. Routing and Simulating traffic in TRANSIMS for each storm under alternate plans.
6. Comparison of current plan to alternate plans and establishment of relevant MOEs

1.3 Contributions

In addition to achieving the main goal through the work tasks outlined above, the study made several contributions in its field. This study was the first to integrate the demand models of Fu (2006) and Cheng (2008) into a regional-scale traffic simulation model. This research improved the New Orleans TRANSIMS model by incorporating a more rigorous routing and microsimulation equilibration procedure. Finally, the study qualitatively and quantitatively assessed the traffic impacts when alternate evacuation plans were used. The results provide
information to researchers in the evacuation field and new knowledge to emergency planners who rely on such information to make life-saving decisions.
Chapter 2. Literature Review

A literature review was performed to gain a context for the current state of evacuation research and to identify where research needs exist. The literature review examined transportation studies relating to hurricane evacuation. Specifically, the current behavioral understanding, traffic characteristics, traffic control strategies, and computer simulation for hurricane evacuations were examined.

2.1 Meteorology

Hurricanes are a special type of weather pattern. The forecasting of these storms is a crucial tool to emergency planners and the transportation officials that aid them in evacuation planning.

Willoughby (2007) states that hurricane progression is rather slow moving. It usually takes at least 12 hours for hurricane track or wind speed to noticeably change. While the public may be generally concerned about a storm’s wind speed (the Safir-Simpson scale is based on this measure), most hurricane related deaths occur because of storm surge (Willoughby, 2007). This fact has been recognized, and emergency managers have worked hard at developing plans that evacuate flood prone areas first.

The general public sometimes questions the reliability of forecasts. Willoughby shows that errors made to forecasts of the storm’s path have steadily decreased since the records began in 1954. Substantial improvement has been made with long-term forecasts over 72 hours, while short-term forecasts were always much better and thus have shown only moderate improvement. In contrast, forecasts for storm’s intensity (local wind, rainfall, and surge) remain unreliable. Typically, 300 miles of coastline will be warned for impending hurricane landfall for any given storm. This warning area is composed of 100 miles that will experience hurricane force winds
and 100 miles on either side that is only warned as a safety precaution. Even though track forecasting is steadily getting better, the only real improvement that one can expect to be made will be on the order of tens of miles.

2.2 Evacuation Preparation and Planning

This finding on hurricane forecasting is tremendously important for hurricane evacuation research. The need for the evacuation of flood prone areas is of primary importance and for any given storm approximately 300 miles of coastline will fall under hurricane advisory. Depending on the size and flooding risk of a city located in this warning zone, the amount of people evacuating could be extremely large. The large traffic demand that highway infrastructure will experience is real; as is the danger families will face if they are not able to quickly evacuate. Therefore it is extremely important that emergency managers are able to develop plans for the evacuation of vulnerable regions and transportation professionals should be able to aid these officials in efficiently loading the traffic network to clear these regions in a timely manner.

Wolshon, et al. (2005) prepared a special report detailing the current state of hurricane evacuation preparation and planning. According to this source, emergency operation officials have historically done the planning of hurricane evacuations. These local-level officials are able to coordinate with state-level officials in order to effectively manage evacuation events. The evacuations for Hurricanes Georges and Floyd were the first mass evacuation of coastline areas that experienced major traffic problems. These were “watershed” events because they prompted the need for transportation professionals in evacuation planning. Transportation planners have been more actively involved in evacuation planning since 1998 (Wolshon, et al, 2005), but perfect coordination between these officials and emergency managers has not been achieved in all localities. The report notes that transportation planners are desirable because they can offer
technical expertise in forecasting evacuation travel demand, analyzing evacuation traffic data, modeling evacuation traffic, and employing ITS technology.

2.3 Evacuation Behavior

Evacuation behavior has been studied in a variety of aspects, from carless population to automobile owners to elderly and disabled. All of these studies seek to answer three main questions: “will they evacuate”, “when will they evacuate”, and “where will they evacuate to?” Five recent studies are summarized that seem to offer acceptable answers. It should be noted, that the reviewed studies all assume the population is comprised mostly of car-owners who are able to evacuate on their own. The evacuation of the carless and disabled population is another topic that was not considered for this review.

Fu, Wilmot, and Baker (2006) developed an evacuation departure time model that was sensitive to hurricane characteristics such as: time of day, hurricane category, and the timing of the evacuation order with reference to storm landfall. This differs from previous research which provided an average response based on past experience. A logit model was employed to estimate the “if and when” decisions made by each household. That is, ‘if’ the household will evacuate and if so, ‘when’ it will evacuate. Data from the evacuation of Hurricane Floyd in South Carolina was used to calibrate the model and data from Hurricane Andrew in Louisiana was used to validate the model. The results showed that the model was able to accurately reproduce part of the Floyd data purposely left out for validation. In addition, a response curve for Hurricane Andrew was created that was found to have no statistical difference from the observed Andrew curve (Fu, Wilmot, & Baker, 2006). This was an encouraging result because it indicated that the model seemed capable of being transferred geographically. This model was thought to be potentially more useful to emergency managers because it allowed for the estimation of
evacuation response based on the type of evacuation order given (mandatory or voluntary),
timing of the evacuation order, and properties of the hurricane itself.

Dixit, Pande, Radwan, and Abdel-Aty (2008) furthered the evacuation response model by
introducing a factor into the logit model that accounts for the amount of time that has passed
since a previous hurricane. The study essentially modeled the “mobilization time” or delay of
individual households to load the network during an evacuation. Mobilization time is the time a
household takes to make an evacuation decision and then leave their house. An important
finding in this study was that some household characteristics that increased mobilization time in
the first instance of a hurricane had diminished effect on the mobilization time for subsequent
hurricanes (Dixit, et al. 2008). These characteristics included pet ownership, number of children,
and presence of elderly family members. This can intuitively be understood that following a
major hurricane, households are more likely to be better prepared and reduce their mobilization
time for the next hurricane.

The next question to be answered in the literature was that of the destination of evacuees.
Three separate studies were found that use conventional planning models to predict the
destination choice of the evacuating public. Modali (2005) viewed the destination as a function
of productions and attractions and, thus, used a gravity model. The model was calibrated using
Hurricane Floyd travel survey data and data from Hurricane Andrew was used to measure the
transferability of the model. The statistacal tests found no large variation between the observed
and predicted data sets. Modali’s findings suggested that the gravity model can be successfully
applied in an evcaution context, but classic trip purpose stratification (home-based work, home-
based other, etc) should be modified to destination type (hotel, friend, relative).
Chen (2005) used another type of model on the data sets from Hurricanes Floyd and Andrew: the intervening opportunity model. This type of model differs from the gravity model in that destinations are considered sequentially based on travel time. It can be thought of as concentric circles emanating from the origin, and each traveler will consider the closest one first before moving on to the next closest. This type of model makes more sense intuitively, but the study found that it needed modification in order to have reliable results. Chen suggested that the “concentric circle” view of the model needed to be modified into a “bowtie” shape to account for the effect of storm path on traveler decision (see Figure 2.1b). The study compared the standard intervening opportunity model (IOM), the modified opportunity model, and the gravity model of Modali (2005). The results were that the standard IOM severely underperformed compared to the gravity model and that the modified IOM was slightly better than the gravity model (Chen, 2005). Chen felt that the gravity model’s weakness lay in the fact that it incorrectly placed the most importance on travel impedance instead of hurricane path or availability of shelter. The IOM’s weakness was that it could not reflect changes to roadway infrastructure. Contraflow, for example, can not be accounted for in this model. The final conclusion was that a hybrid of the two models with a “general impedance,” that takes travel difficulty as well as attractiveness into account, might best serve future studies in this area of evacuation planning.

The weaknesses observed in the previous two planning models lead to the application of a third general planning model to forecast evacuation trip distribution. Cheng, Wilmot, and Baker (2008) assumed that there existed a discrete choice among destinations and, thus, used a logit model in order to predict evacuee destination. Two separate models were created based on evacuees either seeking out friends and family or seeking lodging. Each model contained variables such as distance from origin, likelihood of destination to experience gale-force winds,
ethnicity, and the size of the destination city in the model. The model was found to reasonably fit observed data. It showed that evacuees would choose a closer, safe destination over one more distant when they are relying on hotels for shelter. However, evacuees seeking out family or friends will travel farther, if necessary, since their choices are restricted (Cheng, Wilmot, & Baker, 2008).

![Travel Time Contours](image1)

![Path of danger](image2)

**Figure 2.1: Pictorial Representations of (a) Standard IOM (b) Modified IOM (Chen 2005)**

### 2.4 Evacuation Traffic Characteristics

Two recent studies have been published that quantify the type of traffic patterns exhibited under mass evacuation conditions both spatially and temporally. Both of these studies are important because they are based on observed data from Louisiana during the 2005 evacuation of Hurricane Katrina, whereas other studies rely on simulation results in order to quantify evacuation traffic.

Wolshon and McArdle (2009) focused directly on temporospatial patterns present in the Katrina data. The analysis of the count stations (located throughout the state of Louisiana) showed that traffic volumes levels rose across the state during the evacuation period, even at stations that were hundreds of miles away from the storm landfall zone. The data showed an increased level of volume for a period of 60 hours, taken as the duration of the evacuation event,
but the vast majority of activity occurred just two days before the actual landfall of the storm. Interstate highway routes were the most utilized, but secondary routes were also used in areas that did not have access to the interstate or in areas where the interstate was closed due to contraflow implementation (Wolshon and McArdle, 2009).

Wolshon (2008) quantified the traffic flows seen during the evacuation event. The general finding was that freeway volumes during the evacuation were found to be significantly lower than HCM suggested maximums, and furthermore, some flows were actually lower than standard afternoon peak periods. In addition, a contraflow segment was found to exhibit a lower volume than its standard lane counterpart: a result that had previously been assumed from simulation of contraflow lanes. The report infers from its analysis the following practical, sustainable flows under evacuation conditions: 1300-1500 vphpl on conventional freeways and 1000-1200 vphpl for contraflow lanes (Wolshon, 2008).

2.5 Evacuation Traffic Engineering Strategies

Wolshon, Urbina, et al. (2005) published a general report summarizing the current practice in evacuation strategies. The authors sent a survey to various state organizations in order to make this assessment. At that time, they found that the most prevalent strategy being implemented was contraflow. However, the study also noted the early emergence of ITS strategies that worked to provide the public with real-time traffic updates and information. Since that time, more research effort has been placed on these strategies in order to further enhance current strategies, allowing the public to evacuate as quickly as possible.

One area of focus has been on contraflow itself. Theodoulou and Wolshon (2004) were one of the first to use computer simulation to study the effect of reversing lane flows under evacuation conditions. The study used older generation behavioral data in order to estimate volumes and network loading rates under evacuation conditions. The study was able to compare
the benefits against the shortcomings of implementing contraflow. Theodoulou was able to estimate that the use of contraflow would add approximately 53% additional outbound capacity to the network. He was also able to show the importance of proper planning of the entry points of a contraflow segment, stating that the segment would not be very useful if adequate capacity was not provided at the entry (Theodoulou and Wolshon, 2004). The simulation data showed that a classic three-phase bottleneck regime was created in the case study with congestion upstream, capacity conditions at the crossover, and near free-flow conditions downstream. Theodoulou’s suggestion was to either add more crossovers upstream or downstream in order to offset this problem or try to spread the demand on the network temporally and/or spatially (create a “staged” evacuation). Lim and Wolshon (2005) furthered this research by assessing the placement of contraflow termination points using computer simulation. Lim concluded that a split-design termination is more advantageous because no backup is caused due to merging.

The early ideas of implementing ITS during hurricane evacuations have become more sophisticated. Liu, H. et al. (2007) suggested the use of a “Model Reference Adaptive Control” (MRAC) framework to establish a real-time traffic management scheme. The general basis for this framework is that the system should be able to observe the existing traffic patterns and react in an appropriate way as to allow traffic to flow as efficiently as possible. Liu’s framework consisted of several models that all feed into one another in order to achieve this effect. Computer simulation of an evacuation scenario using this framework was found to operate much better than if the framework wasn’t present. However, this type of framework does require a very robust set of ITS equipment to be present on the infrastructure.

Another control strategy that has been heavily researched is the idea of “staging” an evacuation. This entails splitting an evacuation area into zones and allowing these to evacuate at
different times. Most studies treat this as a mathematical optimization problem in order to determine the benefit of using such a strategy versus allowing the population to evacuate simultaneously. Liu, Y. et al. (2006) developed model that assumed a known start time for each zone’s evacuation and a known total demand and network loading pattern for each zone. The underlying flow network that Liu employed was the cell-transmission model in order to more easily compute an optimal start time and the best route for each zone. Sbayti and Mahmassani (2006) used bi-level programming formulation in order to tackle the issue. The upper level was defined as a dynamic network assignment problem that allows for the optimal determination of route assignment. The lower level was a dynamic loading problem that determines a corresponding route travel time. Both papers showed that there was a decrease in travel time, and therefore, congestion when a staging procedure was implemented. Sbayti’s paper also took it a step further and claimed that there exists a minimum network clearance time that cannot be improved by staging procedures or coordinating of evacuee destinations.

Dixit and Radwan (2009) proposed a strategy for modeling the road system of destination cities called “network breathing”. The basis for the model was the observation that destination networks become inundated with evacuees over time and cause backups and congestion on the evacuation routes. The proposed solution to this problem was to close the exits to these destinations when their networks became “full” and then open them again when the network traffic levels dissipated. This process is analogous to breathing in that the network is able to “inhale” vehicles up to a certain capacity and then they must be “exhaled”. The authors claim that an advantage of this strategy is that is does not require real-time feedback. All that is required in order to calculate a network’s “exhalation” and “inhalation” time are the destination network’s traffic properties (jam density, capacity, etc). A simulation comparing the use of this
strategy and normal conditions, showed that more vehicles were able to pass through destination networks using the network breathing strategy (Dixit and Radwan, 2009). This was due to the reduction in travel time afforded by the use of the strategy. In practice, this type of finding would be used by metering exit ramps during an evacuation. This would be best implemented by closing off interstate exits during the network’s “exhale” time and then opening them again during the “breathe” time.

2.6 Computer Simulation of Evacuation Scenarios

As shown in the previous section, the advent of computer technology now allows traffic planners to experiment with different strategies through the use of computer simulation. While these software packages were developed for normal, day-to-day planning, researchers have been successfully able to adapt the software in order to simulate evacuation procedures (Radwan, Mollaghasemi, Mitchell, & Yildirim, 2005).

Hardy and Wunderlich (2007) compiled an extensive inventory of all current transportation planning and simulation software packages available. According to the report, there are three distinct levels of simulation packages based on their ability to model certain sizes of geographic area and precision of analysis: macro, meso, or micro. A macro model is able to simulate large metropolitan areas but cannot represent individual vehicles or people within the network. Micro models are usually only able to represent one to two corridors, but are able to simulate individual drivers and pedestrians. A meso model lies somewhere inbetween the two approaches, as it is able to model larger areas with more precise results than a macroscopic model. Figure 2.2 shows a ranking of the available computer simulators on a mutli-variable “spectrum”.

The decision to use one type of simulator over another is entirely up to the researcher. Indeed, a broad look at the literature shows that software from across the “spectrum” has been used. The decision to use one over another is left entirely to the researcher and the type of results that are required. The testing of small-scale networks is usually done in microscopic simulators such as VISSIM and urban/regional testing is usually done in mesoscopic models such as DYNASSMART-P.

