Technical Report Documentation Page

<table>
<tr><td>1. Report No.
SWUTC/10/476660-00041-1</td><td>2. Government Accession No</td><td>3. Recipient's Catalog No</td></tr>
<tr><td colspan="2" rowspan="2">4. Title and Subtitle
Thinking Critically About Models Used to Predict Emergency Evacuation in Gulf Coast States</td><td>5. Report Date
July 2010</td></tr>
<tr><td>6. Performing Organization Code</td></tr>
<tr><td colspan="2">7. Author(s)
Carol Abel Lewis, Brandon Moseley and Garlin Wynn</td><td>8. Performing Organization Report No.
Report 476660-00041-1</td></tr>
<tr><td colspan="2" rowspan="2">9. Performing Organization Name and Address
Center for Transportation Training and Research
Texas Southern University
3100 Cleburne
Houston, Texas 77004</td><td>10. Work Unit No. (TRAIS)</td></tr>
<tr><td>11. Contract or Grant No.
DTRT07-G-0006</td></tr>
<tr><td colspan="2" rowspan="2">12. Sponsoring Agency Name and Address
Southwest Region University Transportation Center
Texas Transportation Institute
Texas A&M University System
College Station, Texas 77843-3135</td><td>13. Type of Report and Period Covered</td></tr>
<tr><td>14. Sponsoring Agency Code</td></tr>
<tr><td colspan="3">15. Supplementary Notes
Supported by a grant from the U.S. Department of Transportation, University Transportation Centers Program.</td></tr>
<tr><td colspan="3">16. Abstract
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<tr><td colspan="2">17. Key Words
Evacuation Modeling, Hurricane Ike Evacuation, Hurricane Rita</td><td>18. Distribution Statement
No restrictions. This document is available to the public through NTIS:
National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161</td></tr>
<tr><td>19. Security Classif.(of this report)
Unclassified</td><td>20. Security Classif.(of this page)
Unclassified</td><td>21. No. of Pages
42

22. Price</td></tr>
</table>

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

Thinking Critically About Models Used to Predict Emergency Evacuation in Gulf Coast States

by

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SWUTC/10/476660-00041-1

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June 2010

Abstract

Evacuations from Hurricanes Katrina, Rita and Wilma in 2005 illuminated issues with clearing large numbers of residents via urban area roadways and public transportation systems. In addition, other events including potential terrorists' attacks or wildfires need to better understand and predict community evacuation. Much work has been done to improve evacuation times and experiences when the need to evacuate occurs. A number of models exist that forecast evacuation under a variety of scenarios. This work examines the application of these models in Gulf Coast states and discusses future direction for improving their use by government officials. Further, an assessment of evacuations during Hurricanes Rita and Ike is included that makes use of an index comparing evacuation travel time to average daily peak travel time.

Executive Summary

Hurricane season begins June 1 and is announced in print and by auditory and visual media in communities at high risk during this season. Billboards caution people against complacency during the hurricane season and encourage preparation. Each state and most local governments prone to hurricanes have web sites with extensive information providing guidance about what to do before, during and after a hurricane. Officials sponsor community seminars that assist residents in making plans; families are encouraged to gather their emergency kits and consider whether they will shelter in place or if evacuating, determine their travel route. Government officials stress planning ahead as the key to efficiency during an emergency. All levels of government are involved in successfully handling an evacuation situation, when necessary. Evacuations may be voluntary or mandatory.

A 2007 US Department of Transportation Research and Innovative Technology Administration (RITA) report identified more than 30 transportation modeling applications that have or could be used to forecast evacuations. Of those reviewed, some are designed to address very small scale evacuations, such as at the neighborhood level, corridor or route level (micro), while others apply to much larger regions (macro and meso). Between the small area micro models and the macro models are meso models. Planners and engineers for large cities often apply macro and meso models such as EMME/2, OREMS, TransCAD and TRANSIM.

Models and their refinement are important; attention to model improvements is usually the domain of academics and commercial professionals. Getting a perspective of what is important to top policy and decision makers would further enhance the refinements occurring to hurricane and other evacuation models. Once evacuations occur, time should be spent reflecting on whether the evacuation has been successful. Adoption of an index that allows a frame of reference by which to gauge the evacuation is advised. Knowledge exchange between model experts and policy makers, especially as emergencies are occurring would be beneficial. With the advancement of commercial tools, mobile devices and social networks, an opportunity exists to transfer more information from modeling outputs for consideration by officials during an event. In this way, both planning phases and actual responses to events can be improved in order to take better advantage of the modeling capabilities and technologies.

Currently only a few locales have the option of the computer modeling. For instance, in Texas, only evacuation of the Houston Galveston area is assessed using models. There is much to be learned through the evacuation models. If the modeling is important for large areas known to face capacity problems during evacuation, smaller areas especially those with known physical infrastructure shortcomings would benefit from modeling, as well. As officials become more aware of the available capabilities, they will want to take advantage of the opportunity to better understand evacuation and the potential options. Engineers and planners would appreciate a clearer concept of the thinking that goes into requiring mandatory evacuation and issuing voluntary evacuation alerts. More direct communication between the decision makers and the transportation modelers would offer the potential to improve the planning and implementation of community evacuation when it is needed.

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Disclaimer

Acknowledgement

The authors recognize that support for this research was provided by a grant from the U.S. Department of Transportation, University Transportation Centers Program to the Southwest Region University Transportation Center.

