Development of a Dynamic Traffic Assignment Model to Evaluate Lane-Reversal Plans for I-65

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UTCA Report Number 07408
May 2010

Technical Report Documentation Page

1. Report No FHWA/CA/OR-	2. Government Accession No.	3. Recipient Catalog No.

4. Title and Subtitle Development of a Dynamic Traffic Assignment Model to Evaluate Lane-Reversal Plans for I-65	5. Report Date May 2010 6. Performing Organization Code
7. Authors Virginia P. Sisiopiku, Andrew Sullivan, Abdul Muqueet Abro, Michael Shinouda, Kyriacos Mouskos, Curtis Barrett	8. Performing Organization Report No. UTCA Report 07408
9. Performing Organization Name and Address Department of Civil, Construction & Environmental Engineering The University of Alabama at Birmingham 1075 13th Street South Birmingham, AL 35294-4440	10. Work Unit No. 11. Contract or Grant No. 930-670R
12. Sponsoring Agency Name and Address Alabama Department of Transportation 1100 John Overton Drive Montgomery, AL 36110	13. Type of Report and Period Covered Final Report 1/1/06-12/31/09 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This report presents the methodology and results from a project that studied contra-flow operations in support of hurricane evacuations in the state of Alabama. As part of this effort, a simulation model was developed using the VISTA platform for I-65 from the Alabama Gulf Coast region to Montgomery, AL and alternate evacuation routes. The model was used to test the current lane-reversal plan under a variety of evacuation scenarios and assess the potential impacts of modifications to this plan. Special attention was given to the development of realistic evacuation demand profiles to account for user preferences and seasonal (tourist) demand. The report discusses traffic and evacuation data requirements and acquisition, model development and calibration approach, evacuation scenarios considered and results from the systems analyses and scenarios evaluation. Moreover, it highlights some of the challenges in the development of large scale mesoscopic model for evacuation analyses. A summary of recommendations is also included that can be used to improve current practices and assist future traffic management under evacuation conditions.

17. Key Words Hurricane Evacuation, Contra-Flow Operations, Lane Reversal, I-65, Alabama	18. Distribution Statement

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No of Pages	22. Price
Unclassified	Unclassified	63 pages	

Form DOT F1700.7 (8-72)

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Executive Summary

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The report discusses traffic and evacuation data requirements and acquisition, model development and calibration approach, evacuation scenarios considered, and results from the systems analyses and scenarios evaluation. Moreover, it highlights challenges in the development of large-scale mesoscopic model for evacuation analysis. A summary of recommendations is also included that can be used to improve current practices and to assist future traffic management under evacuation conditions.

The results from the analysis provided insights on the effectiveness of existing lane-reversal operations and potential impacts from changes to used procedures. It was found that evacuation from Mobile and Baldwin counties under Category 1-2 hurricanes can be accomplished without the need of lane reversals, thus saving time and resources.

Section 1
Introduction

1.1 Background

Natural disasters occur throughout the world, and evacuation of people from the affected area is often required. Some disasters occur quickly, and evacuation before the event is not possible. Tornados are one example of this type of natural disaster. Tornados develop quickly and require taking shelter, rather than attempting to evacuate the area. Earthquakes are another type of natural disaster that do not offer the opportunity to move people to safety before the incident occurs. Flash flooding also occurs quickly and without warning, providing no chance to evacuate the area in an organized manner before the disaster occurs.

On the other hand, some types of natural disasters do offer the opportunity to plan for evacuations that occur prior to the event striking the area. One such natural disaster is a large-scale fire. Wildfires, such as those seen in California, usually afford citizens enough time to evacuate an area before it is hit by the fire. Also, flooding downstream from large rain events can sometimes be foreseen, and therefore evacuation plans can help get people to safety before the disaster strikes. Tsunamis generally occur quickly, without warning in the area closest to the earthquake origin. However, monitoring has become more diligent and warnings sent out more readily in response to the Asian tsunami in December 2005. Therefore, governments may have enough warning to implement evacuations of coastal areas before a tsunami strikes.

Hurricanes are unique in that they almost always provide enough warning time to adequately evacuate an area to minimize casualties and damage. Hurricanes are the type of natural disaster that is addressed in this report as they often affect coastal areas in the state of Alabama. However, the methods discussed in this study and the evacuation strategies evaluated could be applied to any situation that offers lead-time to evacuate ahead of the disaster.

1.1.1 Hurricanes and Evacuations

Hurricanes are prevalent in the Atlantic Ocean and Gulf of Mexico. The US states that border these bodies of water are vulnerable to intense destruction from hurricanes. Thus, governments and transportation-planning agencies must plan and prepare for the evacuation of residents of these areas in case of an impending hurricane.