The use of large-scale microsimulation is on the rise. In particular, Wolshon, et al. (2009) was able to simulate the New Orleans emergency evacuation plan using the TRANSIMS platform. This report was one of the first to include a multi-modal aspect in the simulation as both cars and buses were simulated on the case study New Orleans network. In addition, the report included the first use of observed traffic conditions during an evacuation to calibrate and validate an evacuation microsimulation model. Dixit, et al. (2011) was able to pursue a unique validation methodology for large-scale models based on the TRANSIMS experience. The validation method compares cumulative evacuation volumes for both the simulated and observed
data sets at select points in the network. The fit is determined using linear regression and standard $R^2$ coefficients.

The ability to model evacuation scenarios provides an extremely useful aid to emergency planners as well as transportation officials. Sisiopiku (2007) advocated the use of traffic simulation modeling as a tool for training and aiding emergency management centers (EMCs). By using software, the EMCs were able to assess the impact of their decisions on the transportation network in a controlled environment. The case study Sisiopiku developed was for the Birmingham, AL region, and the author was able to conclude that transportation and emergency response agencies needed to interact regularly in order to ensure that both parties were able to understand what the other can offer. Transportation officials learned what alternatives EMCs are considering and the emergency planners were able to further understand the capabilities of the transportation system. It is readily apparent that computer simulation will only grow within the emergency evacuation research community. As planners develop new scenarios and schemes to move more people out of the network at a faster pace, they will undoubtedly need a laboratory in which to test their theories.

2.7 Conclusion

Currently, there is still knowledge to be gained through research in the area of emergency evacuation. The most thoroughly researched areas are currently in understanding evacuation behavior and how to optimize existing infrastructure to allow as many citizens as possible to evacuate as quickly as possible.

Evacuation behavior research seeks to understand the response from the population when hurricanes threaten their homes. This includes how they will react to changes in the storm’s track, their perceived danger, and how they will respond to orders from emergency officials. This is important from a transportation context because it can be used to forecast demand on the road.
network and then determine if there is adequate capacity available on the road network to facilitate an evacuation within the constraints of anticipated hazards.

Optimization of the infrastructure requires the use of mathematical programming models and computer simulation. Research results show that more can be done to evacuate the public more efficiently than currently implemented strategies. For example, the reviewed research showed that staging the evacuation by zones will decrease the overall clearance time. However, evacuation strategy research requires reliable characterization of the traffic volumes, speeds, and densities that can be expected under evacuation conditions specifically. Without observed information, the network capacities, jam densities, and speeds used in the optimization models can only be estimated from other congested traffic conditions. Therefore, while more efficient strategies are being developed for evacuation, care must be taken to ensure that the results accurately reflect traffic conditions that will be experienced in the field.

Another avenue of research that can be taken to optimize the existing network infrastructure is the development of adaptive evacuation plans. The envisioned adaptive plans will rely on a pre-determined set of options agreed upon by emergency managers after anticipating likely storm scenarios and the predicted response to those scenarios. This lies in contrast to an ITS-oriented approach suggested by others (i.e., Liu’s MRAC system) in which traffic monitors will identify traffic demand and response in real-time. The adaptive model will rely on state-of-the-art evacuation response models to generate the travel demand expected for each storm scenario. The literature shows that the union of evacuation response models within the context of a region-scale evacuation simulation model has not yet been attempted. Based on the review, this study fits in the context of evacuation-related research and will enhance the current knowledge base.
Chapter 3. Development of an Integrated Evacuation Demand and Traffic Simulation Model

To develop adaptive evacuation plans, the need to incorporate evacuation behavior models into regional-scale traffic evacuation models was recognized. The merit of using evacuation behavior models lie in their ability to generate evacuation demand based on various storm features, including storm path, storm strength, and type of evacuation order given (Fu, Wilmot, & Baker, 2006). In this study, a technique was developed which would allow for determining the effects of various types of storms and evacuation orders on the evacuation demand, which was hypothesized to be critical for determining evacuation operations under various storm conditions.

3.1 Components

The most advance and current method to predict hurricane evacuation departure time was developed by Fu, Wilmot and Baker (2006). In their work, they developed a transferable sequential logit model that was able to produce the probability of evacuation at the household-level considering several factors at the desired time interval (30 minues, 1 hour, etc), including: hurricane wind speed, distance of storm, evacuation order type, and time of day. A study on evacuee destination choice produced a logit model, developed by Cheng, Wilmot and Baker (2008), and can assign a destination probability per city based on a variety of factors, including: destination’s distance from origin city, if destination is likely to be in hurricane landfall zone, destination population, and destination’s racial make-up. Both of these household-level decision models offer insight into the household-level decision making process during hurricane evacuations.
A recent series of projects sponsored by the United States Department of Transportation (USDOT) and the Department of Homeland Security, sought to evaluate the use of TRANSIMS for the analysis of regional evacuations (Wolshon, et al., 2009). A traffic simulation model using TRANSIMS was developed for the New Orleans region which was capable of reproducing the evacuation processes for a Hurricane Katrina scenario. This base model was calibrated using traffic data recorded during the evacuation due to Hurricane Katrina in 2005. This observed traffic data was also used to estimate destination choice and the temporal evacuation demand curves for the evacuation. The results showed that TRANSIMS was capable of producing output that could be useful to evacuation planners. However, the base model used observed traffic volumes to determine the destination choice and departure choice of evacuees. While relying on this data set was acceptable to recreate an event that had happened before, it would not be usable in the development of storm scenarios that have yet to occur.

The household-level decision models and the simulation network of the former TRANSIMS study were used to develop an integrated approach to large-scale simulation model demand generation. The idea was to develop a storm scenario that matched Hurricane Katrina, run this scenario through the decision models, and simulate the traffic demand that would be generated. The results were then compared to the observed traffic levels during the evacuation for Hurricane Katrina to validate the effectiveness of the integrated model.

### 3.2 Data Sources

The observed traffic volume data used in this study was collected by the Louisiana Department of Transportation and Development (LA DOTD) Office of Planning and Programming as part of their statewide traffic data collection program. The objective of this program is to continuously record traffic volumes to monitor long-term traffic trends on a statewide level. The data are used primarily for aggregate-level planning and trend analyses.
However, they can also be extracted more frequently and compiled for the assessment of traffic conditions associated with particular events; such as in this case, the evacuation for Hurricane Katrina. In addition, the Mississippi Department of Transportation (MDOT) provided volume counts and average speeds for the contraflow period of the evacuation at a station just past the Louisiana-Mississippi state line along I-59.

As part of the LA DOTD monitoring program, traffic volumes are collected on a routine basis using a network of 82 permanent count stations located on various roads across the state. These automated recorders are arranged to provide a representative sample of traffic on all road classifications (freeway, arterial, collector, etc.) across the non-urbanized and urbanized regions of the state. For this study, data from a total of seven stations located on the major outbound evacuation routes from the New Orleans metropolitan areas were used for comparison. The locations of these stations are shown in Figure 3.1. Of the seven stations, six were on freeways (two of which were located on a contraflow segment) and one was on a US highway. These stations were selected because they were the stations that monitored output routes in the New Orleans area while limiting the potential inclusion of local (i.e., non-evacuation specific) traffic.

Each household was assumed to evacuate in one vehicle. Therefore, each household represented one evacuation trip. Also, as in the base model, only the metro New Orleans area was considered to generate substantial evacuation traffic, and therefore, only this area was used as possible origins for the evacuating public. In Figure 3.1, the Traffic Analysis Zones (TAZs) that were used for the study are shown in orange. The number of households in these zones was gathered from 2000 Census data. In total, over 365,000 households were contained in this analysis area. This total number was further reduced based on the predicted percentage that would not evacuate from the evacuation response logit model.
The evacuation departure time model required storm data that was time-dependent. This storm information was obtained through archives with the National Hurricane Center. Specifically, the data that needed to be collected included the time-dependent latitude, longitude, and wind speed recorded for Hurricane Katrina. The archives contained forecast information at 6-hour intervals. Linear interpolation was used between these intervals to convert the data into the hour-intervals, the interval at which output from the model was desired.

The destination choice model required demographic information obtained from the 2000 Census records. The data gathered for each destination city included population and ethnic
characteristics. The destination choice model also required the distance between each city and New Orleans. Google Earth was used to find a distance (in miles) from city center to city center. Four general trip terminal points in the network were created to represent a collection of destination cities (WEST, NORTH, NORTHEAST, EAST). This assumption was necessary because the highway network in TRANSIMS was not created to extend to all of the likely destinations from New Orleans. A likely drivable radius of 400 miles was chosen as the boundary from which destination cities were selected. Dallas and Atlanta, two cities that are known destinations through previous surveys, were also included although they are located slightly outside of the 400 mile radius. Because the network did not extend to these destinations, likely routes to each destination were examined. This was done to categorize the destination city correctly by WEST, NORTH, NORTHEAST, or EAST and assign the correct percentage of travelers to these points on the network. Figure 3.2 shows the radius of 400 miles drawn around New Orleans and the 14 destination cities selected. The figure also shows the expected routes evacuees will take to reach their destinations. It should be noted here that this study only utilized the friends and relative destination model created by Cheng, Wilmot, and Baker (2008). It was assumed, for the purpose of this study, that the population size variable included would act as a surrogate measure for the amount of friends, relatives, and hotels likely to be located in a destination city. The friends and relatives model was used over the hotel model because of the preference of evacuees to seek out friends and relatives before hotels or shelters (Cheng, Wilmot, and Baker, 2008).

3.3 Evacuation Demand Generation

The traffic generated for the simulation network was based on output from the evacuation demand models. The evacuation departure time model was used to generate a time-dependent probability distribution for evacuation demand along with the percentage of the population that
would choose not to evacuate, while the destination choice model was used to assign a probability for trips to terminate at a certain destination. Each model required a different set of inputs to generate their respective utility functions. The coefficients for the logit models are included in Table 3.1.

![Figure 3.2 Likely Drivable Destinations, Radius, and Routes from New Orleans](image)

A key assumption made while using the above logit models was that each household would evaluate each alternative in approximately the same way. In other words, an aggregate model was assumed. However, since both models are disaggregate models, it was assumed that the aggregate distribution was approximately equal to the disaggregate distribution. This is why some of the variables listed above were not used. If the variables *flood* and *mobile* were to be included, then a disaggregate household model would also have been necessary. Instead,
TRANSIMS was used to disaggregate the data as it randomly assigned each household a trip and a time to leave based on aggregate results generated by the logit models.

### Table 3.1: Logit Model Variables and Their Coefficients

#### Destination Choice Model*

<table>
<thead>
<tr>
<th>Covariate</th>
<th>Definition</th>
<th>Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIST</td>
<td>O-D Distance (mi)</td>
<td>-0.004655</td>
</tr>
<tr>
<td>POP</td>
<td>Destination City Population</td>
<td>1.66E-07</td>
</tr>
<tr>
<td>DANGER</td>
<td>Risk Indicator (Dummy Variable)</td>
<td>-0.5171</td>
</tr>
<tr>
<td>MSA</td>
<td>Metro Area Indicator (Dummy Variable)</td>
<td>1.5562</td>
</tr>
<tr>
<td>ETHEPCT</td>
<td>White Percentage</td>
<td>0.6711</td>
</tr>
</tbody>
</table>

#### Evacuation Response Model**

<table>
<thead>
<tr>
<th>Covariate</th>
<th>Definition</th>
<th>Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>intercept</td>
<td>Model constant</td>
<td>-8.18</td>
</tr>
<tr>
<td>flood*</td>
<td>1 if the residence is believed very likely to be flooded, 0 otherwise</td>
<td>0.555</td>
</tr>
<tr>
<td>mobile*</td>
<td>1 if residence is a mobile home, 0 otherwise</td>
<td>0.267</td>
</tr>
<tr>
<td>speed</td>
<td>Hurricane wind speed (mph)</td>
<td>0.008</td>
</tr>
<tr>
<td>TOD(1)</td>
<td>Time-of-Day, 0 for night (from 6 p.m to 6 a.m.) as reference category, 1 for morning (from 6 a.m. to 12 p.m.), 2 for afternoon (12 to 6 p.m.), Two Dummy Variables</td>
<td>1.543</td>
</tr>
<tr>
<td>TOD(2)</td>
<td></td>
<td>1.721</td>
</tr>
<tr>
<td>dynaorder(1)</td>
<td>Evacuation order. 1 for voluntary, 2 for mandatory, and 0 for none. Two Dummy Variables.</td>
<td>1.681</td>
</tr>
<tr>
<td>dynaorder(2)</td>
<td></td>
<td>1.998</td>
</tr>
<tr>
<td>gammadist</td>
<td>Transformation of distance (mi), with gamma distribution.</td>
<td>5.247</td>
</tr>
</tbody>
</table>

*Cheng, Wilmot, Et Al 2009

**Fu, Wilmot, Et Al 2006 (p23)

*Not Used

The use of the *gammadist* variable required the selection of a gamma distribution shape and scale parameters. The parameters selected for the model calibrated with Hurricane Floyd data were 8 and 0.6 for shape and scale, respectively (Fu, Wilmot, & Baker, 2006). This was necessary because the survey data showed that most respondents evacuated when the storm was approximately 450-500 miles away. However, the Hurricane Andrew data showed that residents chose to evacuate only when the storm was much closer, some 200-300 miles away (Fu, Wilmot,
& Baker, 2006). After reviewing the observed traffic data, it was found that the Louisiana population was more likely to evacuate in the 200-300 mile range for Katrina as they did for Andrew. Therefore, parameter values of 4 and 0.9 for shape and scale, respectively, were selected for the gamma distribution used to transform the storm distance. Figure 3.3 shows a comparison between the gamma distribution used in the original paper and the one selected for this study.

![Graph showing the effects of parameters on the shape of the gamma distribution.](image)

**Figure 3.3: Effects of Parameters on Shape of the Gamma Distribution**

The next step was to use resulting logit model probabilities to generate trips for the simulation. TRANSIMS is able to utilize conventional Origin-Destination information in the form of trip tables. Four tables were created that assigned trips from each TAZ to one of the four destinations. The number of households in each TAZ was multiplied by the probability determined by the logit model for the particular destination. In the WEST table, for example, each zone’s household count was multiplied by the probability of heading WEST for the evacuation.
Once the trip tables were created, the next step was to assign the loading distribution to the trips. TRANSIMS accepts a time distribution file along with the trip table file that assigns a probability for trips to start in any time increment for the simulation period. The sequential logit model generated a probability distribution in hourly increments. This distribution was read into TRANSIMS. With all these elements in place, traffic could be assigned to the network to begin microsimulation.

### 3.4 Simulation Procedure

After using the logit models to generate the evacuation demand, the next step was to route and simulate traffic on the network shown in Figure 3.1. It should be noted, that this study used the same network files and calibrated microsimulator parameters as the base model. The network was designed to include detailed information of the metro New Orleans area and more sparse information toward the ultimate destinations. This was required because it was assumed that no evacuation traffic demand was generated in these outlying areas. The simulation period lasted for 48-hours, the two days leading up to Hurricane Katrina. The network files were coded to activate all contraflow links located on Interstates 10, 55, and 59 at the same time during the simulation as was initiated for the actual Katrina event. The simulation was run under five different random seeds, and the results were analyzed based on the average of these runs.