Introduction

Evacuations from Hurricanes Katrina, Rita and Wilma in 2005 illuminated issues with clearing large numbers of residents via urban area roadways and public transportation systems. Major television networks profiled the extreme traffic congestion from Houston as people with cars tried to leave the city during Hurricane Rita. While grueling and extremely time consuming, people choosing to leave were able to make their trips. Typical travelers reported that a normal four hour trip took as many as 23 hours. Persons evacuating New Orleans due to Hurricane Katrina noted similarly long travel times between New Orleans and Baton Rouge. Images from New Orleans were of thousands of persons without vehicles trapped in a City under a mandatory evacuation order. In these instances, the goals of the elected officials, transportation personnel and residents are the same – when there is a need for evacuation, whether mandatory or voluntary – the traveling public will exit efficiently and in a reasonable time. Decisions to order mandatory evacuations are made by varying elected officials. In Texas, local officials including mayors for incorporated areas and county judges for unincorporated areas issue evacuation orders based on predictions of approaching storms. During Louisiana's experience with Hurricane Katrina, the New Orleans' mayor was charged with issuing evacuation orders. In Mississippi, Florida, and South Carolina, the governors can call for mandatory evacuations. Consultation between appropriate officials and safety and transportation personnel occurs during these crisis situations. In non-emergency times and between severe weather and other events, transportation professionals and emergency personnel routinely plan and evaluate evacuation scenarios. The US government requires evacuation and implementation plans for Gulf Coast States—Alabama, Georgia, Florida, Louisiana, Mississippi, and Texas. A 2006 review showed adequate preparation, but noted that additional demonstration exercises and subsequent adjustments based on real experience would strengthen decision and management of events (US DOT, 2006). Because the demonstration exercises are time consuming and expensive and the opportunity to learn from actual experiences is sporadic, a cadre of computer models are available that enable professionals to assess scenarios and options.

Sophisticated computer models, given predictions of who will evacuate, analyze routing options, potential traffic flows, and anticipated bottlenecks. A minimum of 30 basic software applications provide the capacity to forecast trip volumes and distributions to be accommodated during an evacuation. This study set out to review the models in use by Gulf Coast states and assess how plans for evacuations consider these models. These states were selected because they are most commonly affected by Hurricanes (Figure 1). The study also determines whether there is room for improvement in incorporating outputs of the models into planning and implementation strategies of public decision makers. Lastly, this work assesses the travel times during Hurricanes Rita and Ike and compares those times to average weekday freeway volumes for selected locations.

Evacuation Planning and Preparation

Hurricane season begins June 1 and is announced in print and by auditory and visual media; billboards caution people against complacency during the hurricane season and encourage preparation. Each state and most local governments prone to hurricanes have web sites with extensive information providing guidance about what to do before, during and after a hurricane. Officials sponsor community seminars that assist residents in making plans; families are encouraged to gather their emergency kits and consider whether they will shelter in place or if evacuating, determine their travel route. Government officials stress planning ahead as the key to efficiency during an emergency. All levels of government are involved in successfully handling an evacuation situation, when necessary. Evacuations may be voluntary or mandatory. State governors, emergency management offices, state transportation officials and local governments are extremely visible and work together to achieve the most streamlined outcomes. Behind the scenes, public safety personnel, transportation engineers and planners and police officers conduct assessments and make recommendations that affect the flow of evacuation travel. In non-emergency times, government planning organizations, private consulting firms and university researchers spend thousands of hours collecting background information that facilitates smooth responses during evacuations. Included are the analyses of the routes available, capacity to handle volumes and the potential impact of anticipated or unanticipated hindrances or bottlenecks. For instance, traffic signals can cause delays and may be managed differently when evacuating large volumes of people. Unexpected occurrences, such as vehicle breakdowns, have a different impact on the system and require a response. Because evacuations occur rather infrequently, the potential to learn from experience does not provide the array of possibilities that planners and researchers wish to explore. Evacuation models and simulation tools offer the opportunity to develop and evaluate scenarios in order to better accommodate the citizenry during evacuations.

Methodology

The primary focus of this research is on the state departments of transportation (DOTs) that border the Gulf Coast and the Florida eastern shore – areas that are most prone to hurricanes. Figure 1 shows that since 1950 all Category 5s and five of seven Category 4 hurricanes landed in these areas. The DOTS serve as key responsibility centers for roadway lengths sufficient in length for successful evacuation.

While the Gulf Coast states are the focus of this research, to ensure inclusiveness and reduce potential bias, the office responsible for disaster preparedness in each US state for any category of emergency evacuation (e.g., fire, chemical spill) was verified by internet or telephone. A case study approach that included a survey instrument was begun. Twenty-five contacts were confirmed and received the survey instrument. The survey queried whether the state utilizes a transportation model in evacuation planning and implementation and if so, solicited details about the model and its capabilities. If the state DOT contact did not indicate use of a model, they were asked to indicate if another entity performed this function for them. When surveys were returned, the number of states responding affirmatively about the use of a model was so small, the study team added an interview instrument for persons in Florida, Georgia,