The Saffir-Simpson Hurricane Scale is used to rate a hurricane's intensity. The scale ranges from 1 to 5, and is seen in Table 1-1. The scale is used to estimate the damage and flooding expected from a storm. Wind speed is the determining characteristic of classification. Wind speed is used instead of storm surge because storm surge varies greatly depending on the shape of the coastline and slope of the continental shelf at the landfall location (NOAA 2007). The hurricane is recorded based on the intensity it maintains as it reaches landfall.

Table 1-1. Saffir-Simpson Hurricane Scale (NOAA 2007)

Category	Wind Speed (mph)	Estimated Storm Surge (ft)	Damage
1	74 – 95	4 – 5	Minimal
2	96 – 110	6 – 8	Moderate
3	111 – 130	9 – 12	Extensive
4	131 – 155	13 – 18	Extreme
5	> 155	> 18	Catastrophic

An average of five hurricanes make landfall on the United States coast between Maine and Texas every three years, killing 50 to 100 people. Prior to the ability to forecast hurricanes and evacuate people in harm's way, high casualty and injury rates could occur when a hurricane came ashore. Approximately 8000 people lost their lives in a category 4 hurricane that came ashore in Galveston, Texas, on September 8, 1900. In September 1926, residents were warned of the "Great Miami" Hurricane only hours before the eye of the storm entered Miami, Florida. The category 4 storm caused almost 400 fatalities and more than 6000 casualties (NOAA 2007).

However, with improvements in forecasting come the opportunity and obligation to evacuate before disaster strikes, and thus to save lives. Hurricane Hugo made landfall as a category 4 storm in South Carolina in September 1989, resulting in only 21 deaths. Hurricane Ivan made landfall in September 2004, with the eye of the storm passing just west of the center of Gulf Shores, Alabama.

To facilitate the evacuation process the state of Alabama used reverse-laning on Interstate 65 (I-65), the main thoroughfare leaving the Gulf coast. Twenty-five deaths in the US were attributed to Hurricane Ivan (NOAA 2007). It is evident that the ability to forecast approaching hurricanes and evacuate coastal areas results in increased safety for residents and visitors. Further illustrating this point is the large death toll from Hurricane Katrina, which made landfall on the US Gulf Coast in September 2005. Katrina caused record-breaking damage and casualties and is responsible for 1,200 deaths, many of which resulted from poor evacuation planning (NOAA 2007).

1.1.2 Reverse-Laning

In recent years, reverse-laning has gained popularity in emergency-evacuation procedures, especially in the Gulf Coast states. Reverse-laning is also known as contra-flow. One of the main benefits of using contra-flow operations is the ability to maximize the number of lanes used to evacuate people from the coastal area. Many southeastern US states have planned for and modeled contra-flow techniques for evacuation of coastal areas. However, since this technique is still relatively new in emergency-management procedures, further studies should be done to assess the effectiveness of reverse-laning in different scenarios and the accuracy of existing procedures.

Reverse-laning procedures almost always occur on controlled-access highways. In fact, most contra-flow plans operate on divided four-lane controlled-access highways "such that traffic in all four lanes is traveling away from the coast toward inland destinations where the dangers posed by the approaching hurricane are significantly reduced" (Ballard 2006). Reverse-laning can also be implemented such that one lane remains in normal operation, carrying traffic toward the coast.

An important consideration in reverse-laning is the termination point, or inland terminus. The inbound traffic is twice the normal flow and must be distributed to minimize congestion. This can be accomplished by locating the terminus at a freeway interchange with direct-connect ramps with a crossover just past the interchange for through traffic. Another method is to use multiple termini directing each lane of contra-flow to a separate exit (Ballard 2006). Based on infrastructure and traffic needs, the termini should be selected to minimize congestion and driver confusion.

1.2 Project Motivation and Problem Statement

The concept of reversing traffic lanes for evacuation purposes in the case of emergency or disasters has received a lot of attention in recent years. The necessity and efficiency of capacity reversibility is a topic of interest for transportation and emergency-management agencies and the scientific community. The concept was successfully implemented by Georgia and South Carolina while it was rejected by Florida as a response during Hurricane Floyd. In recent years, a number of southern coastal states introduced disaster-management plans that included reversing traffic lanes for evacuation. In implementation, there are still ongoing discussions about the feasibility and operationality of contra-flow designs.

In 2000 ALDOT developed a plan for reversing the southbound lanes of I-65 during hurricane evacuations. Since then, the lane-reversal plan has been implemented twice: during Hurricane Ivan on Wednesday, September 15, 2004, and again during Hurricane Dennis on Saturday, July 9, 2005. During Ivan, the lane reversal was ordered by the governor and implemented by ALDOT shortly thereafter. During Dennis, the decision to implement the lane-reversal plan was made by ALDOT with the concurrence of the governor.