In TRANSIMS, the method of routing and simulating traffic on the network involves an iterative process based on feedback loops between the different modules. The process, while static within an iteration, leads to a dynamic routing solution. Two general algorithms were followed to lead to this solution. This first is called router stabilization. This algorithm requires that all trips be routed onto the network for the first iteration, and then only selected travelers are re-routed in successive iterations. After each iteration, the travel time for each link is determined based on BPR formulas and used in the next routing iteration.
The router stabilization incorporated three bracket criteria for selecting eligible travelers for re-routing. The criteria started with travel time improvements of 25 percent, then 20 percent, and finally a 15 percent improvement. Within each bracket, the percentage of travelers selected needed to converge to a 1 percent or less difference from the previous iteration before moving to the next bracket. The bracket levels and convergence criteria were changed from the base model, which used a less stringent equilibration procedure. The brackets and convergence criteria were selected after trial-and-error routing solutions were compared to the observed traffic data set. In addition, three key router parameters that affect link impedance were altered from the base router control file: DISTANCE_VALUE, COST_VALUE, and TRANSFER_PENALTY. The DISTANCE_VALUE parameter attributes a scalar impedance to each link based on its length. The COST_VALUE and TRANSFER_PENALTY parameters are used to alter impedance for transit users, but where found to also alter the results in the case of this simulation, which was auto-only. Values of 1.0, 5, and 1500 were selected for the parameters (respectively) after a trial-and-error process of comparing the router output to the observed traffic data. The selected router parameters produced results that best fit the observed data, as described in Section 3.6. The overall objective of the router stabilization algorithm and altered parameters was to route traffic as logically as possible before allowing the traffic to be simulated.

The second algorithm worked in much the same way, but instead of travel times being determined by BPR formulas, they were determined by the microsimulator. The output of the microsimulator contains second-by-second movements of each vehicle and can lead to a more precise solution. However, it was found that microsimulation iterations did not lead to significant improvements in the overall convergence, thus this process was limited to five iterations. The output from the final microsimulator iteration that was used to produce the simulation results for
this study. The entire script used to perform the equilibration procedure, along with the parameters used to run each TRANSIMS module is included in Appendix A.

By using this equilibrium process, it was assumed that each driver had some information about congestion levels on the evacuation routes. This assumption implied that drivers would be listening to local radio service, using a smartphone, or another means of communication to find out about traffic congestion and alter their route during the evacuation. The alternative would be to assume that drivers have no information about the congestion and would simply use major routes (i.e., interstates and U.S. highways). This topic is debatable. It is recognized that evacuations represent a one-time occurrence that may not be familiar for evacuees, and thus it would be incorrect to assume that evacuees would have prior information about road conditions. Conversely, in the particular instance of hurricane evacuation, the evacuee has much more time to assess the traffic conditions on evacuation routes, using the information sources previously listed, before making the decision to evacuate. This stands in contrast to no-notice events such as nuclear disasters, wildfires, tornadoes, etc, in which evacuees would have no time to consider alternate routes. Therefore, the assumption of drive information during the evacuation was used in this study.

3.5 Logit Model Application Results

Figure 3.4 shows two plots that compare the evacuation demand curves generated from observed values and those predicted based on the departure time model. The two plots describe the same information in two different ways. The plot on the left shows the cumulative demand over the 48 hour period, and the plot on the right shows the probability of evacuation for each time interval.

The cumulative curves show a characteristic “double-S” shape that is typical for a 48-hour evacuation. This plot shows that most of the evacuation took place during the daylight
hours, although the observed curve does not decline as much as the predicted curve. This means that the model under-predicted the amount of people that would evacuate during the night.

Figure 3.4: Evacuation Demand Curves

The probability plot on the right shows more clearly the under- and over-predicting tendencies of the model. A peak occurs on the predicted model at the time the first evacuation order is given, and another spike is seen during the afternoon hours. This is because the sequential logit model assigns higher utility to hours under evacuation order and also during afternoon. The model descends below the observed level at hour 20 (8 pm, Day 1) because the model places a low utility on evacuating during the evening.

The steep peaks observed on the predicted curve are due to the use of dummy variables in the sequential logit model. The utility function was extremely sensitive to dummy variables. One consideration was to ‘smooth’ the dummy variables (i.e., give a value between 0 and 1 over time) to provide a steady transition over time rather than the sharp rises observed. However, this type of alteration was rejected because it would affect the calibrated parameters of the model.
Table 3.2 compares the predicted and observed probabilities for the destinations. The observed probabilities provided in Table 3.2 were estimated based on the traffic counts recorded during Hurricane Katrina. Destination probabilities resulting from an evacuation travel survey were not available at the time of this study. The probability from the logit model was very close to the observed for the collective WEST destination choice. Larger differences were experienced for the other three network termini, however, the differences were within a 5 percent tolerance. The resulting utilities are also included in Table 3.2 to compare how the different cities were rated by the model. The biggest factors affecting a destination’s utility were distance and population. The negative utility for Atlanta, for example, was due to the fact that the city is distant from New Orleans despite its large population. The high utility for Baton Rouge is similarly explained by the city’s close proximity to New Orleans.

Table 3.2 Destination Choice Probabilities

<table>
<thead>
<tr>
<th>Destination</th>
<th>City</th>
<th>Utility</th>
<th>Probability</th>
<th>Predicted</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>WEST:</td>
<td>Baton Rouge</td>
<td>0.9899</td>
<td>0.4565</td>
<td>0.4427</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shreveport</td>
<td>0.4385</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Monroe</td>
<td>0.5565</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dallas</td>
<td>-0.1915</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NORTH:</td>
<td>Jackson, MS</td>
<td>0.9037</td>
<td>0.2389</td>
<td>0.2671</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Memphis</td>
<td>0.0303</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Little Rock, AK</td>
<td>0.0006</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NORTHEAST:</td>
<td>Hattiesburg</td>
<td>-0.6850</td>
<td>0.1186</td>
<td>0.1590</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Meridian</td>
<td>-0.6198</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Birmingham</td>
<td>0.1749</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EAST:</td>
<td>Mobile</td>
<td>0.7193</td>
<td>0.1860</td>
<td>0.1312</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Atlanta</td>
<td>-0.3411</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tallahassee</td>
<td>-0.3021</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.6 Simulation Model Results

The simulation output was compared to observed data at each of the stations shown in Figure 3.1. The first comparison was made for temporal volume distributions in a qualitative
manner. Figure 3.5 shows this comparison for the westbound LA DOTD data station on I-10 in Laplace. This is the first station along I-10 recording traffic heading toward Baton Rouge. The plot shows that the current model tended to produce more evacuation traffic during daytime hours and less during night than what was actually observed. A similar pattern was also observed at all other stations. The lower volume during night-time hours is attributed to the low probabilities produced by the evacuation departure time model (Figure 3.4). As mentioned previously, the utility functions in the model placed higher weight for daytime hours than for nighttime hours.

![Graph showing temporal volume comparison at WB I-10 in Laplace](image)

**Figure 3.5 Temporal volume comparison at WB I-10 in Laplace**

Regression analysis was used to compare the simulated cumulative volumes with the observed cumulative volumes. The analysis is a direct X-Y comparison of these data sets. This type of analysis was performed because it provided a measure to determine how close the simulation model matched the observed evacuation volumes. Cumulative volumes were used as
a measure of effectiveness since this quantity is used to determine the number of people who have evacuated to safety. Figure 3.6 shows a plot generated for the regression analysis at the count station shown above, westbound I-10 in Laplace. At this station, a good fit was shown with little deviation from the line $y = x$.

![Figure 3.6 Plot showing regression analysis at WB I-10 in Laplace](image)

Table 3.3 shows the results of the regression analysis at each traffic count station. The regression analysis showed that more correlated volumes were found at stations located closer to the study area (shown in Figure 3.1). The three stations located in Kenner and Laplace, towns located very close to the study area, exhibited the highest $R^2$ values. This indicated that the cumulative simulated volumes passing these locations were similar to the observed data set. The
drop in correlation at stations more distant from the New Orleans metro area is because local traffic around these stations was not generated in the simulation model.

### Table 3.3: Regression Analysis Results

<table>
<thead>
<tr>
<th>Count Station</th>
<th>Location</th>
<th>R² Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loyola Dr</td>
<td>WB I-10 Kenner</td>
<td>0.8968</td>
</tr>
<tr>
<td>27</td>
<td>NB US 61 Laplace</td>
<td>0.9877</td>
</tr>
<tr>
<td>54</td>
<td>WB I-10 Laplace</td>
<td>0.9835</td>
</tr>
<tr>
<td>15</td>
<td>NB I-55 Hammond</td>
<td>0.7528</td>
</tr>
<tr>
<td>15</td>
<td>SB I-55 Hammond (Contraflow)</td>
<td>0.7294</td>
</tr>
<tr>
<td>79</td>
<td>WB I-10 Baton Rouge</td>
<td>0.7542</td>
</tr>
<tr>
<td>67</td>
<td>EB I-10 Slidell</td>
<td>0.8600</td>
</tr>
<tr>
<td>MDOT</td>
<td>NB I-59 LA/MS Line</td>
<td>0.7548</td>
</tr>
<tr>
<td>MDOT</td>
<td>SB I-59 LA/MS Line (Contraflow)</td>
<td>0.7353</td>
</tr>
</tbody>
</table>

Although the correlations decreased as the stations were further from the New Orleans metropolitan area, all correlations were above 0.7, which was considered an acceptable correlation value. The model was also able to accurately simulate evacuation traffic patterns as evident from the temporal analysis. All of the plots generated for each count station in Table 3.3 are included in Appendix B.

### 3.7 Discussion

This chapter described the integration of evacuation demand and traffic simulation models. The intent was to demonstrate the use of evacuation demand models to determine destination choice and departure choice in conjunction with a traffic simulation model. The integrated model was also validated based on observed traffic data recorded during the evacuation for Hurricane Katrina in Louisiana in 2005.
On a qualitative basis, the primary issue with the logit models was the jumps in demand caused by the use of dummy variables. This effect is most likely due to transferability issues. The logit models used for this study were originally based on data from Hurricane Floyd in South Carolina. The sequential logit model used was a transferred model calibrated to fit Louisiana behavior, but the model still under-estimated the nighttime evacuation response that was observed in southeastern Louisiana prior to Hurricane Katrina. Error in the destination choice logit model fell within a 5 percent tolerance. This error is likely due to the fact that the model used was not fully calibrated to fit Louisiana behavior as the model was calibrated using a South Carolina evacuation data set.

Despite these drawbacks, the model and corresponding simulation yielded results that were essentially accurate from the evacuation planning perspective. The results indicated that the proposed methodology was able to predict the cumulative evacuation traffic observed during Hurricane Katrina with $R^2$ correlations greater than 0.7. Based on these results, the combined model described in this chapter was used to predict the demand for different storms scenarios and simulate the demand on a traffic network as detailed in the following chapters.
Chapter 4. Alternate Storm Scenario Methodology

Once the integrated evacuation response and simulation model had been tested, the next phase of the study could begin. This phase involved creating storms scenarios that would be input into the logit models to produce different evacuation demand for each scenario. After evaluating the resulting demand patterns, alternate evacuation plans were coded to make more efficient use of the road network based on a particular scenario. These alternate plans collectively formed an adaptive framework for the study. This chapter describes the process undertaken to develop the alternate storm scenarios and alternate evacuation plans. The end of the chapter describes how these components were integrated into the baseline TRANSIMS New Orleans evacuation model.

4.1 Storm Scenario Development

The first step toward developing the alternate storm scenarios was to examine the logit models presented in the previous chapter. The specific variables used in the logit models were examined to understand the types of storm scenarios that could be created using the models. The first of the two models, the departure time logit model, contained variables for a storm’s landfall distance, wind speed, evacuation order, and the time of day. These variables would influence hurricane response in both time, as the hurricane progresses, and space, based on hurricane path. The destination choice logit model was sensitive to each destination’s distance away, population size, metro area indicator (dummy variable), ethnicity, and the likelihood of the destination to experience gale force winds due to the storm. The former variable would be the only variable to change across any given theoretical storm scenario. This variable represented the danger a destination would be likely to experience from gale force wind speeds (>39 mph) as the hurricane made landfall. Therefore, the destination choice logit would only be able to vary
hurricane response spatially while the departure time model would vary based on changes in both
time and space.

After examining the logit model variables, the decision was made to design the storm
scenarios so that differences would be tested in time and space. A total of four storm scenarios
were created for this study. The first two scenarios were designed to force evacuation traffic to
have different spatial patterns, and the second two scenarios were designed to force evacuation
traffic to have different temporal patterns. Four separate storm tracks were mapped to estimate
the distance to landfall during the two-day evacuation period for each storm scenario. The first
two tracks to be developed would elicit different destination choice response by having paths that
landed in different areas while keeping the time variables (landfall distance, wind speeds,
evacuation order, time of day) constant. The second two tracks to be developed would have the
same destination response by landing in approximately the same area, but vary in time.

To determine the destinations that would experience gale force winds, each storm’s cone
of uncertainly was drawn around the path. Any destination city falling within the cone would be
given the DANGER indicator variable in the destination choice logit model (Table 3.1).
Hurricanes often maintain tropical storm force winds even after they are inland; therefore,
destinations slightly beyond the end of the cone were also given the DANGER indicator
variable.

The tracks of each storm scenario were based on historical storm records maintained by
the National Oceanic and Atmospheric Administration (NOAA). The storms scenarios eliciting a
varied spatial response are referred to as Storms WEST and EAST, indicating the cardinal
direction of landfall with respect to New Orleans. Both of these storms were actually altered
paths of the 1992 storm, Hurricane Andrew, with one path given a more westward approach and
the other path given a more eastward approach. Since the paths for both storm scenarios were
similar, the departure time model exhibited little change. However, the preferred destinations
were different for each storm, this impacted the destination direction that the majority of
evacuees favored. The storm scenarios eliciting a varied temporal response were named
CAMILLE and BETSY as the paths of these scenarios were unaltered from actual hurricanes by
the same names. These two storms had different paths and made landfall at different times of
day, but had approximately the same landfall areas. This resulted in two storm scenarios with
varied departure time response but not significant differences in destination choice. A tabular
listing of all hurricane tracks used for the study is listed in Appendix C.

4.2 Storm Scenario Description

After developing a plan for storm scenarios, the experimental scenarios were analyzed by
the logit models. The results of the logit models are presented below. A comprehensive listing of
all storms and their input variables is given in Appendix C. The description for the storms that
maintained constant temporal evacuation patterns is presented first and the scenarios that held
spatial evacuation patterns constant are presented second.

The two storm scenarios developed to alter spatial evacuation patterns are shown in
Figure 4.1. The cones of uncertainly shown in Figure 4.1 were analyzed to determine the
destinations that would be impacted by each storm. The destinations impacted by WEST
included: Houston, Baton Rouge, Hattiesburg, Jackson, Monroe, and Shreveport. The destination
impacted by EAST included: Baton Rouge, Hattiesburg, Mobile, Jackson, Meridian, and
Birmingham. Table 4.1 shows the predicted distribution of destination choice for each scenario.
Comparing the distributions, only the North destination seemed to have no change, while the
remaining destinations exhibited larger differences, as expected.
Figure 4.1  Storm Scenario Paths and Cones of Uncertainty for Spatial Storm Scenarios

Table 4.1 Destination Choices for Spatial Storm Scenarios

<table>
<thead>
<tr>
<th>Destination:</th>
<th>Storm WEST</th>
<th>Storm EAST</th>
</tr>
</thead>
<tbody>
<tr>
<td>WEST:</td>
<td>37.03%</td>
<td>48.74%</td>
</tr>
<tr>
<td>NORTH:</td>
<td>19.82%</td>
<td>19.86%</td>
</tr>
<tr>
<td>NORTHEAST:</td>
<td>12.63%</td>
<td>8.70%</td>
</tr>
<tr>
<td>EAST:</td>
<td>30.51%</td>
<td>22.69%</td>
</tr>
</tbody>
</table>

Under both storms scenarios, approximately 81 percent of the total population of New Orleans was predicted to evacuate, based on the results of the evacuation departure time model. In addition to predicting the evacuating percentage, the evacuation departure time model also predicted the peak evacuation hour to be at 7 A.M. of the second day. Figure 4.2 shows departure time curves for each storm. No discernable difference in temporal patterns was found between the two storm paths. The peak wind speeds of both storms were modeled to reach 170 mph at 1
P.M. on the second day of the simulation. The evacuation period was ended at 12 A.M. for both storms, which was 6 hours before each storm made landfall.