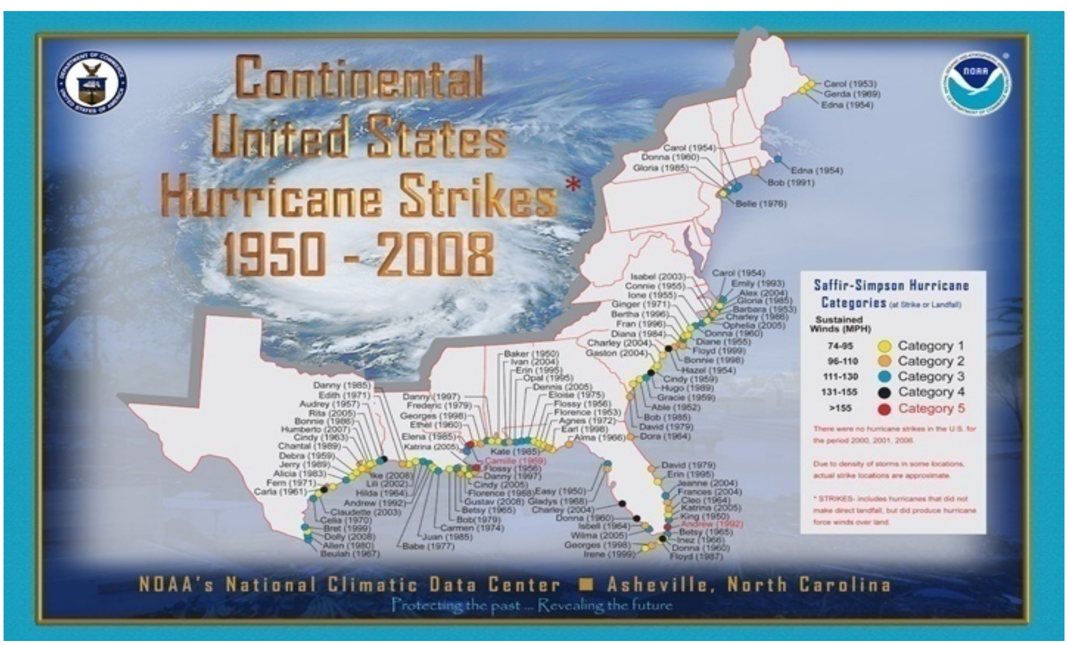

Figure 1: Continental United States Hurricane Strikes 1950-2008
Source: NOAA Satellite and Information Service

Mississippi, Alabama, Louisiana and Texas to learn more about the linkage between the evacuation process and the evacuation modeling outputs.

As a second activity, data were collected from the Texas Department of Transportation for volumes of vehicles on key roadway segments for Hurricanes Rita and Ike[1]. The volumes for all evacuation days were compared for five hour intervals and averaged. The average roadway volume for each segment was compared to the average peak hour daily travel volume and divided to provide an index. The premise is that the average peak hour travel is an accepted, although not necessarily a desirable condition. Evacuation that proceeds at that level can also be deemed acceptable.

[1] Reported via excel spreadsheet received from Houston Galveston Area Council, Transportation Division (undated).

The State of the Practice in Evacuation Models

A US Department of Transportation Research and Innovative Technology Administration (RITA) report identified more than 30 transportation modeling applications that have or could be used to forecast evacuations (Hardy and Wunderlich, 2007). Of those reviewed, some are designed to address very small scale evacuations, such as at the neighborhood level, corridor or route level (micro), while others apply to much larger regions (macro and meso). Macro models forecast evacuation for large geographic regions or across states. Between the small area micro models and the macro models are meso models. Planners and engineers for large cities often apply macro and meso models such as EMME/2, OREMS, TransCAD and TRANSIM. An additional five models described in the report are support tools for real-time decision making and information exchange by official government emergency agencies. Chen et. al. (2007) in their article about the affect of traffic signals on evacuation include an impressive review of literature which describes evacuation models that focus on human behavior, routing and methodologies, plans and policies, information on Geographic Information Systems and contra-flow. Houston's regional transportation planning entity, HGAC, applied one of the meso models, CUBE, taking advantage of the model's capacity to better respond to scenario evaluations. Louisiana State University (LSU) used TRANSIM for the New Orleans area evacuation related to Hurricane Katrina. The US DOT RITA report notes that application of the models and variations from base software is an on-going exercise at regional planning entities, engineering consultant firms, universities and software companies. Model adaptations and software modifications beyond those covered in the 2007 US DOT RITA report have occurred since its publication. For instance, work is beginning that will apply the TRANSIM model used in forecasting the Katrina evacuation to the Houston-Galveston area.

Additional Detail about Micro, Meso and Macro Level Modeling

As noted, decisions regarding appropriate evacuation model scale focus on the corridor or route level (micro), while others apply to much larger regions (macro and meso). Macro models forecast evacuation for large geographic regions or across states. Between the small area micro models and the macro models are meso models. Murray-Tuite and Mahmassani (2003) give an example of a micro model as they studied the effects of household preparation for evacuation travel. Their corridor focused evaluation concluded that the trips made to collect children and conduct other pre-evacuation needs (termed trip-chaining) impact the evacuation travel patterns and that traffic demand estimates should be increased 150% if the trip chaining was not previously considered. They also concluded that evacuees took the shortest path and overlooked roadway congestion.

Church and Sexton (2002) looked at evacuation from a neighborhood in Santa Barbara assessing vehicle movements beginning at the driveway entrance to the network. Their point was to review what was termed bulk lane demand, which indicated where roadways would be too narrow to accommodate travel demand from the neighborhood during an emergency.

Another example of microsimulation**,** examined Daytona Beach and the City of Ormond Beach in Florida, comparing two models, ARENA and INTEGRATION (Radwan et. al.). This work showed that differences in model outputs occur given similar inputs between the two software options with INTEGRATION providing the better results.

Mesa and Macro models are used in the major cities most known for large scale evacuations. Houston's metropolitan transportation planning entity, Houston Galveston Area Council, applied one of the meso models, CUBE, taking advantage of the model's capacity to better respond to scenario evaluations. Louisiana State University (LSU) used TRANSIM for the New Orleans area evacuation related to Hurricane Katrina. Other macro and mesa models are EMME/2, OREMS and TransCAD. In the next year, Houston area professionals will begin work to apply the TRANSIM model to the Houston Gulf Coast area evacuation planning in order to take advantage of its more easily usable simulation tool.