It is generally agreed by ALDOT and the public that in both cases the lane-reversal plans were implemented smoothly and effectively moved people out of the evacuation areas. Still, a need was identified to evaluate the effectiveness of the current plan and to consider potential improvements. This project developed a model and performed a detailed analysis of current and alternative reverse-laning strategies to evaluate the following:

a) The impacts of I-65 lane reversals on network performance under evacuation.
b) The effect of reversal duration on evacuation performance.
c) Alternate termini for the reversal plan and their impacts on local traffic.
d) The impacts of unexpected events and appropriate responses.

1.3 Objective

The purpose of this project was to develop a Dynamic Traffic Assignment (DTA) model that would allow ALDOT to evaluate the current lane-reversal plan for I-65 under a variety of evacuation scenarios and to assess the impact of potential modifications to this plan. The model included major evacuation routes from the Mobile and Alabama Gulf Coast region north to Selma and Montgomery and estimated evacuation times, traffic volumes, and travel speeds on those routes. The developed model was used to perform off-line analyses. Ultimately, the model can be expanded to allow ALDOT to use traffic-count data collected during evacuations to assess responses in real time to unforeseen events such as accidents, excessive congestion, or bridge closures.

1.4 Work Contribution

Because hurricane evacuations are relatively infrequent events, it is difficult for any transportation, planning, or homeland-security agency to test procedures prior to implementation. The development of the detailed evacuation model in this study allows ALDOT and other related agencies to evaluate alternatives, assess potential modifications to current evacuation plans, and develop effective plans to respond to incidents. Moreover, the project provides ALDOT with a tool for planning and optimizing evacuation plans in the future. In the long term, the model can be used for a variety of planning purposes, including refining evacuation measures on other state routes (e.g. evaluating the impact of new signal timings or the benefits of lengthening or staggering evacuation times).

1.5 Organization of the Report

This report is organized into seven sections. Following the Introduction in Section 1, Sections 2 and 3 provide an overview of the state of practice of contra-flow operations and evacuation modeling, respectively. A summary of the Alabama lane-reversing plan is offered in Section 4. Section 5 describes the study methodology, in which details about the study approach, model-selection criteria, study test bed, and experimental scenarios are illustrated. Section 6 provides a summary and interpretation of the simulation results, and Section 7 presents project conclusions and recommendations for further study.

Section 2
Overview of State of the Practice

Since 1998 there have been several developments to improve evacuation traffic flow and route capacity. These changes can be directly attributed to the involvement of highway and transportation agencies. The most notable of these are (PBS&J 2000b):

a. The use of contra-flow operations to increase the capacity of evacuation routes.
b. The application of intelligent transportation systems (ITS) to collect and communicate up-to-date traffic information.

Such information can be used to help control and reroute traffic, provide decision support, and inform evacuees and the media of current conditions.

The following sections provide a summary of information on contra-flow operations and evacuation modeling based primarily on input from a report compiled by Wolshon, *et al*. (2001) and a paper by Waid, *et al*. (2008).

2.1 Contra-Flow Operations Background

Contra-flow, or reverse laning as it is also commonly known, involves the reversal of traffic flow in one or more of the inbound lanes (or shoulders) for use in the outbound direction with the goal of increasing capacity. Contra-flow was implemented for the first time in Georgia during Hurricane Floyd in 1999 with mixed, though overall positive, results. Contra-flow was also improvised in South Carolina during Floyd, after a strong public outcry came from evacuees trapped in congestion on I-26 from Charleston to Columbia. In 1998 only the Florida and Georgia DOTs had plans in place to reverse the flow on their interstate freeways to expedite evacuations. Today, 11 of the 18 mainland coastal states threatened by hurricanes plan to use some type of contra-flow evacuation strategy.

Contra-flow types and their associated benefits, costs, and inherent difficulties are discussed in several recent reports (FEMA 2000, PBS&J 2000b, and Wolshon 2001). While contra-flow is widely viewed as the best way to increase outbound flow during evacuations, it is not a cure-all solution. In fact, the true costs and benefits of contra-flow in terms of its capacity improvements, safety, and manpower requirements remain largely unknown.

Four variants of contra-flow are planned for use. They include: all lanes reversed; one lane reversed and one lane with inbound flow for emergency/service vehicle entry only; one lane reversed and one lane with normal flow for inbound traffic entry; and one lane reversed with the use of the left shoulder of the outbound lanes. Because it offers the largest increase in capacity, the most common contra-flow strategy is to reverse all inbound lanes to the outbound direction. One study estimated that a full reversal would provide a near 70% increase in capacity over conventional two-outbound-lane configurations (FEMA 2000).

Though not as widely planned, single-lane contra-flow strategies are also proposed. Single inbound lane reversals are thought to increase outbound road capacity by about 30%. The main advantage of this strategy is its ability to maintain a lane for inbound law-enforcement personnel and emergency-service vehicles, critical for clearing incidents. It can also permit access for people who want to move against the evacuation traffic. A major drawback of single-lane reversals is that it raises the potential for head-on accidents.