![Cumulative Evacuation Departure Time for Spatial Storm Scenarios](image)

**Figure 4.2 Cumulative Evacuation Departure Time for Spatial Storm Scenarios**

The two storm scenarios developed to alter temporal evacuation patterns are shown in Figure 4.3. The destinations that would be impacted by tropical force winds during the storm were determined by the cones of uncertainty for each scenario. For Storm BETSY, the destinations impacted included: Baton Rouge, Shreveport, Monroe, Jackson, and Hattiesburg. For Storm CAMILLE, the destination impacted included: Baton Rouge, Shreveport, Monroe, Jackson, Meridian, Hattiesburg, and Mobile. Table 4.2 shows the predicted destination choice probabilities after altering the DANGER variable in the destination choice logit model. The table shows that the destination distribution probabilities were not significantly (< 5%) different between the two storms. The greatest difference occurred for the East destination, which held an approximate 5 percent difference between each storm.
(a) Storm *BETSY*  
(b) Storm *CAMILLE*

Figure 4.3 Storm Scenario Paths and Cones of Uncertainty for Temporal Storm Scenarios

<table>
<thead>
<tr>
<th>Destination</th>
<th>Storm <em>BETSY</em></th>
<th>Storm <em>CAMILLE</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>WEST:</td>
<td>39.50%</td>
<td>43.28%</td>
</tr>
<tr>
<td>NORTH:</td>
<td>19.04%</td>
<td>20.86%</td>
</tr>
<tr>
<td>NORTHEAST:</td>
<td>12.14%</td>
<td>12.01%</td>
</tr>
<tr>
<td>EAST:</td>
<td>29.32%</td>
<td>23.84%</td>
</tr>
</tbody>
</table>

The departure time logit model predicted that 69.2 percent of the New Orleans population would choose to evacuate for Storm *BETSY*, while a predicted 82.4 percent would evacuate for Storm *CAMILLE*. The large difference is attributed to both the timing and the maximum wind speed of the two storms. Storm *BETSY* had a peak wind speed of 155 mph at midnight on the second day, which was 6 hours before the storm made landfall. Storm *CAMILLE* reached a maximum wind speed of 190 mph around 6 P.M. of the second day, again, 6 hours before
landfall. It should be noted that even though the two storms had different landfall times, the evacuation period was still assumed to last 48 hours, ending 6 hours prior to the respective storm landfalls. Therefore, when making comparisons between these two storms, the Evacuation Period Hour should be used instead of the time of day. The peak evacuation time period occurred at Hour 32 for Storm BETSY and Hour 36 for Storm CAMILLE. Figure 4.4 shows the cumulative evacuation departure time curve for each storm. The figure shows a lag in the response for Storm CAMILLE compared to Strom BETSY. Although, higher evacuation numbers were predicted on the first day for CAMILLE compared to BETSY.

![Cumulative Evacuation Departure Time for Temporal Storm Scenarios](image)

**Figure 4.4 Cumulative Evacuation Departure Time for Temporal Storm Scenarios**

The result of examining the logit model variables was to create a set of four alternative storm scenarios to test an adaptive evacuation framework. Two of the scenarios tested the spatial aspects of varying demand, and two scenarios tested the temporal aspects of varying demand. After developing the alternative storms, evacuation plans needed to be developed. These plans
would ultimately become part of an adaptive evacuation framework to be tested against an existing “static” evacuation plan.

4.3 Alternate Evacuation Plans

One of the motivations to develop and test adaptive evacuation plans was that alternate plans, developed to better suit the available capacity to the demand created by a particular storm scenario, would result in a decreased overall evacuation trip time. The current evacuation plan used for the entire southeast Louisiana region, including New Orleans, is shown in Figure 4.5. This plan has been implemented for both Hurricanes Katrina and Gustav. All of the alternate plans developed were alterations of the current plan. The alternatives sought to improve bottleneck conditions that may occur and make more efficient use of the road network, including eliminating contraflow segments that were unwarranted.

The development of the alternate plan for Storm EAST was based on the expectation that a large number of evacuees would choose West or North destinations. This expectation is confirmed by Table 4.1, although there is still demand for East destinations as well. There will be almost no traffic evacuating to Northeast destinations; therefore, the contraflow section in this direction on I-59 was eliminated in the alternate plan. Traffic on I-10 eastbound in Slidell was allowed to continue on I-10 east into Mississippi or north on I-59, but the traffic on this route was not allowed to go west on I-12. This was because it was assumed that a bottleneck would develop at the I-12/I-10 eastbound merge. To eliminate this, priority was given to traffic leaving New Orleans and I-12 was closed to eastbound traffic starting at the US 11 exit in Slidell. Traffic heading westbound into Louisiana from Mississippi was allowed to choose between I-59 northbound or I-12 westbound, but could not proceeded on I-10 westbound to New Orleans. These modifications to the Slidell area interchanges are shown in Figure 4.6. In the figure, the red links represent ramps that would be closed during contraflow operations.
Figure 4.5 Metropolitan New Orleans Contraflow Plan

Figure 4.6 Ramp Configuration for Slidell Junctions (All Alternate Plans)
For Storm \textit{WEST}, it was expected that a large number of evacuees would mainly seek destinations to the East. Therefore traffic on I-10 eastbound in Slidell was allowed to continue or access I-59 northbound, as in the altered plan for Storm \textit{EAST}. Also as in the previous plan, contraflow on I-59 was eliminated and eastbound traffic on I-12 was re-routed to US-11 in Slidell. In Hammond, traffic on I-55 northbound was altered to allow traffic to choose I-12 westbound before the contraflow crossover point. Also, a directional fork was created on I-12 westbound with one lane that would divert to I-55 northbound and one lane that would continue on I-12 westbound. This configuration was not used in the previous plan because it was expected that it would lead to congestion, especially in Baton Rouge, as a larger percentage of traffic sought westbound destinations for Storm \textit{EAST}. The altered configuration for Storm \textit{WEST} is shown in Figure 4.7.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure4.7.png}
\caption{Figure 4.7 Ramp Configuration at I-12 & I-55 JCT (Storm \textit{WEST} Alternate Plan)}
\end{figure}

Both plans for Storms \textit{EAST} and \textit{WEST} preserve the current configurations in the New Orleans suburbs of Metairie and Kenner because it was recognized that Baton Rouge would
remain the most attractive destination, regardless of the approach direction of the storm. The configuration at the northern terminus of the Lake Pontchartrain Causeway was also preserved to encourage New Orleans traffic to select this additional route out of the city. For both plans, I-12 westbound in Baton Rouge was closed at Airline Hwy. This closure sought to prevent a major bottleneck at the I-10/I-12 merge in Baton Rouge. Traffic was forced to use US 61 then US 190 if evacuees sought to continue to Baton Rouge. This configuration is shown in Figure 4.8.

Figure 4.8 Ramp Configuration at I-12 & US 61 JCT (All Alternate Plans)

A shift in temporal demand was examined by the next alternative plans. The current plan was implemented at variable times, but for the purpose of this study, it was kept constant for each storm. The timing used for the current plan was kept the same as in Hurricane Katrina, beginning at hour 16 in the simulation (corresponding to 4 P.M. of the first day) and ending at hour 40 (corresponding to 4 P.M. on the second day). For the alternate plans, it was hypothesized that starting contraflow plans during the expected second-day spike in traffic would be the most efficient use of the road network. Otherwise, the traffic levels would not be high enough to justify using contraflow. In the case of Storm *BETSY*, the storm slowly progressed toward New
Orleans and then very rapidly approached the city. The storm had reached category 4 status at hour 31. Therefore, contraflow plans were started at hour 32 (8 A.M., second day, simulation time), corresponding to the spike seen in the evacuation departure time curve shown in Figure 4.4. The contraflow plan was terminated at Hour 43 when traffic levels subsided, leading to an 11-hour contraflow period. Storm CAMILLE gained Category 5 status overnight between the first and second simulation days. Contraflow plans for this storm were started at Hour 35, which corresponded to 5 A.M. of the second day in the simulation. The start of contraflow occurred slightly before the spike in traffic seen in Camille’s evacuation departure time curve in Figure 4.4. The contraflow plans for this storm were allowed to continue until the end of the simulation, corresponding to the landfall of the storm. The resulting evacuation period totaled 13 hours. A summary of all alternate plan junction configurations and timings is presented in Figure 4.9.

### 4.4 Integration with TRANSIMS Model

The final step was to combine all the proceeding elements into the simulation model. The four alternative scenarios were simulated in the TRANSIMS model under both existing static contraflow plans and adaptive evacuation plans. As previously discussed, the adaptive plans were matched to each scenario to tailor to its predicted traffic demand. Again, the same network files and iterative routing process was performed for all storm scenarios as described in the previous chapter. Each storm scenario was simulated under both the existing plan and alternate plan. The storm scenarios were run with five random seed numbers to achieve the necessary level of stochastic variability. This lead to a total of 40 simulation runs processed by TRANSIMS. To consolidate the data, the results from the five random seeds were averaged for each storm, and the results were based on this averaged output.
Three critical files were created by the model. The first was a cumulative volume file which aggregated the total number of vehicles on each link for each hour in the simulation. The second was an average speed file that produced the average speed on each link for each hour of the simulation. The third was a file written during the iterative routing process that showed the results of router convergence as well as the results from the final microsimulator iteration. This information included: number of vehicle turns, average trip time, total vehicle hours for the simulation, and total vehicles successfully completing their trip. The data contained in these files were analyzed to assess the traffic impact of using the adaptive plan set when compared to the current “static” plan.
Chapter 5. Alternate Storm Scenario Results

The analysis of model results began with a qualitative examination of the congestion levels experienced along Interstate 10 during the simulation. Next, plots of the traffic volumes over time were created at key points in the network to investigate the effect of the adaptive plans on traffic levels during the simulation. Lastly, a tabular array of relevant simulation measures of effectiveness was created to arrive at the overall results of the research.

5.1. Congestion Levels

The congestion levels for each simulation are presented in the form of time-space diagrams. The color bars used in all the figures represent the average speeds observed on each link in miles per hour. Red areas indicate the existence of traffic shockwaves which produced a drop in speeds. The plots inform not only where, but how long these disturbances lasted.

![Figure 5.1 Map of I-10 Sections Analyzed by Time-Space Plots](image)
Three separate sections of I-10 were examined. Route 1 was the contraflow section of I-10 that began in the New Orleans Central Business District (CBD) and extended to the I-55 interchange in Laplace. Route 2 stretched from the New Orleans Central Business District to the termination of the network in Slidell. Route 3 extended from the I-55 interchange in Laplace to the termination point of the network in Baton Rouge. Routes 1 and 3 followed the westbound direction of I-10. It should be noted that even though Route 1 included contraflow lanes, these lanes were not included in the analysis. The third section followed the eastbound direction of I-10 and also did not include contraflow lanes. A map of the routes is presented in Figure 5.1.

**5.1.1. Route 1 (I-10 WB New Orleans CBD to Laplace)**

![Figure 5.2 Storm WEST Time-Space Diagrams for Route 1](image)

Figure 5.2 compares congestion levels under (a) existing and (b) alternate plans for Storm WEST. The two-color shift shown throughout all of the following figures for this section of I-10 is due to a speed limit reduction incorporated into the network links beginning at Mile 12 in the figures. This point corresponds to the beginning of a bridge section of highway which required a reduced speed. For the WEST scenario, a majority of traffic was expected to choose destinations
to the East. Therefore, the low levels of congestion experienced in this area were expected. In fact, only two main areas of congestion occurred. The first began at the contraflow crossover location appearing at Mile 7 in the figures. The second occurred at the end of the contraflow section as three lanes of traffic are forced onto a two-lane ramp which leads to I-55 northbound. Temporally, these congestion periods were only experienced during the contraflow period beginning at Hour 16 and ending at Hour 40.

Figure 5.3 Storm EAST Time-Space Diagrams for Route 1

Figure 5.3 compares congestion levels under (a) existing and (b) alternate plans for Storm EAST. For the EAST scenario, a majority of traffic was expected to choose destinations to the West. Therefore, the higher levels of congestion experienced for this storm scenario versus the previous scenario were expected. Also, compared to the previous scenario, an additional area of congestion appears just past the change in speed limit around Mile 12. This area was due to the interchange with I-310 and the subsequent lane drop after that interchange. It did not appear in the previous figures due to the reduced levels of traffic. As in the previous figures, these congestion periods were only present during the contraflow period beginning at Hour 16 and ending at Hour 40.
Figure 5.4 Storm *BETSY* Time-Space Diagrams for Route 1

Figure 5.5 Storm *CAMILLE* Time-Space Diagrams for Route 1

Figure 5.4 compares congestion levels under (a) existing and (b) alternate plans for Storm *BETSY*. Under this scenario, there is a slightly reduced amount of traffic predicted to go to western destinations. Therefore, the lower levels of congestion experienced for this storm scenario were expected. The congestion areas appear in the same places as before (contraflow crossover and termination points). The figure also highlights the temporal change made between
the two current and alternate plans. The current plan extended a 24-hour period, starting at Hour 16 until Hour 40. In contrast, the alternate plan for Betsy lasted for a reduced amount of time beginning at Hour 32 and ending at Hour 43. The reduced time frame did not affect the congestion levels for this highway segment.

Figure 5.5 compares congestion levels under (a) existing and (b) alternate plans for Storm Camille. Under this scenario, a greater amount of traffic was predicted to go to western destinations than the previous scenario. This meant that the higher levels of congestion experienced for this storm scenario were expected. The congestion areas appeared in the same general places as before along the Interstate. The figure also highlights the temporal change made between the two current and alternate plans. The alternate plan lasted for a reduced amount of time beginning at Hour 35 and extending to the end of the simulation period. For this storm scenario, it appeared that the reduced contraflow period had an adverse effect on congestion levels. This point is illustrated when comparing the contraflow crossover point at Mile 7. The shockwave resulted in much lower speeds under the alternate plan than the existing plan.

5.1.2. Route 2 (I-10 EB New Orleans CBD to Slidell)

Figure 5.6 compares congestion levels under (a) existing and (b) alternate plans for Storm West for the eastbound route on I-10, Route 2. Under the West scenario, an increased amount traffic was expected to desire eastern destinations. Therefore, the increased amount of congestion along this route was expected. Under the current contraflow configuration, traffic is not allowed to continue on I-10 eastbound past Slidell. During the simulation, this forced a large number of evacuees to exit the Interstate, causing the congestion seen in Figure 5.6 (a). Under the alternate plan, some congestion was still experienced at the twinspan bridge (Mile 20) due to a lane drop. However, because the alternate plan allowed evacuees to continue on I-10 eastbound past Slidell,
more evacuees stayed on the Interstate and did not cause ramp back-up traffic as seen in under the current plan simulation.

Figure 5.6 Storm WEST Time-Space Diagrams for Route 2

Figure 5.7 Storm EAST Time-Space Diagrams for Route 2

Figure 5.7 compares congestion levels under (a) existing and (b) alternate plans for Storm EAST. Under this scenario, a reduced amount traffic was expected to desired eastern destinations. Therefore, the reduced amount of congestion along this route, compared to the previous scenario,
was expected. Again, under the current plan, travelers must divert off the interstate to continue east into Mississippi. This diversion caused the congestion seen in Figure 5.6 (a). The alternate plan diagram shows the relief in congestion experienced when travelers were allowed to continue on I-10 eastbound.