Variables Affecting Evacuation Models

Models presume essentially orderly, well-timed evacuations with people leaving in concert with requested direction from officials. Lindell (2007) writes that human behavior variables are not well incorporated into existing models. Experience with Hurricanes Rita and Ike showed that much can be gleaned through the models when incorporating experiences from past events. Human behavior is somewhat unpredictable and people may respond other than as requested (Peacock et. al.,2007; Murray-Tuite and Mahmassani, January 2005). A major shortcoming in the Houston Rita event where congestion was extreme was that residents did not abide by the requested evacuation zones. A preponderance of those leaving were influenced by seeing their neighbors leaving (Peacock, 2007). Individuals from mandatory evacuation areas became stuck on roadways because persons not identified for evacuation filled the highways. One of the most difficult aspects of modeling is incorporation of that subjective citizen decision making about whether to leave and given a positive decision, when to leave and which route to travel. The decision sequences determine the traffic volumes on the roadways. Not only do personal requirements such as collecting children from school or waiting on all family members to arrive affect traveler decisions, the variables in the decision making sequence may change from one hurricane event to the next and from year to year. That these considerations affect the behavior of travelers when emergencies are imminent is noted in a report by North Carolina DOT (2002). Social and economic variables influence when people decide to evacuate and whether they will travel to a shelter, relative or friend or go to a motel/hotel. In neighboring South Carolina 25 percent of evacuating families took more than one car and most people essentially began their trip within a six hour period. A number traveled farther than required. Models and simulations consider aggregate human response not individualized decisions; these individual decisions are more impactful at the micro level of evaluation, but become meshed at the meso and macro scales.

Important to note about the models are the limitations. Traffic simulations and models may be designed to reflect a range of roadway conditions. The expectations and base conditions coded into the model must be fairly accurate in representing the travel nodes, segment lengths, speeds and other parameters. Every hurricane event will be different in strength and location of direct land assault, which will influence who evacuates and result in varying transportation network outputs(Florida Department of Community Affairs, 2004) Also, different evacuation models used to predict based on the same set of input parameters will likely yield varying results. Florida researchers tested two models, ARENA and INTEGRATION, for an area in their state. They found that ARENA did not forecast as well for the larger scale network and developing the networks per this application was more complicated. The ARENA model was not easily modified and required input assumptions the researchers were not comfortable including. The research team concluded the INTEGRATION model showed greater statistical strength for their locale (Radwan et. al., 2005).

Effective movement on a regional level cannot occur if residents are delayed from leaving their neighborhoods by inadequate capacity. Micro scale evacuations examine the exit capacity for small geographic areas via individual or small groups of arterials. For example, Church et. al (2002) looked at evacuation from a neighborhood in Santa Barbara assessing vehicle movements beginning at the driveway entrance to the network. Their point was to review what was termed bulk lane demand, which indicated where roadways would be too narrow to accommodate travel demand from the neighborhood during an emergency. Chen et. al. (2007) reviewed a Washington, D.C. corridor and evaluated evacuation time on local streets based on the ratio of green light or red light time of the traffic signals. They found that total green light time along a corridor in the direction of the evacuation best facilitated exit. Other combinations of mixed red and green signal time ratios resulted in no clear optimum scenario.

Static or Dynamic Model

Static models accept the input parameters and assign trips across the prepared networks based on the demands and networks provided. Static models read the trip tables and network as input, and assign volumes and routes as output. Generally it is microsimulation which requires volumes and routes as input, not macro or static model. A static model does not reflect bottlenecks accurately because it allows volume over capacity and also it does not model queuing. Therefore, it generally under-estimates the congestion caused by a bottleneck

On the other hand, with a dynamic network flow model, the system will change over time and the dynamic model accommodates change on both supply and demand sides. Urbanik (2000) cautions about applying generalized traffic congestion simulation models to evacuation in a static way. OREMS, a USDOT endorsed model, produces a dynamic evacuation code called DSIM, which more closely replicates driver behavior during congestion such as experienced in an evacuation (Hardy and Wunderlich).

Modeling experts often advise against use of static models for evacuation due to the following reasons:

- Evacuation demand and queuing is dynamic in nature, and networks could be changed due to lane closures or other reasons. Static models cannot reflect temporal demand (the evacuees) and supply (the transportation networks) changes over time within the evacuation periods.
- Static models, in general, cannot pulse queuing back to upstream links.

- Evacuation success is often measured by temporal delay and queue length that changes dynamically during evacuation

Even though there are some exceptions, most macro-models are static while meso and micro models are dynamic. Macro models measure traffic as flow, while micro models simulate each individual vehicle movements. Meso model are somewhat between macro and micro.

Other Model Capabilities and Variables

As noted, one of the most difficult components of the modeling process is anticipating and predicting human behavior (Peacock et. al., 2007; Murray-Tuite and Mahmassani, January 2005). Professionals must make a series of decisions to represent the collective behaviors, which will include the trip chaining, decisions about leaving and route choices. Decision makers should be interested in models capable of responding to changes in trip volume and travel speeds and other variables that affect the rate of evacuation. Chien and Korikanthimath (2007) used a series of algorithms to assess transit, delay estimates, and queuing times to determine evacuation time and determine the optimal number of evacuation stages.

US DOT and FEMA worked together to develop a GIS based tool designed to address congestion problems that occurred during Hurricane Floyd in 1999. ETIS includes weather information and incorporates tourist occupancy rates in projecting evacuation.

An Overview of the Models

Identification of the most appropriate model for a community will depend on its desired use of the model outputs. Typically, officials wish to identify preferred routes, determine the time required to evacuate a given number of people, recognize potential congestion locations, consider optional traffic control alternatives, and estimate travel speeds. Tables 1 and 2 summarize key macro and meso models used for evacuation according to the Hardy and Wunderlich research.

Table 1. Primary Macro Models Used for Hurricane Evacuations

Model	Special Focus
Emme/2	Planning Model
ETIS	Hurricanes
HEADSUP	Hurricanes
HURREVAC	Hurricanes
MASSVAC	Evacuation Management
NETVAC	Evacuation Management
OREMS	Traffic Simulation
PCDYNEV	Evacuation Management
REMS	Evacuation Management
TEDSS	Evacuation Management

Source: Modified from Evacuation Modeling Tool Inventory (Hardy and Wunderlich, p. 25)

Table 2. Primary Meso Models Used for Hurricane Evacuations

Model	
Simulex	Evacuation Management
Cube	Traffic Simulation
DyynaSmart	Traffic Simulation
Transmodeler	Planning Simulation
TRANSIMs	Planning Simulation

Source: Modified from Evacuation Modeling Tool Inventory (Hardy and Wunderlich, p.25)

Models are basically structured to address general planning, matters of management during an event, traffic under normal conditions, hurricanes or other emergency circumstances. The models must be run by experts which limits the locales using models to those who have professionals with the skill set to perform the function or those who have funds to purchase the expertise. There is no one software or model that would work in a prescribed manner; each community must assess their needs and match them to the model's capabilities. In selecting a model and expert personnel to execute the model, questions asked by policy makers should include, but not be limited to the following:

- What information do we need to make proper decision?
    - Anticipated number of evacuees
    - Available routes and alternative routing scenarios
    - Variables affecting individual decisions

    - Potential bottlenecks and delay locations
    - Possible traffic control strategies
    - Projected length and duration of congestion; estimated travel speeds
    - Quantity of public transportation needed
- What are necessary skill sets and finances and what professionals are available to conduct the work?
- Are we interested in neighborhood/route level or regional scale outputs?
- Would there be an advantage to using a static model over a dynamic model?
- Do we want a model specifically designed to address hurricane evacuation, or would a general planning or traffic model better suit our needs?
- By what measures will we claim evacuation success?

Discovery and Discussion

Of the states returning the survey instrument, two states, Mississippi and Texas, answered that the results of evacuation modeling are incorporated into their pre-hurricane planning. We began this work anticipating that each of these states would incorporate a model, but use different software with varying capabilities. Our expectation was that our research would explore the strengths and weaknesses of the software applications, then recommend streamlining and cross state applications of the modeling tools. That so many of the states answered that they were not utilizing the models raised several interesting questions. What are the applications of the many evaluations, research and software demonstrations as discussed in the USDOT report and observed through the literature? Is there a disconnect and chasm between the transportation and traffic simulation capability and the transportation and event emergency decision makers or did the survey instrument not reach the appropriate persons? Please recognize that this research is not ascertaining that evacuation modeling is not occurring in these states, but rather a two-stepped effort to determine who is using the models and how, did not yield those individuals or entities. The survey responses and interviews with individuals in the six Gulf Coast states yielded the information described below.

Florida: The state of Florida responded that they do no evacuation modeling and directed us to the Office of Emergency Management. This office also responded that they conduct no modeling in preparation for their evacuations. However, several universities in Florida are known to conduct evacuation modeling assessing traffic conditions in the state.

Georgia: A response was not received to the survey and active application of evacuation models could not be confirmed for Georgia.

Alabama: Emergency personnel rely on the Alabama DOT for evacuation routes and some modeling occurs through FEMA and the Army Corps of Engineers.

Mississippi: Representatives from Mississippi indicated through the survey that evacuation planning is done, but not computer evacuation modeling.

Louisiana: Louisiana State University faculty members conduct simulation for the state, focusing on the New Orleans area. They apply TRANSIM, which has increased micro simulation capability. This model will be applied over the next several years for the Houston-Galveston area with the anticipation of providing greater decision making opportunities.

Texas: Modeling along the Houston-Galveston Gulf Coast is done by the metropolitan planning organization, Houston-Galveston Area Council, using a static meso model. Additional decision making would be aided by incorporating more elements that are capable of simulating real-time bottlenecks and other disruptions that cause a change in network routings. No other modeling is conducted for the areas near Brownsville, Corpus Christie or Beaumont/Port Author. Hurricane Rita served as a pivotal turning point in preparation.

Table 3 provides the information summary from the states.

Table 3. State DOT Responses to Evacuation Model Survey

State	Evacuation Plan	Use of Computer Model for Evacuation Planning	Referred To	Other Notes
Arkansas*	**No**	**No**		**Department of Emergency Management Uses Mapping Software, but not for Natural Disaster**
Florida	**Yes**	**No**	**Emergency Management Office**	
Georgia	**Yes**	**No**		
Mississippi	**Yes**	**No**	**Emergency Management Agency**	
Texas	**Yes**	**Yes**	**Houston Galveston Area Council**	
Indiana*	**Yes**	**No**		

* Responded to Survey, But Not a Hurricane Prone State

Communication Sequences; Inputting Results from the Modeling

Evacuation model results display projected vehicle volumes, routes of people exiting a locale and bottlenecks that would constrain traffic flow. In addition, numerous capabilities are available and include, but are not limited to:

- Alternative traffic control scenarios can be evaluated.
- Different evacuation strategies can be assessed.
- Estimated operating speeds on specific roadways can be determined.
- Queuing times are quantified.
- Clearance times in cases of congestion can be determined.