![Figure 5.8 Storm BETSY Time-Space Diagrams for Route 2](image1)

![Figure 5.9 Storm CAMILLE Time-Space Diagrams for Route 2](image2)
Figure 5.8 compares congestion levels under (a) existing and (b) alternate plans for Storm BETSY. Under this scenario, a reduced amount traffic was expected to desired eastern destinations. Again, some relief from the congestion experienced in the current plan was found when compared to the alternate plan.

Figure 5.9 compares congestion levels under (a) existing and (b) alternate plans for Storm CAMILLE. Again, a relief in congestion was found when comparing the current plan to the alternate plan.

5.1.3. **Route 3 (Laplace to Baton Rouge)**

![Figure 5.10 Storm WEST Time-Space Diagrams for Route 3](image)

Figure 5.10 compares congestion levels under (a) existing and (b) alternate plans for Storm WEST for the westbound route on I-10, Route 3. A reduced level of traffic was expected to desire western destinations under this storm scenario. Therefore, the lack of congestion found on this highway segment was appropriate, given that ambient traffic in Baton Rouge was not included in the simulation. The color pattern seen in this figure (and the next three) was due to speed limit changes present in the network. The yellow area was located just past the I-55...
interchange and was a continuation of the reduced bridge speed limit also seen in the contraflow segment. The red area across the top of the figures represented a reduced speed limit as the highway segment entered the Baton Rouge metropolitan area. This reduction in speed was not based on a posted speed. This speed reduction was meant to mimic the reduction in speed that would be necessary due to the increased ambient traffic present in the Baton Rouge area.

Figure 5.11 compares congestion levels under (a) existing and (b) alternate plans for Storm EAST. An increased level of traffic was expected to desire western destinations under this storm scenario. Therefore, the increased congestion found was reasonable. Two main areas of congestion occurred. The first was due to the traffic stream entering the Baton Rouge area and encountering a reduction in speed. The second occurred in the Gonzales area as more opportunities for traffic to enter and exit the interstate were introduced along the route.

![Figure 5.11 Storm EAST Time-Space Diagrams for Route 3](image)

(a) Current Plan  (b) Alternate Plan
Figure 5.12 compares congestion levels under (a) existing and (b) alternate plans for Storm BETSY. Again, reduced levels of traffic were expected under this scenario, leading to very little congestion present in the figure. A small area of congestion did occur in the Baton Rouge metropolitan area that did not appear under the current plan. This was due to the time constraint placed on the contraflow period in the alternate plan.

Figure 5.13 Storm CAMILLE Time-Space Diagrams for Route 3
Figure 5.13 compares congestion levels under (a) existing and (b) alternate plans for Storm *CAMILLE*. For this storm scenario, a large area of congestion was present for the alternate plan, beginning in Baton Rouge, which did not appear in the current plan simulation. It is believed that this was due to the time constraint placed on the contraflow period in the alternate plan.

5.2. Volume Distribution Comparison

This section describes the comparison of volume distribution over time at different points on the network under the different storm scenarios. Only key figures are presented that highlight the differences in routing made by introducing alternate evacuation plans. All other figures are included in Appendix D. The purpose of the volume comparison was to identify any evacuee route changes than may have been influenced by the use of adaptive plans.

Spatial differences were identified first. It was found that allowing evacuees to continue eastbound on I-10 in the alternate plan had significant impacts on the routing decisions. Figure 5.14 shows a comparison on hourly volume distribution between the existing and alternate plans (“Flex Plan” in the figures) for each storm scenario as recorded at a point on I-10 eastbound just after the junction with I-12 and I-59 but before the route enters Mississippi. It is interesting to note that higher volumes were generally present under the alternate plan compared to the existing plan. The initial assumption was that the lack of a ramp restriction under the alternate plans created the surge in volumes. However, it may also have been due to the fact that less congestion was experienced, thereby allowing more traffic flow and increasing the volume when the ramp restriction was removed.
Figure 5.14 Volume Distribution under Each Evacuation Plan at I-10 EB Slidell
Figure 5.15 Volume Distribution Comparison at US 11 Northbound in Slidell

Figure 5.15 shows the comparison of volume distributions at a point on U.S. 11 in Slidell before its junction with I-12. In the figures, it is apparent that this route was the main detour used by travelers to travel east into Mississippi during the contraflow hours (16-40) in the existing plan. Although there was a restriction on I-10 for this plan, no lane restriction was placed at the termination of I-12 eastbound; therefore, evacuees were able to leave I-10 for US 11, access I-12 eastbound and then continue onto I-10 eastbound past the lane restriction. By comparing Figure 5.15 with Figure 5.14, a generalization can be made that removing restrictions on the Interstate
System during contraflow hours will encourage the use of these routes over the local road system.

Figure 5.16 Volume Distribution Comparison on Lake Ponchatrain Causeway Bridge

Figure 5.16 compares the volume distribution on the Lake Ponchatrain Causeway Bridge at its northern terminus near Mandeville, LA. It is interesting to note the drop in volumes for all storm scenarios under the alternate plans. This drop in volume was again attributed to removing the lane restriction on I-10 eastbound. Evacuees using the Causeway Bridge accessed I-12 eastbound through either the Mandeville or Madisonville interchange as it was not possible to access I-12 EB directly from the Causeway/I-12 interchange. This finding further supports the
generalization that removing the lane restriction on the Interstate encouraged the use of the Interstate System directly rather than relying on the local road system.

The next issue that was examined was the temporal aspects of contraflow operations. As mentioned in the previous chapter, the contraflow implementation times were changed for the BETSY and CAMILLE scenarios. These changes were examined at two locations that were directly affected by contraflow operations.

Figure 5.17 shows the volume distribution comparison on I-10 WB at the Loyola Avenue interchange during both the BETSY and CAMILLE storm scenarios. The figures highlight traffic forced to use the normalflow side of the interstate more during the afternoon on the first simulation day during the alternate plans. Once the contraflow operations activated in the alternate plans, the volumes steadily decreased during each storm scenario until the end of the simulation. This result implies that reducing the contraflow period to an 11-13 hour period before hurricane landfall encouraged more evacuees to leave the day before when no restrictions are placed on the Interstate System.
Figure 5.18 Volume Distribution Comparison on I-55 NB (Normalflow) in Hammond

Figure 5.18 compares the volume distribution on I-55 northbound in Hammond in the normalflow lanes for both the BETSY and CAMILLE scenarios. The beginning of contraflow operations under the alternate plans is apparent in the BETSY scenario because of the sharp decreases in volume that occurred between Hours 35 and 44. The beginning of contraflow operations is also seen in the CAMILLIE scenario beginning with a sharp decrease in volume at Hour 36 under the alternate plan. The decrease in volume in the normalflow lanes for this simulation model was attributed to the fact that only metropolitan New Orleans traffic was generated. The vehicles that accessed this normalflow section of highway during the contraflow period were those diverted onto it from westbound I-12. This was a low number of vehicles when compared to those coming from I-55 northbound who were diverted into the contraflow lanes, as Figure 5.19 illustrates. Realistically, more traffic would be found on this roadway segment as local traffic and evacuees from the Northshore of Lake Ponchatrain (shadow evacuees) would make use of the highway.
Figure 5.19 shows the volume distribution comparison for the contraflow section of I-55 in Hammond. Because traffic was only present on this roadway section during the contraflow period, there is a reduced temporal amount of volume present in the figures. As mentioned previously, the traffic accessing this highway segment were those diverted from the normal lanes of I-55 northbound. The amount of traffic present was greater than that found on the normal lanes because of the contraflow restrictions and the routes evacuees took. Again, the effect of reducing the time of the contraflow period was noticed. In Figure 5.18, more traffic volume was recorded in the alternate plans than in the current plans on the first 24 hours of the simulation. The first day, alternate plan volumes peak around 1,400 veh/hr for BETSY and 2,300 veh/hr for CAMILLE in Figure 5.18. The first day, current plan volumes peak at 1,200 veh/hr for BETSY and 1,700 veh/hr for CAMILLE in Figure 5.19. These peaks should match across the alternate and current plans due to the temporal shift made in the alternate plans. The traffic recorded in the contraflow lanes in the current plan was not diverted to these lanes until Day 2 in the alternate plans. This finding reinforces the earlier result explored at the Loyola Avenue interchange, that
shortening the contraflow period encourages more traffic to use the Interstate System before the contraflow plan begins.

Figure 5.20 Volume Distribution Comparison on I-59 NB (Normalflow) at LA/MS State Line

Figure 5.20 shows the volume distribution comparison for the normalflow lanes of I-59 northbound at the Louisiana/Mississippi state line. Under the alternate plans for each storm scenario, the contraflow lanes in this section of highway were eliminated, forcing the increase in traffic shown in the figures. Again, because of the lack of local traffic and shadow evacuees generated in the simulation model, it was reasonable to eliminate this contraflow section. The decision is verified by examining the peak flows for each scenario. At no time does the volume
reach 2,000 vehicles per hour (or 1,000 vehicles per hour per lane), which is well below theoretical capacities for this type of facility (Wolshon 2008). However, if additional volume from local traffic was factored into the analysis, the theoretical capacity may have been reached in this segment and, thus, contraflow usage would be justified. However, the simulated traffic originating from the New Orleans metropolitan area did not require contraflow in this section of highway.

The preceding examination of volume distributions was performed to identify any evacuee route changes that may have been influenced by the alternate plan. One result found was that removing a major ramp restriction during the contraflow operations encouraged the use of the Interstate System over other major arterials or local roads. A second result was found by restricting the time period for contraflow operations. By decreasing the contraflow time period, more evacuees were found to make use of the non-restricted Interstate System the day before contraflow operations were implemented.

5.3. Overall Effectiveness

The overall effectiveness of the use of adaptive evacuation plans is presented in this section. The results are tabulated by comparing certain key measures of effectiveness produced by the microsimulator for each storm scenario under both the current and alternate plan. Each table is specific to a certain storm scenario. Each table is divided between measures aggregated across the full microsimulation, average measures obtained by dividing the simulation into 15 minute intervals and individual links assigned by the router, and microsimulation performance indicators.
Table 5.1: Comparison of MOEs for Storm WEST under Existing and Alternate Plans

<table>
<thead>
<tr>
<th>Storm WEST</th>
<th>Existing</th>
<th>Alternate</th>
<th>Δ</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Vehicle Trips</td>
<td>301,643.00</td>
<td>301,643.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of Total Population</td>
<td>81.32%</td>
<td>81.32%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Vehicle Hours</td>
<td>428,541.14</td>
<td>406,888.60</td>
<td>21,652.54</td>
<td>5.05%</td>
</tr>
<tr>
<td>Average Completed Trip Time</td>
<td>90.50</td>
<td>81.12</td>
<td>9.38</td>
<td>10.36%</td>
</tr>
</tbody>
</table>

Values per link per 15-min simulated interval

<table>
<thead>
<tr>
<th></th>
<th>Existing</th>
<th>Alternate</th>
<th>Δ</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Speed (mph)</td>
<td>44.271</td>
<td>44.360</td>
<td>-0.0886</td>
<td>-0.20%</td>
</tr>
<tr>
<td>Average Travel Time (sec)</td>
<td>24.944</td>
<td>23.504</td>
<td>1.4397</td>
<td>5.77%</td>
</tr>
<tr>
<td>Average Delay (sec)</td>
<td>3.979</td>
<td>2.570</td>
<td>1.4090</td>
<td>35.41%</td>
</tr>
<tr>
<td>Average Density (# of veh)</td>
<td>2.164</td>
<td>1.887</td>
<td>0.2770</td>
<td>12.80%</td>
</tr>
<tr>
<td>Time Ratio (Actual/Free Flow)</td>
<td>1.591</td>
<td>1.508</td>
<td>0.0834</td>
<td>5.24%</td>
</tr>
<tr>
<td>Average Queue (# of veh)</td>
<td>0.521</td>
<td>0.224</td>
<td>0.2970</td>
<td>57.02%</td>
</tr>
</tbody>
</table>

Microsimulation Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Existing</th>
<th>Alternate</th>
<th>Δ</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of Completed Trips</td>
<td>94.18</td>
<td>99.8</td>
<td>-5.62</td>
<td>-5.97%</td>
</tr>
<tr>
<td>Final Iteration Number</td>
<td>27.4</td>
<td>30.2</td>
<td>-2.8</td>
<td>-10.22%</td>
</tr>
</tbody>
</table>

Table 5.1 shows the results for storm scenario WEST under both existing and alternate plans. Under this storm scenario, 81.32% of the total New Orleans population was predicted to evacuate leading to a total of 301,643 vehicle trips simulated on the network for the 48-hour evacuation period. The aggregate total vehicle hours and average complete trip time for the simulation decreased when run under the alternate plan. On assigned network links, average speeds slightly increased while average travel times, delay, density, and queues all decreased. To expand these averaged results, consider that there were 192 fifteen-minute intervals in the 48-hour simulation period. Therefore, the 1.41 seconds of reduced delay reported in Table 5.1 becomes 4.5 minutes of reduced average delay for the entire evacuation period. This reduced delay can be applied to each link that was assigned by the router. However, the exact number of assigned links is not produced by the TRANSIMS router, therefore further expansion is not possible. In addition, the number of trips that were completed during the simulation increased,
meaning fewer trips were terminated in the system due to errors. The most common type of error were trips that lasted over 2 hours longer in the microsimulator than was predicted by the routing assignment, resulting in the termination of the trip. Lastly, the number of iterations required when using alternate plans increased, signifying that the alternate plan allowed the router to spread traffic to alternative routes.

Table 5.2 shows the results for storm scenario EAST under both existing and alternate plans. Under this storm scenario, 81.20% of the total New Orleans population was predicted to evacuate leading to a total of 302,028 vehicle trips simulated on the network for the 48-hour evacuation period. The aggregate total vehicle hours and average complete trip time for the simulation decreased when run under the alternate plan. On assigned network links, average speeds slightly increased while average travel times, delay, density, and queues all decreased.

Table 5.2: Comparison of MOEs for Storm EAST under Existing and Alternate Plans

<table>
<thead>
<tr>
<th>Storm EAST</th>
<th>Aggregate Results</th>
<th>Values per link per 15-min simulated interval</th>
<th>Microsimulation Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing</td>
<td>Alternate</td>
<td>Δ</td>
<td>%</td>
</tr>
<tr>
<td>Number of Vehicle Trips</td>
<td>302,028.80</td>
<td>302,029.00</td>
<td></td>
</tr>
<tr>
<td>% of Total Population</td>
<td>81.20%</td>
<td>81.20%</td>
<td></td>
</tr>
<tr>
<td>Total Vehicle Hours</td>
<td>470,653.72</td>
<td>405,579.00</td>
<td>65,074.72</td>
</tr>
<tr>
<td>Average Completed Trip Time</td>
<td>98.54</td>
<td>82.80</td>
<td>15.74</td>
</tr>
<tr>
<td>Average Speed (mph)</td>
<td>44.702</td>
<td>44.828</td>
<td>-0.1253</td>
</tr>
<tr>
<td>Average Travel Time (sec)</td>
<td>24.569</td>
<td>23.576</td>
<td>0.9931</td>
</tr>
<tr>
<td>Average Delay (sec)</td>
<td>3.820</td>
<td>2.956</td>
<td>0.8637</td>
</tr>
<tr>
<td>Average Density (# of veh)</td>
<td>2.268</td>
<td>2.100</td>
<td>0.1682</td>
</tr>
<tr>
<td>Time Ratio (Actual/Free Flow)</td>
<td>1.540</td>
<td>1.520</td>
<td>0.0205</td>
</tr>
<tr>
<td>Average Queue (# of veh)</td>
<td>0.521</td>
<td>0.280</td>
<td>0.2405</td>
</tr>
<tr>
<td>% of Completed Trips</td>
<td>94.90</td>
<td>97.40</td>
<td>-2.50</td>
</tr>
<tr>
<td>Final Iteration Number</td>
<td>27.20</td>
<td>28.40</td>
<td>-1.20</td>
</tr>
</tbody>
</table>
Table 5.3 shows the results for storm scenario *Betsy* under both existing and alternate plans. Under this storm scenario, 69.20% of the total New Orleans population was predicted to evacuate leading to a total of 267,983 vehicle trips simulated on the network for the 48-hour evacuation period. The aggregate total vehicle hours and average complete trip time for the simulation decreased when run under the alternate plan. On assigned network links, average speeds slightly increased while average travel times, delay, density, and queues all decreased. The 2.18 seconds of reduced delay reported in Table 5.2 becomes 7.12 minutes of reduced average delay when expanded for the entire evacuation period. Similarly, Table 5.4 shows the results for storm scenario *Camille* under both existing and alternate plans. Again, the aggregate total vehicle hours and average complete trip time decreased when the simulation was run under the alternate plan.