Outputs from modeling may be directed in several ways. Most typically, results go directly into large scale, regional transportation planning activities as professionals determine evacuation routes and prepare plans and scenarios or staging. Private consultants may be hired by state or local governments that will utilize the outputs for individual corridor planning. These corridor plans may be primarily for daily travel, but also designed with possible evacuation in mind. DOTs may solicit the information to determine whether improvements to a particular roadway would add value both for daily operations and during times of emergency events. Cities and counties may ask for the information to include in their local decision making about routine roadway decisions. In these cases, if there are two roadway options to consider for improvement, but money to improve only one roadway, priorities could be set if one road offered greater evacuation potential as shown through the evacuation models.

When impending emergencies occur, those making decision about evacuation (mayors, governors, county heads) are somewhat removed from those who have planned the emergency roadways and routes. Missing is the direct communication line during the planning phases between those persons conducting the models and simulation displays to the first-line decision makers, who make the evacuation decisions. Figure 2 displays the evacuation planning and implementation scenarios. Professional planners and engineers provide input to the evacuation models, conduct the simulations and assess the results. Model outcomes are provided to agency officials, who incorporate findings into the near-term preparations and route planning, as well as develop plans for future roadways. For instance during pre-construction phases, a transportation planner may intend for a proposed roadway to serve as an evacuation route long before the route is actually constructed. The traffic model and simulation helps predict its future viability. Simultaneously, local and area governments, along with state emergency personnel work on emergency and evacuation plans. A better discussion stream between those who conduct the models and simulations and those who make the evacuation decisions could improve the efficiency of evacuation and better inform first-line officials about the characteristics of mobility during emergency events.

Defining Evacuation Success

Judging an evacuation as successful or not is largely a perception of the citizenry, elected officials, and media. For example, consensus around the Houston area evacuation preceding the 2008 Hurricane Ike deemed that evacuation a success. Traffic moved fairly well, long delays while in route did not occur, communication between government officials and with the public occurred smoothly, and merchants maintained fuel availability. Also, a number of residents stayed home during the hurricane (termed shelter in-place), and those evacuating seemed to follow the recommended zonal evacuation schedule. The opposite of all these parameters defined evacuation that accompanied Hurricane Rita in 2005, which was noted by the national news coverage of the excessive congestion and delays. Common anecdotal accounts noted trips that would take one hour during a typical rush hour took nine hours during the Rita evacuation; some typical 4 hour trips took 20 hours. The seeming better response during Hurricane Ike might be challenged given a review of some key details. Most important is the number of evacuees during each event; the estimate for Ike is 1.2 million persons leaving and for Rita, 2 to 3.5 million persons leaving. An on-line voluntary survey conducted by TranStar, the Houston region's joint governmental emergency management organization, indicated 77% of residents did not leave. Clearly, the reduction in volume contributed, in part, to the better evacuation flow.

While all the positive improvements experienced during Ike (good communication between officials and the public, following evacuation zone guidelines, reasonable traffic flow and available fuel) must be maintained for future successful evacuations, a standard is needed, a benchmark against which to measure success. For consideration is a look at traffic for one location in Houston during the region's evacuation prior to landfall of Hurricanes Rita and Ike. The recommendation is to assess the movement during these evacuations compared to normal rush hour travel volumes. Table 4 shows the peak hour average week day volume at the location for Hurricane Rita and Table 5 for Hurricane Ike[2] compared with the average volumes for the two evacuation days. A value of *one* or higher shows travel as well or better than a typical day. Values less than *one* indicate a higher level of congestion than a normal day. Table 3 indexes confirm the perceptions about travel during Hurricane Rita with the best value, the fifth hour into the evacuation showing the highest value of .87. Other values reflect the sluggish mobility experienced during the evacuation associated with Hurricane Rita as compared to typical average daily traffic flow; the lowest value is .36, fifteen hours into the evacuation.

Table 5 shows values for evacuation during Hurricane Ike and reflects far better mobility than during Rita with two values in excess of one, or travel flow exceeding a normal weekday. For all evacuation hours, the total shows a value of .85 for Hurricane Ike, materially better than the .55 for all hours during Hurricane Rita.

Table 4
Comparison of Normal Traffic Volume to Hurricane Rita Volume at One Location (I-45 near The Woodlands)

Hours into Evacuation	Average Weekday Volume	Volume Sept. 21, 2005	Volume Sept. 22, 2005	Index: Evacuation Average to Weekday Average
5	1667	1906	1000	.87
10	4613	5280	1024	.68
15	5403	2419	1502	.36
20	3445	2184	1166	.48
Total all hours	87,995	67,129	31,050	.55

[2] Counter locations differed slightly for Hurricanes Rita (I45 northbound/Hardy Toll Road) and Ike(I45 northbound/FM1488), but are proximate and considered comparable across the events.

Table 5
Comparison of Normal Traffic Volume to Hurricane Ike Volume at One Location in Houston (I-45 near The Woodlands)

Hours into Evacuation	Average Weekday Volume	Volume Sept. 11, 2008	Volume Sept. 12, 2008	Index: Evacuation Average to Weekday Average
5	1132	1623	1569	1.40
10	3407	5103	3787	1.30
15	4676	3389	1877	0.56
20	2557	2334	435	0.54
Total all hours	65431	68697	42,124	0.85

Note: Shaded cells show when travel time was better than for the average rush hour.

The indexes confirm the perception that traffic flow during Hurricane Ike was improved as compared to that for Hurricane Rita. Data for additional locations are in Appendix 1. Key elements included a manageable volume of evacuees, encouragement of sheltering-in-place for those who are able and adherence to the evacuation zones and timing for those leaving.

Synthesis Findings

Great advances have occurred over the past 10 years, when as noted in a LSU 2001 report that following Hurricane Floyd, transportation agencies at the federal, state, and local levels began to take a more active role in the planning, management, and operation of hurricane evacuations. Still, use of evacuation models for assessing traveler responses is a relatively recent tool for planners. This is somewhat of a departure from prior practice when evacuation tasks were planned and directed nearly exclusively by emergency management officials. Since the involvement of transportation professionals in evacuation has been a fairly recent development, it is not surprising that the level of understanding of evacuation computers assessment capabilities is not understood or fully taken advantage of by front line decision makers and responders. It likely means that many of the newly examined scenarios have not been vetted or placed into actual practice. There would be great benefit for greater communication between the needs and questions of front-line decision makers and those having the capacity to review scenarios via computer technology.

In considering why there has not been more modeling or attention to the models, the following may be considered.

- Those traditionally responsible for making the decisions about emergencies and evacuation have not historically relied on in-depth technical analysis as part of the decision-making. This may in part be due to the smaller past evacuations. The recent trending to evacuating far larger numbers of people is likely to render historical methods obsolete, especially since more sophisticated methods are available.
- Since large scale evacuations are a recent phenomenon in the US, and until there was an observed problem, the need for advanced planning was underestimated.
  - There had been smaller area evacuations in case of fires, chemical spills, or hurricanes, but the first large citywide evacuation in the US was the 2005 New Orleans evacuation after Hurricane Katrina. The pressures of moving large numbers of persons without automobiles caused extreme problems.
  - One month later, evacuation of the Gulf Coast near Galveston during Hurricane Rita (September 2005) showed the difficulties of evacuating vehicles when the demand for roadway space exceeds roadway capacity.
- Upgrades in computer processing time and greater availability of data resources has enabled more sophisticated analyses.
- Preparing for and conducting the model runs is complex and time consuming. Many governmental entities do not have financial or staff resources to structure or process the models and simulations.
- For communities that have the resources, staff may not possess the technical skill set necessary to plan, data gather or run the models.

Better understanding of technological advances and capabilities by first line decision makers or their executive personnel offers the potential to improve evacuations by reviewing a variety of scenarios. It is important to model because every event is different. Examining a variety of scenarios would be beneficial as decision makers could consider the strength of an impending hurricane, where it is projected to hit, and other variables. Planners can predict traffic or other choke-points and show how they can be eased. Decision makers could develop a cadre of options given the anticipated circumstances.

Our research shows inadequate liaison between planners, engineers and decision makers. Greater attention should be paid to the nexus of state government, local government and university planning and preparation. Better integrating the role of evacuation modeling with the preparation and planning by government implementers would result in smoother evacuations in the future.

Summary and Remaining Questions

Models and their refinement are important; attention to model improvements is usually the domain of academics and commercial professionals. Getting a perspective of what is important to top policy and decision makers would further enhance the refinements occurring to hurricane and other evacuation models. Once evacuations occur, time should be spent reflecting on whether the evacuation has been successful. Adoption of an index that allows a frame of reference by which to gauge the evacuation is advised. With the advancement of commercial tools, mobile devices and social networks, an opportunity exists to transfer more information from modeling outputs for consideration by officials during an event. Knowledge exchange between model experts and policy makers, especially as emergencies are occurring would be beneficial. In this way, both planning phases and actual responses to events can be improved in order to take better advantage of the modeling capabilities and technologies. Several questions remain as computer modeling of evacuations continues to improve. Currently only a few locales have the option of the computer modeling. For instance, in Texas, only evacuation of the Houston Galveston area is assessed using models. Is the modeling most important for large areas known to face capacity problems during evacuation? Would smaller areas especially those with known physical infrastructure shortcomings benefit, as well? How can this opportunity be cost-efficiently extended to more communities? There is much to be learned through the evacuation models. As officials become more aware of the available capabilities, they will want to take advantage of the opportunity to better understand evacuation and the potential options. Engineers and planners would appreciate a clearer concept of the thinking that goes into requiring mandatory evacuation and issuing voluntary evacuation alerts. More direct communication between the decision makers and the transportation modelers would offer the potential to improve the planning and implementation of community evacuation when it’s needed.

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US Hurricane Locations 1950 -2008

Appendix 1

Indexes for Locations throughout Harris County and

Adjacent Counties for Hurricane Rita and Hurricane Ike

The locations and volumes presented below are provided by TxDOT for the Hurricanes Rita and Ike. Locations chosen are not the same for the two hurricanes, so in most cases direct comparisons are not possible. Still, the indexes show the movement compared to the average peak hour.

Table A1. SH 146 NB -- North of I-10 East 463-N (in Mt. Belvieu). Hurricane Rita and Ike

		WB	— Hurricane Rita —					Hurricane IKE		
		Typical 2005	9/21/2005	9/22/2005			Typical 2008	9/11/2008	9/12/2008	
HOUR		Avg Wkday	Wednesday	Thursday	Index		Avg Wkdy	Thursday	Friday	Index
5:00		344	449	884	1.94		557	572	136	0.64
10:00		639	1300	628	1.51		677	1300	453	1.29
15:00		864	1653	671	1.34		917	98	158	0.14
20:00		539	958	114	0.99		560	450	10	0.41

Table A2. SH 146 NB -- South of US 90 (Dayton). Hurricane Rita and Ike

	NB	— Hurricane Rita —				NB— Hurricane IKE				
	Typical 2005	9/21/2005	9/22/2005			Typical 2008	9/11/2008	9/12/2008		
	Avg Wkday	Wednesday	Thursday	Index		Avg Wkdy	Thursday	Friday	Index	
	115	174	836	4.39		154	206	72	0.90	
	332	1518	529	3.08		328	929	290	1.86	
	478	1368	416	1.87		518	442	94	0.52	
	214	770	954	4.03		193	254	10	0.68	