<table>
<thead>
<tr>
<th>Storm <em>Betsy</em></th>
<th>Existing</th>
<th>Alternate</th>
<th>Δ</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aggregate Results</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Vehicle Trips</td>
<td>267,983.00</td>
<td>267,983.00</td>
<td>0.00</td>
<td>0.00%</td>
</tr>
<tr>
<td>% of Total Population</td>
<td>69.20%</td>
<td>69.20%</td>
<td>0.00</td>
<td>0.00%</td>
</tr>
<tr>
<td>Total Vehicle Hours</td>
<td>365,122.34</td>
<td>319,046.54</td>
<td>46,075.80</td>
<td>12.62%</td>
</tr>
<tr>
<td>Average Completed Trip Time</td>
<td>88.68</td>
<td>71.74</td>
<td>16.94</td>
<td>19.10%</td>
</tr>
<tr>
<td><strong>Values per link per 15-min simulated interval</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Speed (mph)</td>
<td>44.463</td>
<td>44.685</td>
<td>-0.2222</td>
<td>-0.50%</td>
</tr>
<tr>
<td>Average Travel Time (sec)</td>
<td>25.009</td>
<td>22.833</td>
<td>2.1756</td>
<td>8.70%</td>
</tr>
<tr>
<td>Average Delay (sec)</td>
<td>4.247</td>
<td>2.070</td>
<td>2.1779</td>
<td>51.28%</td>
</tr>
<tr>
<td>Average Density (# of veh)</td>
<td>2.118</td>
<td>1.541</td>
<td>0.5767</td>
<td>27.23%</td>
</tr>
<tr>
<td>Time Ratio (Actual/Free Flow)</td>
<td>1.612</td>
<td>1.463</td>
<td>0.1492</td>
<td>9.25%</td>
</tr>
<tr>
<td>Average Queue (# of veh)</td>
<td>0.551</td>
<td>0.097</td>
<td>0.4542</td>
<td>82.43%</td>
</tr>
</tbody>
</table>

**Microsimulation Characteristics**

| % of Completed Trips | 92.2 | 99.6 | -7.4 | -8.03% |
| Final Iteration Number | 29.2 | 29 | 0.2 | 0.68% |
Table 5.4: Comparison of MOEs for Storm CAMILLE under Existing and Alternate Plans

<table>
<thead>
<tr>
<th></th>
<th>Existing</th>
<th>Alternate</th>
<th>Δ</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aggregate Results</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Number of Vehicle Trips  | 305,509.00 | 305,509.00 | 0.00   | 0.00%
| % of Total Population    | 82.40%   | 82.40%    | 0.00%  |       |
| Total Vehicle Hours      | 490,392.18 | 429,436.40 | 60,955.78 | 12.43%
| Average Completed Trip Time | 98.66   | 85.16   | 13.49  | 13.68%|
| **Values per link per 15-min simulated interval** |          |           |        |       |
| Average Speed (mph)      | 44.600   | 44.619   | -0.0188 | -0.04%
| Average Travel Time (sec)| 24.211   | 23.657   | 0.5538  | 2.29%
| Average Delay (sec)      | 3.181    | 2.676    | 0.5060  | 15.90%
| Average Density (# of veh)| 2.163   | 2.106    | 0.0570  | 2.64%
| Time Ratio (Actual/Free Flow) | 1.519 | 1.513 | 0.0065  | 0.43%
| Average Queue (# of veh) | 0.419    | 0.247    | 0.1721  | 41.09%
| **Microsimulation Characteristics** |          |           |        |       |
| % of Completed Trips     | 97.66    | 99.04    | -1.38   | -1.41%
| Final Iteration Number   | 30.20    | 27.60    | 2.60    | 8.61%

Table 5.5 Overall Results Comparing Existing Plans to Alternate Plans

<table>
<thead>
<tr>
<th></th>
<th>EAST</th>
<th>WEST</th>
<th>BETSY</th>
<th>CAMILLE</th>
<th>OVERALL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg Trip Time Reduction (mins)</td>
<td>15.74</td>
<td>9.38</td>
<td>16.94</td>
<td>13.49</td>
<td>13.89</td>
</tr>
<tr>
<td>Avg Trip Time Reduction (%)</td>
<td>15.97%</td>
<td>10.36%</td>
<td>19.10%</td>
<td>13.68%</td>
<td><strong>14.78%</strong></td>
</tr>
<tr>
<td>Total Vehicle Hours Reduction</td>
<td>65,074.72</td>
<td>21,652.54</td>
<td>46,075.80</td>
<td>60,955.78</td>
<td>48,439.71</td>
</tr>
<tr>
<td>Total Vehicle Hours Reduction (%)</td>
<td>13.83%</td>
<td>5.05%</td>
<td>12.62%</td>
<td>12.43%</td>
<td><strong>10.98%</strong></td>
</tr>
</tbody>
</table>

Table 5.5 shows the final overall results of the simulation procedure comparing the alternate plans to existing plans under each scenario. A reduction in both the average trip time and total vehicle hours was experienced for each storm scenario tested when ran under the alternative plan compared to the existing plan. Overall, the average trip time on the network was reduced 14.8% and the total vehicle hours were reduced 11% by implementing alternate plans to fit each storm scenario.
The overall trip time savings of approximately 14 minutes is substantial, especially when viewed from a fuel and cost saving perspective. Assuming an average traveling speed of 45 mph and average fuel economy of 27.5 miles per gallon, approximately 0.4 gallons of fuel is saved by each vehicle experiencing a 14 minute reduction in travel time. This savings totals to 117,716 gallons of fuel saved for the average 294,290 evacuees simulated in each scenario. Furthermore, the savings would amount to $412,006 for an average fuel price of $3.50 per gallon.

The overall results shown in this section indicate that adaptive evacuation plans result in a savings in travel time and other costs over the use of a static evacuation plan. Different storms generate different evacuation patterns, and the results indicate that these altered patterns are better served by adaptive evacuation plans.
Chapter 6. Summary and Conclusions

Significant efforts are currently being made by transportation officials to improve the planning and preparation of mass evacuations. The idea of an adaptive evacuation plan is an avenue of research that could help improve future evacuation processes. Adaptive evacuation stems from the observation that different disaster threat scenarios require different evacuation responses. While adaptive evacuation planning can be generalized to any form of evacuation planning, this study has focused on adaptive planning in the context of a hurricane evacuation.

This study incorporated two primary components. The first was the development of a new method that linked evacuation travel demand modeling with evacuation traffic flow modeling. The second was to test and evaluate the traffic effects of employing an adaptive evacuation plans as compared to a static evacuation plan for a set of theoretical storm scenarios.

A review of the literature found that there is knowledge to be gained through research in the area of emergency evacuation. Much research is already underway in the areas of understanding evacuation behavior and optimizing existing infrastructure for evacuation. Research results show that more improvements can be made toward evacuating the public more efficiently. The topic of adaptive evacuation is one of many ideas aimed at improving evacuation strategies. However, while most current research relies on complex mathematical models, adaptive plans rely on a pre-determined set of options agreed upon by emergency managers after anticipating likely storm scenarios and the predicted response to those scenarios. These plans also rely on state-of-the-art evacuation response models that are capable of generating the travel demand expected for any scenario. The combination of evacuation response models within the context of a region-scale evacuation simulation model was not found in the literature.
The use of evacuation demand models to determine destination choice and departure choice in conjunction with a traffic simulation model was demonstrated. One of the main issues apparent with the decision models was spikes in demand caused by the use of dummy variables. The evacuation response logit model under-estimated the nighttime evacuation response that was observed in southeastern Louisiana prior to Hurricane Katrina. Error in the destination choice logit model fell within a 5% tolerance. These errors did not detract from the overall effectiveness of the model. The combination of the household decision models with the simulation model of New Orleans yielded results that were essentially accurate from an evacuation planning perspective. The results indicated that the combination of models were able to accurately predict the cumulative evacuation traffic observed during Hurricane Katrina with $R^2$ correlations of at least 0.7. The end result was that the method was able to be utilized to predict evacuation operations under different storm scenarios and evacuation orders.

To test adaptive hurricane response, different storm scenarios were created using the evacuation demand logit models. Four scenarios were created after an examination of the logit model variables. Two scenarios would exploit the model’s characteristics of dispersing traffic spatially and two scenarios would exploit temporal traffic characteristics. In addition, alternate contraflow operation plans were created that would aid in effective traffic movement based on the expected traffic conditions predicted by the household decision models. The plans included eliminating contraflow sections that were unwarranted, removing restrictions and imposing new restrictions to prevent bottlenecks. The results were obtained by comparing simulations of each storm scenario under both the current contraflow plans and alternate plans.

The results showed that simple alterations to the existing plan had significant impacts on the simulated network. Removing the restriction on the eastbound ramp along I-10 in Slidell
during contraflow hours resulted in relieved congestion along the entire I-10 eastbound route. In addition, this alteration encouraged the use of the Interstate System over the local roads. When contraflow plans were shortened to a length between 11 and 13 hours instead of the 24-hour period in the current plans, more simulated traffic was observed using the non-restricted interstate on the first day of the simulation. The results showed a decrease in both the average trip completion time and the total vehicle hours reported in each storm scenario when adaptive evacuation plans were used. Overall, a 14.8% reduction in average travel time and 11% reduction in total vehicle hours were found after using the adaptive evacuation plans.

6.1 Contributions and Significance

This study was the first to adapt the demand models of Fu, et al, and Cheng, et al, into a regional-scale traffic simulation model. This process was pioneered specifically for the incorporation of multiple hurricane scenarios and their resulting traffic demand into the simulation model. It allowed for a measureable approach to generating evacuation traffic rather than subjectively assigning departure times and destinations for each scenario. However, the method also has merit for any evacuation simulation model in which the traffic load generated must have a quantifiable basis. The end conclusion of this component of research was that the use of such household-level evacuation response models to generate traffic demand in a simulation model can produce accurate cumulative evacuation patterns. The cumulative volumes produced were highly correlated with observed hurricane evacuation data.

This research improved the base New Orleans TRANSIMS model by incorporating a more rigorous routing and microsimulation equilibration procedure. The base New Orleans model developed by Wolshon, et al, (2009) was adjusted by incorporating three equilibration “brackets” into the routing stabilization algorithm. The three brackets were based on iterative
travel time improvements of 25%, then 20%, then 15% as calculated by the router module. This more stringent equilibration process led to results which reflect a larger amount of “traveler information” present in the network, meaning that traffic was spread more evenly across the network as evacuees avoided routes with too much congestion in favor of alternate routes.

Finally, the study was able to qualitatively and quantitatively assess the traffic impacts observed when adaptive evacuation plans were used. Less congestion was observed along all routes when adaptive plans were used when compared to the existing evacuation plan. Additionally, the use of adaptive plans encouraged evacuees to choose the Interstate System, which holds more capacity, over the local road system. Overall, the simulation network experienced a 14.8% reduction in average travel time across the entire simulated region when the adaptive framework was employed. This reduction is substantial when put in terms of fuel and other costs saved. Over $400,000 in fuel costs alone could be saved by adapting a static evacuation plan to fit a set of likely evacuation responses.

The significance of these results lies in their applicability in effectively moving more people out of danger when faced with a threat. The main argument behind this research is that to begin to effectively transport these evacuees, something must be known about how they will react to any given threat. A single, static evacuation plan does not consider the broad range of response that could come from evacuees. Evacuation plans that have been adapted to suit a range of likely evacuation responses have been shown in this study to better serve evacuees. While the research was based on a hurricane case study, the results can be generalized to evacuation planning for any threat. The general results should be enormously important to all researchers in the evacuation field, but they will also provide a new wealth of knowledge to emergency planners who rely on such information to make critical decision.
References


Appendix A: TRANSIMS Routing and Microsimulation Script
Note: This script was executed using the TRANSIMS Studio GUI and Run Time Environment.

TRANSIMS is open-source software, freely available by searching on [www.sourceforge.net](http://www.sourceforge.net).

```python
# Main Script for Thomas Montz's Thesis!
# NOTE:
# Must Run ConvertTrips.py FIRST to Create HH, Trip, and Plan Files
# Change Var TRIPS to match the name used in ConvertTrips.py
#
# Runs Router Convergence Based on Re-routing travelers that can improve Trip Time
# ----> First 25%, Then 20%, Then 15% differences.
# Runs 5 Router--Mircosim Iterations
# Saves LinkSum Info of Final Microsim Performance File (Vol and Speed)

# Allows use of TRANSIMS Run Time Environment (RTE)
import os
import sys
sys.path.insert ( 0 , '../../../TransimsRTE' )
from TransimsRTE import *
var.BINDIR = 'C:/Program Files/TRANSIMS Studio/Bin32; C:/Program Files (x86)/TRANSIMS Studio/Bin32; C:/TRANSIMS/Bin'
var.USE_CACHE = True
var.OUTPUT_WIDTH = 125
var.SHOW_MODULE_OUTPUT = 'PROGRESS'

# CHANGE STUDY NAME AND RUN NUMBER HERE
var.ALT = 'BETSYflex5'
var.TRIPS = 'Storm3'
var.RUN = 1

# These are "Global" Keys that will appear in ALL control files generated by the script
GlobalKeys.FromString ( ""
TITLE     New Orleans - Model: @ALT@ - Run: @RUN@
OUTPUT_COORDINATE_SYSTEM  UTM, 18N, METERS
DEFAULT_FILE_FORMAT       TAB_DELIMITED
PROJECT_DIRECTORY         ../
CREATE_NOTES_AND_NAME_FIELDS   YES
LANE_WIDTH                3.5 //---- meters ----
LINK_DIRECTION_OFFSET     0.0 //---- meters ----
ACTIVITY_LOCATION_SIDE_OFFSET 15 //---- meters ----
PARKING_SIDE_OFFSET       5 //---- meters ----
TRANSIT_STOP_SIDE_OFFSET  8 //---- meters ----
TRANSIT_DIRECTION_OFFSET  4 //---- meters ----
NET_LANE_USE_TABLE        ../network/Lane_UseBet.txt
RANDOM_NUMBER_SEED        200905
"")

# variables controlling the loops
NumRouterIterations = 5
NumMicrosimulatorIterations = 5

#BEGIN!
Event ( 'Partitioning' )

var.NUM_PARTITIONS = 4

# Create Partitions Based on HHList
HHList = ControlKeys ( 'HHList' )
HHList.FromString ( ""
HOUSEHOLD_FILE   demand/@TRIPS@.Households
NEW_HOUSEHOLD_LIST   demand/@ALT@.HH_Partition
# NUM_SPLIT_FILES   @NUM_PARTITIONS@
"")
HHList.Run ( 'ctl/Router.@ALT@.HHList.ctl' )
```

81
#Create Control Files

```c
Router = ControlKeys ( 'Router' )
Router.FromString ( "
NET_DIRECTORY../network
NET_NODE_TABLENode
NET_LINK_TABLELink
NET_PARKING_TABLEParking
NET_LANE_CONNECTIVITY_TABLELane_Connectivity
NET_ACTIVITY_LOCATION_TABLEActivity_Location
NET_PROCESS_LINK_TABLEProcess_Link

HOUSEHOLD_LISTdemand/@ALT@.HH_Partition
TRIP_FILEdemand/@TRIPS@.Trips
TIME_OF_DAY_FORMAT24_HOUR_CLOCK
VEHICLE_FILEdemand/@TRIPS@.Vehicles
NEW_PLAN_FILEplans/@NEW@.@ALT@.TravelPlans
NEW_PROBLEM_FILErouter/@NEW@.@ALT@.Problems

#------Options------#
NODE_LIST_PATHSYES
LIMIT_PARKING_ACCESSYES
IGNORE_TIME_CONSTRAINTSYES
PERCENT_RANDOM_IMPEDANCE20 //---Randomly adjusts how a traveler views link impedance

#------Parameters------#
WALK_SPEED1.0 //--- meters / second ----
WALK_TIME_VALUE20.0 //--- imped / second ----
VEHICLE_TIME_VALUE10.0 //--- imped / second ----
FIRST_WAIT_VALUE15.0 //--- imped / second ----
TRANSFER_WAIT_VALUE20.0 //--- imped / second ----
DISTANCE_VALUE1.0 //--- imped / meter ---- * <These diff
COST_VALUE5 //---- imped / cent. ---- * <than Joe's
TRANSFER_PENALTY1500 //--- impedance ---- * <Router file
#LEFT_TURN_PENALTY300 //---- impedance ----
#PARKING_HOURS_BY_PURPOSE8.5, 2.5, 1.0, 1.0 //---- hours ----

#------Constraints------#
MAX_WALK_DISTANCE2000 //---- meters ----
MAX_KISS_RIDE_DROP_OFF_WALK100 //---- meters ----
MIN_WAIT_TIME60 //---- seconds ----
MAX_CIRCUITY_DISTANCE100000 //---- meters ----
"
"
```

PlanSum = ControlKeys ( 'PlanSum' )
PlanSum.FromString ( "
NET_DIRECTORY../network
NET_NODE_TABLENode
NET_LINK_TABLELink
NET_PARKING_TABLEParking
NET_ACTIVITY_LOCATION_TABLEActivity_Location
NET_LANE_CONNECTIVITY_TABLELane_Connectivity

PLAN_FILEplans/@NEW@.@ALT@.TravelPlans.t*
SUMMARY_TIME_PERIODS0:00..48:00 //---- minutes ----
SUMMARY_TIME_INCREMENT15 //---- minutes ----
NEW_LINK_DELAY_FILErouter/@NEW@.@ALT@.Performance
NEW_LINK_DELAY_FORMATTAB_DELIMITED
EQUATION_PARAMETERS_1BPR, 0.15, 4.0, 0.75
EQUATION_PARAMETERS_2BPR, 0.40, 3.3, 0.75
#NEW_LINK_VOLUME_FILErouter/@NEW@.@ALT@.Volume
#NEW_TRIP_TABLE_FILErouter/@NEW@.@ALT@.TripData
#NEW_TRIP_TABLE_FORMATTAB_DELIMITED
#ZONE_EQUIVALENCE_FILEinputs/Zone_Equiv.txt
NEW_TRIP_TIME_FILErouter/@NEW@.@ALT@.TripTimes
PLANSUM_REPORT_1TOP_100_V/C_RATIOS
PLANSUM_REPORT_2TRAVEL_SUMMARY_REPORT

```
```

82
### Run Bootstrap Routing Process

Event ( 'Partitioned bootstrap routing' )

```python
var.NEW = 1

Router.Run ( 'ctl/@NEW@.Router.@ALT@.Router.ctl', Partitioned=True)
PlanSum.Run ( 'ctl/@NEW@.Router.@ALT@.PlanSum.ctl' )
```

### Select Travel Times 25% Different

```python
PlanSelect = ControlKeys ( 'PlanSelect' )
PlanSelect.FromString ( "
VEHICLE_FILE                           demand/@TRIPS@.Vehicles
PLAN_FILE                              plans/@OLD@.@ALT@.TravelPlans
LINK_DELAY_FILE
NEW_HOUSEHOLD_LIST                     demand/@OLD@.@ALT@.HH_List
LINK_FILE                              plans/@OLD@.@ALT@.TravelPlans
NET_DIRECTORY                          ../network
NET_NODE_TABLE                         Node
NET_LINK_TABLE                         Link
NET_PARKING_TABLE                      Parking
NET_LANE_CONNECTIVITY_TABLE           Lane_Connectivity
PERCENT_TIME_DIFFERENCE                25             // travel time ratio
MINIMUM_TIME_DIFFERENCE                5               // minutes
MAXIMUM_TIME_DIFFERENCE                30              // minutes
SELECTION_PERCENTAGE                   50              // percent
MAXIMUM_PERCENT_SELECTED               8               // percent
RANDOM_NUMBER_SEED                     255
"
)
```

### Reset previous router keys

```python
Router.SetKey ( 'HOUSEHOLD_LIST' , 'demand/@OLD@.@ALT@.HH_List' , ReplaceKeys=True )
Router.SetKey ( 'LINK_DELAY_FILE' , 'router/@OLD@.@ALT@.Performance' )
Router.SetKey ( 'NEW_PLAN_FILE' , 'plans/@NEW@.@ALT@.Plans' , ReplaceKeys=True )
```

### Merge Plans

```python
PlanMerge = ControlKeys ( 'PlanPrep' )
PlanMerge.FromString ( "
INPUT_PLAN_FILE                        plans/@NEW@.@ALT@.Plans
MERGE_PLAN_FILE                        plans/@OLD@.@ALT@.TravelPlans
OUTPUT_PLAN_FILE
"
)
```

### Setup Stat Spreadsheet

```python
PerformanceFile = open ( '../results/' + var.ALT + '.Performance.csv' , 'wt')
PerformanceFile.write ( 'Iteration, HouseholdsSelectedPct, NumHouseholdsSelected, ' +
'HouseholdsWrittenPct, NumHouseholdsWritten, NumInputPlans, ' +
'NumInputTravelers, NumInputTrips, NumTurns, TotalVehHrs\n')
```

### Router Iterations - Running Them Partitioned

```python
HouseholdsSelectedPct = 0
Diff = 100
count = 0

# for i in range(5):
while (Diff > 1):
    var.OLD = var.NEW
    var.NEW += 1
    Event ( 'Router Iteration @NEW@' )
    PlanSelect.Run ( 'ctl/@NEW@.Router.@ALT@.PlanSelect.ctl' , Partitioned=True )
    Router.Run ( 'ctl/@NEW@.Router.@ALT@.Router.ctl' , Partitioned=True )
```
PlanMerge.Run ('ctl/@NEW@.Router.@ALT@.PlanMerge.ctl', Partitioned=True)
PlanSum.Run ('ctl/@NEW@.Router.@ALT@.PlanSum.ctl')

HHSelectOld = HouseholdsSelectedPct
HouseholdsSelectedPct = PlanSelect.GetResult ('Households Selected PCT', Default = 0 , Type = 'AVERAGE' )
Diff = abs(HouseholdsSelectedPct - HHSelectOld)

NumHouseholdsSelected = PlanSelect.GetResult ('Households Selected', Default = 0 )
HouseholdsWrittenPct = PlanSelect.GetResult ('Households Written PCT', Default = 0 , Type = 'AVERAGE' )
NumHouseholdsWritten = PlanSelect.GetResult ('Households Written', Default = 0 )
NumInputPlans = PlanSelect.GetResult ('Input Plans', Default = 0 )
NumInputTravelers = PlanSelect.GetResult ('Input Travelers', Default = 0 )
NumInputTrips = PlanSelect.GetResult ('Input Trips', Default = 0 )
NumTurns = PlanSum.GetResult ('Total Number of Turns', Default = 0 )
HoursOfTravel = PlanSum.GetResult ('Total Vehicle Hours of Travel', Default = 0 )

PerformanceFile.write (
    str ( var.NEW ) + ', ' +
    str ( HouseholdsSelectedPct ) + ', ' +
    str ( NumHouseholdsSelected ) + ', ' +
    str ( HouseholdsWrittenPct ) + ', ' +
    str ( NumHouseholdsWritten ) + ', ' +
    str ( NumInputPlans ) + ', ' +
    str ( NumInputTravelers ) + ', ' +
    str ( NumInputTrips ) + ', ' +
    str ( NumTurns ) + ', ' +
    str ( HoursOfTravel ) + ',' +
    '\n' )

PerformanceFile.flush ()

if count > 0:
    #if i > 0:
        ReplaceFilesWithPlaceholders ( '../plans/@OLD@.@ALT@*Plans*' )
        ReplaceFilesWithPlaceholders ( '../router/@OLD@.@ALT@*Performance*' )
        ReplaceFilesWithPlaceholders ( '../router/@OLD@.@ALT@*LinkDelay*' )
    else:
        Event ( 'Files for restart: '+str(var.OLD) )

if count > 20:
    break

count += 1

#*******************************************************************************
#Select Travel Times 20% Different
#*******************************************************************************
PlanSelect.FromString ( """ PERCENT_TIME_DIFFERENCE                 20             //
""" , ReplaceKeys=True )

HouseholdsSelectedPct = 0
Diff = 100
count = 0

#for i in range(5):
while (Diff > 0.5):
    var.OLD = var.NEW
    var.NEW += 1
    Event ( 'Router Iteration @NEW@' )

PlanSelect.Run ( 'ctl/@NEW@.Router.@ALT@.PlanSelect.ctl', Partitioned=True )
Router.Run ( 'ctl/@NEW@_Router.@ALT@.Router.ctl', Partitioned=True )
PlanMerge.Run ( 'ctl/@NEW@.Router.@ALT@.PlanMerge.ctl', Partitioned=True )
PlanSum.Run ( 'ctl/@NEW@.Router.@ALT@.PlanSum.ctl' )
Diff = abs(HouseholdsSelectedPct - HHSelectOld)

HouseholdsSelected = PlanSelect.GetResult ( 'Households Selected', Default = 0 )
HouseholdsWritten = PlanSelect.GetResult ( 'Households Written', Default = 0 )
InputPlans = PlanSelect.GetResult ( 'Input Plans', Default = 0 )
InputTravelers = PlanSelect.GetResult ( 'Input Travelers', Default = 0 )
InputTrips = PlanSelect.GetResult ( 'Input Trips', Default = 0 )
NumTurns = PlanSum.GetResult ( 'Total Number of Turns', Default = 0 )
HoursOfTravel = PlanSum.GetResult ( 'Total Vehicle Hours of Travel', Default = 0 )

PerformanceFile.write (
    str ( var.NEW ) + ', ' +
    str ( HouseholdsSelectedPct ) + ', ' +
    str ( NumHouseholdsSelected ) + ', ' +
    str ( HouseholdsWrittenPct ) + ', ' +
    str ( NumHouseholdsWritten ) + ', ' +
    str ( NumInputPlans ) + ', ' +
    str ( NumInputTravelers ) + ', ' +
    str ( NumInputTrips ) + ', ' +
    str ( NumTurns ) + ', ' +
    str ( HoursOfTravel ) + ', ' +
    '\n' )
PerformanceFile.flush ()

if count > 0:
  #if i > 0:
    ReplaceFilesWithPlaceholders ( '../plans/@OLD@.@ALT@*Plans*' )
    ReplaceFilesWithPlaceholders ( '../router/@OLD@.@ALT@*Performance*' )
    ReplaceFilesWithPlaceholders ( '../router/@OLD@.@ALT@*LinkDelay*' )
else:
  Event ( 'Files for restart: '+str(var.OLD) )

if count > 20:
  break

count += 1

#***********************************
#Select Travel Times 15% Different

PlanSelectFromString ( ""
SELECT VC RATIOS
NULL
PERCENT_TIME_DIFFERENCE 15 //---- travel time ratio ----
MINIMUM_TIME_DIFFERENCE 10 //---- minutes ----
MAXIMUM_TIME_DIFFERENCE 70 //---- minutes ----
"", ReplaceKeys=True )

HouseholdsSelectedPct = 0

while (Diff > 0.5):
  var.OLD = var.NEW
  var.NEW += 1
  Event ( 'Router Iteration @NEW@' )
  PlanSelect.Run ( 'ctl/@NEW@.Router.@ALT@.PlanSelect.ctl', Partitioned=True )
  Router.Run ( 'ctl/@NEW@.Router.@ALT@.Router.ctl', Partitioned=True )
  PlanMerge.Run ( 'ctl/@NEW@.Router.@ALT@.PlanMerge.ctl', Partitioned=True )
  PlanSum.Run ( 'ctl/@NEW@.Router.@ALT@.PlanSum.ctl' )
  HHSelectOld = HouseholdsSelectedPct
  HouseholdsSelectedPct = PlanSelect.GetResult ( 'Households Selected PCT', Default = 0 ,
              Type = 'AVERAGE' )
  Diff = abs(HouseholdsSelectedPct - HHSelectOld)

HouseholdsSelected = PlanSelect.GetResult ( 'Households Selected', Default = 0 ,
              Type = 'AVERAGE' )
HouseholdsWrittenPct = PlanSelect.GetResult ( 'Households Written PCT', Default = 0 ,
              Type = 'AVERAGE' )
NumHouseholdsWritten = PlanSelect.GetResult ( 'Households Written', Default = 0 )
NumInputPlans = PlanSelect.GetResult ( 'Input Plans', Default = 0 )
NumInputTravelers = PlanSelect.GetResult ( 'Input Travelers', Default = 0 )
NumInputTrips = PlanSelect.GetResult ( 'Input Trips', Default = 0 )
NumTurns = PlanSum.GetResult ( 'Total Number of Turns', Default = 0 )
HoursOfTravel = PlanSum.GetResult ( 'Total Vehicle Hours of Travel', Default = 0 )
PerformanceFile.write ( str ( var.NEW ) + ', ' + str ( HouseholdsSelectedPct ) + ', ' + str ( NumHouseholdsSelected ) + ', ' + str ( HouseholdsWrittenPct ) + ', ' + str ( NumHouseholdsWritten ) + ', ' + str ( NumInputPlans ) + ', ' + str ( NumInputTravelers ) + ', ' + str ( NumInputTrips ) + ', ' + str ( NumTurns ) + ', ' + str ( HoursOfTravel ) + ', ' + '\n' )
PerformanceFile.flush ()
if count > 0:
  if i > 0:
    ReplaceFilesWithPlaceholders ( '../plans/@OLD@.@ALT@*Plans*' )
    ReplaceFilesWithPlaceholders ( '../router/@OLD@.@ALT@*Performance*' )
    ReplaceFilesWithPlaceholders ( '../router/@OLD@.@ALT@*LinkDelay*' )
else:
  Event ( 'Files for restart: '+str(var.OLD) )
if count > 20:
  break
  count += 1