Table A3. SH 146 NB -- South of I-10 East [463-N in Baytown] Hurricane Rita and Ike

SH 146 NB -- South of I-10 East [463-N in Baytown]												
		WB	--- Hurricane Rita ---						--- Hurricane Ike - evac Southeast TX ---			
		Typical 2005	9/21/2005	9/22/2005					9/11/2008	9/12/2008		
HOUR		Avg Wkday	Wednesday	Thursday	Index			Avg Wkdy	Thursday	Friday	Index	
START												
5:00		498	642	1776	2.43			784	1202	198	0.89	
10:00		860	2237	1170	1.98			903	2276	670	1.63	
15:00		1,016	2636	1070	1.82			984	1487	242	0.88	
20:00		526	2043	110	2.05			526	666	25	0.66	

Table A4. SH 6 WB -- West of SH 288 (652-V in Manvel). Hurricane Rita and Ike

HOUR START	WB Typical 2005 Avg Wkday	— Hurricane Rita — 9/21/2005 Wednesday	9/22/2005 Thursday	Index	Typicla 2008 Avg Wkdy	— Hurricane Ike - evac Southeast TX - 9/11/2008 Thursday	9/12/2008 Friday	Index
5:00	216	692	1116	4.19	271	282	96	0.70
10:00	508	1417	652	2.04	480	1036	536	1.64
15:00	601	1583	210	1.49	641	1452	235	1.32
20:00	346	1148	114	1.82	537	594	22	0.57

Table A5. SH 6 NB -- South of US 59 (568-X in Sugarland). Hurricane Rita and Ike

HOUR START	NB Typical 200… Avg Wkday	--- Hurricane Rita --- 9/21/2005 Wednesday	9/22/2005 Thursday	Index	Hurricane IKE Typical 2008 Avg Wkdy	9/11/2008 Thursday	9/12/2008 Friday	Index
5:00	355	457	1344	2.54	433	480	246	0.84
10:00	1,630	1986	908	0.89	1677	1981	1324	0.99
15:00	1,750	1510	1034	0.73	1777	1806	738	0.72
20:00	1,151	1797	423	0.96	1122	1076	96	0.52

Table A6. SH 6 NB – North of US 59 (568-X in Sugarland). Hurricane Rita and Ike

		NB	— Hurricane Rita —			Hurricane IKE			
		Typical 2005	9/21/2005	9/22/2005		Typical 2008	9/11/2008	9/12/2008	
HOUR		Avg Wkday	Wednesday	Thursday	Index	Avg Wkdy	Thursday	Friday	Index
START									
5:00		338	388	1418	2.67	360	399	202	0.83
10:00		1,330	1740	880	0.98	1393	1804	1094	1.04
15:00		1,720	1784	974	0.80	1963	2116	705	0.72
20:00		1,163	1769	348	0.91	1318	1096	94	0.45

Table A7. SH 6 NB -- North of Memorial (488-A in Houston). Hurricane Rita and Ike

		NB	--- Hurricane Rita ---			Hurricane Ike--			
		Typical 2005	9/21/2005	9/22/2005		Typical 2008	9/11/2008	9/12/2008	
HOUR		Avg Wkday	Wednesday	Thursday	Index	Avg Wkdy	Thursday	Friday	Index
START									
5:00		1,125	456	602	0.47	985	1135	306	0.73
10:00		1,458	1708	604	0.79	1003	1564	1106	1.33
15:00		2,004	1978	1170	0.79	1306	2400	855	1.25
20:00		1,283	1514	530	0.80	919	932	259	0.65

Table A8. SH 36 – South of US 59 (604-Y in Rosenburg). Hurricanes Rita and Ike

HOUR START	NB Typical 2005 Avg Wkday	--- Hurricane Rita --- 9/21/2005 Wednesday	9/22/2005 Thursday	Index	Typical 2008 Avg Wkdy	--- Hurricane Ike - evac Southeast TX --- 9/11/2008 Thursday	9/12/2008 Friday	Index
5:00	206	284	1059	3.26	189	381	110	1.30
10:00	427	1042	632	1.96	507	1080	734	1.79
15:00	451	1225	306	1.70	520	578	246	0.79
20:00	331	1008	132	1.72	429	449	32	0.56

Table A9. SH 36 – North of US 59 (604-Y in Rosenburg). Hurricane Rita and Ike

HOUR START	NB Typical 2005 Avg Wkday	--- Hurricane Rita --- 9/21/2005 Wednesday	9/22/2005 Thursday	Index	Hurricane Ike-- Typical 2008 Avg Wkdy	9/11/2008 Thursday	9/12/2008 Friday	Index
5:00	320	146	193	0.53	433	336	47	0.44
10:00	461	770	129	0.98	474	674	115	0.83
15:00	642	1460	45	1.17	587	294	42	0.29
20:00	307	480	27	0.83	274	88	3	0.17

Table A10. SH 6 NB @ Hempstead Road [408-C] Hurricane Rita and Ike

		NB	--- Hurricane Rita ---					Hurricane Ike			
		Typical 2005	9/21/2005	9/22/2005				9/11/2008	9/12/2008		
HOUR		Avg Wkday	Wednesday	Thursday	Index		Avg Wkdy	Thursday	Friday	Index	
START											
5:00		772	216	692	0.71		1047	991	376	2.71	
10:00		1,430	1835	688	2.37		1297	1398	1062	1.27	
15:00		1,455	1752	1171	1.37		1315	1361	638	2.10	
20:00		1,035	1443	576	2.15		929	835	190	4.64	