# MICROSIMULATOR ITERATIONS - PREPARTIONS
Microsimulator = ControlKeys ( 'Microsimulator' )
Microsimulator.FromString ( """
NET_DIRECTORY                          ../network
NET_NODE_TABLE                         Node
NET_LINK_TABLE                         Link
NET_POCKET_LANE_TABLE                  Pocket_Lane
NET_PARKING_TABLE                      Parking
NET_LANE_CONNECTIVITY_TABLE            Lane_Connectivity
NET_ACTIVITY_LOCATION_TABLE            Activity_Location
NET_PROCESS_LINK_TABLE                 Process_Link
NET_UNSIGNALIZED_NODE_TABLE           Unsignalized_Node
NET_SIGNALISED_NODE_TABLE             Signalized_Node
NET_TIMING_PLAN_TABLE                  Timing_Plan
NET_PHASING_PLAN_TABLE                Phasing_Plan
NET_DETECTOR_TABLE                     Detector
NET_SIGNAL_COORDINATOR_TABLE           Signal_Coordinator
VEHICLE_FILE                           demand/@TRIPS@.Vehicles
SORT_VEHICLES                          TRUE
VEHICLE_TYPE_FILE                      demand/Vehicle_Type
PLAN_FILE                              plans/@NEW@.@ALT@.TimePlans
NODE_LIST_PATHS                        Yes
CELL_SIZE                               7.5             //---- meters ----
TIME_STEPS_PER_SECOND                  1               //----- steps / second ----
TIME_OF_DAY_FORMAT                     24_HOUR_CLOCK
SIMULATION_START_TIME                  0:00
SIMULATION_END_TIME                    50:00
SPEED_CALCULATION_METHOD               CELL-BASED
PLAN_FOLLOWING_DISTANCE                525             //---- meters ----
LOOK_AHEAD_TIME_FACTOR                 1.0             //----- imped / second ----
LOOK_AHEAD_LANE_FACTOR                 4.0             //----- imped / lane change ----
LOOK_AHEAD_DISTANCE                    260             //----- meters ----
MAXIMUM_SWAPPING_SPEED                 22.5             //----- meters / second ----
"""
ENFORCE_PARKING_LANES            YES
SLOW_DOWN_PROBABILITY              0  //---- percent by facility type ----
SLOW_DOWN_PERCENTAGE               10  //---- percent by facility type ----
DRIVERREACTION_TIME                0.7, 0.8, 0.9, 1.0
RANDNUMBER_SEED                    1623
MINIMUM_WAITING_TIME               180  //---- seconds ----
MAXIMUM_WAITING_TIME               9000  //---- seconds ----
MAX_ARRIVAL_TIME_VARIANCE           180  //---- minutes ----
MAX_DEPARTURE_TIME_VARIANCE         180  //---- minutes ----
PERMISSION_PROBABILITY             55  //---- percent ----
NEW_PROBLEM_FILE                   results/@NEW@.@ALT@.MsimProblems
OUTPUT_SUMMARY_FILE_1              results/@NEW@.@ALT@.Performance
OUTPUT_SUMMARY_TIME_FORMAT_1       24_HOUR_CLOCK
OUTPUT_SUMMARY_INCREMENT_1         0:15
OUTPUT_SUMMARY_TIME_RANGE_1        0:00..48:00
OUTPUT_EVENT_FILTER_1              60
OUTPUT_EVENT_TIME_FORMAT_1         24.HOUR_CLOCK
OUTPUT_EVENT_TIME_RANGE_1          0..86400

PlanSort = ControlKeys ('PlanPrep')
PlanSort.fromString ( ""
INPUT_PLAN_FILE                     plans/@NEW@.@ALT@.TravelPlans.t*
OUTPUT_PLAN_FILE                    plans/@NEW@.@ALT@.TimePlans
PLAN_SORT_OPTION                    TIME
PLAN_COMBINE_OPTION                 FILE
"
)

# ROUTER AND MICROSIMULATOR ITERATIONS - RUNNING THEM PARTITIONED
ProblemSelect = ControlKeys('ProblemSelect')
ProblemSelect.fromString(""
PROBLEM_FILE                        results/@OLD@.@ALT@.MsimProblems
#HOUSEHOLD_LIST                     demand/@ALT@.HH_Partition
NEW_HOUSEHOLD_LIST                  demand/@OLD@.@ALT@.HH_List

#SELECT_TIME_PERIODS               6:00..18:00
SELECT_PROBLEM_TYPES               PATH_BUILDING, TIME_SCHEDULE, ZERO_NODE, VEHICLE_ACCESS, WAIT_TIME, LINK_ACCESS, LANE_CONNECTIVITY, LANE_MERGING, LANE_CHANGING, TURNING_SPEED, POCKET_MERGE, VEHICLE_SPACING, ACCESS_RESTRICTION

SELECTION_PERCENTAGE                100
MAXIMUM_PERCENTSeleccioned         20
#RANDNUMBER_SEED                    1223
"
)
HouseholdsSelectedPct = PlanSelect.GetResult ('Households Selected PCT',
Default = 0, Type = 'AVERAGE')
NumHouseholdsSelected = PlanSelect.GetResult ('Households Selected',
Default = 0)
HouseholdsWrittenPct = PlanSelect.GetResult ('Households Written PCT',
Default = 0, Type = 'AVERAGE')
NumHouseholdsWritten = PlanSelect.GetResult ('Households Written',
Default = 0)
NumInputPlans = PlanSelect.GetResult ('Input Plans',
Default = 0)
NumInputTravelers = PlanSelect.GetResult ('Input Travelers',
Default = 0)
NumInputTrips = PlanSelect.GetResult ('Input Trips',
Default = 0)
NumTurns = 0
HoursOfTravel = Microsimulator.GetResult ('Total Hours for Completed Vehicle Trips',
Default = 0)
AverageTravel = Microsimulator.GetResult ('Average Travel Time for Completed Trips',
Default = 0)
TripsCompletedPct = Microsimulator.GetResult('Number of Vehicle Trips Completed PCT',
Default =0)
PerformanceFile.write (str ( var.NEW ) + ', ' + str ( HouseholdsSelectedPct ) + ', ' + str ( NumHouseholdsSelected ) + ', ' + str ( HouseholdsWrittenPct ) + ', ' + str ( NumHouseholdsWritten ) + ', ' + str ( NumInputPlans ) + ', ' + str ( NumInputTravelers ) + ', ' + str ( NumInputTrips ) + ', ' + str ( NumTurns ) + ', ' + str ( HoursOfTravel ) + ', ' + str ( AverageTravel ) + ', ' + str (TripsCompletedPct) + ', ' + '
\n' )
PerformanceFile.flush ()

else:
#The rest of the loop allows ProblemSelect to run instead of PlanSelect
#Order: ProblemSelect, Router, Old Plan File Sorted by Traveler, New Plan File Merged with Old One, Resulting Plan File Sorted by Time, Microsim
Router.SetKey ( 'LINK_DELAY_FILE', 'results/@OLD@.@ALT@.Performance', ReplaceKeys = True)
ProblemSelect.Run ( 'ctl/@NEW@.Microsimulator.@ALT@.ProblemSelect.ctl')
Router.Run ( 'ctl/@NEW@.Microsimulator.@ALT@.Router.ctl', Partitioned = False)
PlanSort = ControlKeys ("PlanPrep'
PlanSort.FromString ( "***
INPUT_PLAN_FILE plans/@OLD@.@ALT@.TimePlans
OUTPUT_PLAN_FILE plans/@NEW@.@ALT@.TravPlans
PLAN_SORT_OPTION TRAVELER
PLAN_COMBINE_OPTION FILE
"***", ReplaceKeys = True )
PlanSort.Run('ctl/@NEW@.Microsimulator.@ALT@.Router.ctl')
PlanMerge = ControlKeys ( 'PlanPrep' )
PlanMerge.FromString ( "***
INPUT_PLAN_FILE plans/@NEW@.@ALT@.Plans
MERGE_PLAN_FILE plans/@NEW@.@ALT@.TravPlans
OUTPUT_PLAN_FILE plans/@NEW@.@ALT@.TravelPlans
"***", ReplaceKeys = True )
PlanMerge.Run ( 'ctl/@NEW@.Microsimulator.@ALT@.PlanMerge.ctl', Partitioned = False)
PlanSort = ControlKeys ("PlanPrep'
PlanSort.FromString ( "***
INPUT_PLAN_FILE plans/@NEW@.@ALT@.TravelPlans
OUTPUT_PLAN_FILE plans/@NEW@.@ALT@.TimePlans
PLAN_SORT_OPTION TIME
"***", ReplaceKeys = True )
PLAN_COMBINE_OPTION                    FILE
""", ReplaceKeys = True)

PlanSort.Run ( 'ctl/@NEW@.Microsimulator.@ALT@.PlanSort.ctl' )
Microsimulator.Run ( 'ctl/@NEW@.Microsimulator.@ALT@.Microsimulator.ctl' )

# and we keep writing additional records to the Performance.csv file
HouseholdsSelectedPct = ProblemSelect.GetResult ( 'Households Selected PCT',
Default = 0)
NumHouseholdsSelected = ProblemSelect.GetResult ( 'Households Selected',
Default = 0)
HouseholdsWrittenPct = ProblemSelect.GetResult ( 'Households Written PCT',
Default = 0)
NumHouseholdsWritten = ProblemSelect.GetResult ( 'Households Written',
Default = 0)
NumInputPlans = ProblemSelect.GetResult ( 'Input Plans',
Default = 0)
NumInputTravelers = ProblemSelect.GetResult ( 'Input Travelers',
Default = 0)
NumInputTrips = ProblemSelect.GetResult ( 'Input Trips',
Default = 0)

NumTurns = 0
HoursOfTravel = Microsimulator.GetResult ( 'Total Hours for Completed Vehicle Trips',
Default = 0)
AverageTravel = Microsimulator.GetResult ( 'Average Travel Time for Completed Trips',
Default = 0)
TripsCompletedPct = Microsimulator.GetResult ( 'Number of Vehicle Trips Completed PCT',
Default = 0)

PerformanceFile.write ( 'str ( var.NEW ) + ',' +
str ( HouseholdsSelectedPct ) + ',' +
str ( NumHouseholdsSelected ) + ',' +
str ( HouseholdsWrittenPct ) + ',' +
str ( NumHouseholdsWritten ) + ',' +
str ( NumInputPlans ) + ',' +
str ( NumInputTravelers ) + ',' +
str ( NumInputTrips ) + ',' +
str ( NumTurns ) + ',' +
str ( HoursOfTravel ) + ',' +
str ( AverageTravel ) + ',' +
str ( TripsCompletedPct ) + ',' +
'\n' )
PerformanceFile.flush ()

# only keep the plan files for every tenth Microsimulator iteration as a potential restart point
if i not in ( 0 , 10 , 20 ):
    ReplaceFilesWithPlaceholders ( '../plans/@OLD@.@ALT@*Plans*' )
    ReplaceFilesWithPlaceholders ( '../router/@OLD@.@ALT@*Performance*' )
    ReplaceFilesWithPlaceholders ( '../router/@OLD@.@ALT@*LinkDelay*' )
else:
    Event ( 'File set for restart: '+str(var.OLD) )
Event('Run Link Sum')
LinkSum = ControlKeys ( 'LinkSum' )
LinkSum.FromString ( """
#---- Input Files ----
LINK_DELAY_FILE results/@NEW@.@ALT@.Performance
NET_DIRECTORY ../network
NET_LINK_TABLE Link
SUMMARY_TIME_PERIODS 0:00..48:00
SUMMARY_TIME_INCREMENT 60
MINIMUM_LINK_VOLUME 1

#---- Output Files ----
NEW_LINK_VOLUME_FILE SpreadsheetResults/VOL.@ALT@.txt
NEW_LINK_SPEED_FILE SpreadsheetResults/SPD.@ALT@.txt
"""", ReplaceKeys = True)
LinkSum.Run ( 'ctl/@ALT@.LinkSum.ctl', Partitioned = False
Event ('Done!')
Appendix B: Integrated Model Simulation Result Plots
Observed Cumulative Volume vs. Simulated Cumulative Volume

Loyola Count Station, R² = 0.89684
Station 79, I-10 WB BR, R2 = 0.75417

Station 67, I-10 EB Slidel, R2 = 0.86003
Appendix C: Storm Scenario Variables
<table>
<thead>
<tr>
<th>Time</th>
<th>Sim Hour</th>
<th>Evac Order</th>
<th>Hurricane Wind Speed</th>
<th>Lat</th>
<th>Long</th>
<th>Dist (m)</th>
<th>Dist (mi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12:00 AM</td>
<td>0</td>
<td>N/A</td>
<td>105</td>
<td>24.6</td>
<td>83.3</td>
<td>910206.7</td>
<td>565.5763</td>
</tr>
<tr>
<td>1:00 AM</td>
<td>1</td>
<td>N/A</td>
<td>110</td>
<td>24.4</td>
<td>84</td>
<td>875014.4</td>
<td>543.7087</td>
</tr>
<tr>
<td>2:00 AM</td>
<td>2</td>
<td>N/A</td>
<td>111</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3:00 AM</td>
<td>3</td>
<td>N/A</td>
<td>112</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4:00 AM</td>
<td>4</td>
<td>N/A</td>
<td>113</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5:00 AM</td>
<td>5</td>
<td>N/A</td>
<td>114</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6:00 AM</td>
<td>6</td>
<td>N/A</td>
<td>115</td>
<td>24.4</td>
<td>84.7</td>
<td>827464.9</td>
<td>514.1629</td>
</tr>
<tr>
<td>7:00 AM</td>
<td>7</td>
<td>N/A</td>
<td>115</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8:00 AM</td>
<td>8</td>
<td>N/A</td>
<td>115</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9:00 AM</td>
<td>9</td>
<td>N/A</td>
<td>115</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10:00 AM</td>
<td>10</td>
<td>Voluntary</td>
<td>115</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11:00 AM</td>
<td>11</td>
<td>Voluntary</td>
<td>115</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12:00 PM</td>
<td>12</td>
<td>Voluntary</td>
<td>115</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1:00 PM</td>
<td>13</td>
<td>Voluntary</td>
<td>115</td>
<td>24.5</td>
<td>85.3</td>
<td>780490</td>
<td>484.974</td>
</tr>
<tr>
<td>2:00 PM</td>
<td>14</td>
<td>Voluntary</td>
<td>115</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3:00 PM</td>
<td>15</td>
<td>Voluntary</td>
<td>115</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4:00 PM</td>
<td>16</td>
<td>Voluntary</td>
<td>115</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5:00 PM</td>
<td>17</td>
<td>Voluntary</td>
<td>115</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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Appendix D: Volume Distribution Comparison Plots
I-10 WB @ Loyola

[Graphs showing volume vs. time for different count stations: Loyola Count Station STORM/WEST, Loyola Count Station STORM/EAST, Loyola Count Station STORM/BETSY, Loyola Count Station STORM/CAMILLE. Each graph compares Current Plan and Flex Plan.]
I-12 WB @ US 61 (Baton Rouge)

US 61 @ I-12 (Baton Rouge)
I-55 NB Hammond
Causeway Bridge

[Graphs showing traffic volume over time for different storms, with legends indicating Current Plan and Flex Plan.]
US 11 @ I-12 (Slidell)
I-59 NB @ LA/MS State Line
Vita

Thomas J. Montz, Jr was born in Mobile, Alabama, in 1987 to parents native to Louisiana. Thomas earned his Bachelor of Science in Civil Engineering from Louisiana State University in 2009. He is a registered Engineer Intern in the state of Louisiana. Thomas is a candidate to receive a Master of Science in Civil Engineering for 2011. During his graduate and undergraduate career, he focused on research involving transportation modeling, especially in the context of emergency evacuations. Thomas also worked on research studies involving traffic flow characteristics, traffic simulation, and work zones.

In addition to academic work, Thomas has held several internship positions. He worked for Bechtel, an international project management and construction firm. He worked for the Louisiana Department of Transportation and Development. He also held a position at ABMB Engineers, a local consulting engineering firm in Baton Rouge, Louisiana.

Following graduation, Thomas has accepted an engineer intern position at ARCADIS U.S., an international company specializing in infrastructure, water, environment, and construction. Thomas will be working out of the company’s Baton Rouge office and will focus on projects related to traffic analysis, ITS, and emergency evacuation.