Another strategy to improve capacity is to use the outbound left shoulder as an additional outbound lane. This has been estimated to increase capacity by only about 8% (FEMA 2000). The capacity increase depends on the width and condition of the shoulder, since flow rates are decreased and drivers tend to reduce speeds when they are laterally constrained. Two additional concerns associated with the use of shoulders are pavement suitability and bridge widths. Shoulders are typically designed with a thinner pavement cross-section and greater cross-slope. They may not be able to withstand prolonged traffic loading and still provide an inadequate riding surface. Cross-section width can be a problem on bridges. Many freeway bridges, particularly older ones, have been constructed with narrow shoulders or no shoulders. If shoulders were used as outbound lanes, these locations would create bottlenecks, causing additional congestion as vehicles merge back into the through lanes.

2.2 Hurricane Evacuation Procedure Case Studies

In recent years, reverse-laning has gained popularity in hurricane-evacuation procedures, and many states have planned for and modeled contra-flow techniques for evacuation of coastal areas. Table 2-1 provides a summary of planned contra-flow evacuation routes from a number of states across the United States. The following sections provide a brief overview of selected case studies from states in the southeastern United States that have developed and implemented hurricane-evacuation procedures in recent years.

2.2.1 Florida

Florida presents unique challenges due to its shape and location. The entire state is vulnerable to hurricanes. Over 11 million people live within 10 miles of Florida's coast (Collins 2003). Therefore, to minimize traffic congestion and make evacuations more efficient, targeted evacuations are important, meaning only citizens who are in harm's way should evacuate and all others should not be on the road. This is especially challenging since hurricanes can change course and intensity.

Florida is leading the way in using ITS technology in evacuation procedures and planning. Motorist call boxes cover over 85% of the evacuation routes. Other ITS technology used includes closed-circuit television (CCTV), vehicle-detection sensors, road rangers, dynamic message signs (DMS), and highway advisory radio (HAR) (Collins 2003). These technologies are important for collecting traffic data and disseminating information to the public during normal and emergency operating conditions.

Table 2-1. Planned contra-flow evacuation routes (Wolshon 2001)

State	Route	Approx. Distance (miles)	Origin	Termination
Alabama	I-65	135.	Mobile	Montgomery
Florida	I-10 Westbound	180.	Jacksonville	Tallahassee
	I-10 Eastbound	180.	Pensacola	Tallahassee
	I-4 Eastbound	110.	Tampa	Orange County
	I-75 (Alligator Alley)	100.	Coast	Coast
	I-75 Northbound	85.	Charlotte County	I-275
	FL Turnpike	75.	Ft. Pierce	Orlando
	SR 528 (Beeline)	20.	SR 520	SR 417
Georgia	I-16	120.	Savannah	Dublin
Louisiana	I-10/I-59 (east/north)	115.	New Orleans	Hattiesburg, MS
	I-10 Westbound	25.	New Orleans	I-55
Maryland	MD-90	11.	Ocean City, MD	US 50
New Jersey	Atlantic City Expressway	44.	Atlantic City	Washington Twp
	72/70	29.5	Ship Bottom Boro	Southampton
	138/I-195	26.	Wall Twp	Upper Freehold
	47/347	19.	Dennis Twp	Maurice River Twp
	35	3.5	Mantoloking Boro	Pt. Pleasant Beach
North Carolina	I-40	90.	Wilmington	Benson (I-95)
South Carolina	I-26	95.	Charleston	Columbia
Texas	I-37	90.	Corpus Christi	San Antonio
Virginia	I-64	80.	Hampton Roads Bridge	Richmond

Note: The Delaware; Virginia; and New Orleans, LA, to Hattiesburg, MS, contra-flow plans are under development.

The Florida Department of Transportation (FDOT) has installed permanent traffic-count stations, which are used for monitoring travel speeds along evacuation facilities. Average travel speed is the best indicator of traffic congestion in an evacuation (PBS&J 2002). In addition to speed, the FDOT traffic counters provide hourly vehicle counts, which can be compared with historical numbers for that specific day and time. Each counter can sense vehicles in both directions and therefore can be used in contra-flow conditions. Some of these have live video camera viewing capabilities (Collins 2003). These traffic counters provide many operational uses. They allow officials to alert communities upstream of evacuation traffic regarding arrival times and potential number of evacuees to expect on roadways and in shelters. Another important benefit is the ability to inform evacuees and disseminate information to the public regarding traffic congestion and the presence of incidents on the roadways. These traffic counters also monitor the actual status on a real-time basis to predict clearance times (Collins 2003). Traffic conditions are also monitored through Civil Air Patrol and highway patrolmen stationed at strategic locations (PBS&J 2002).

FDOT recognizes the importance of implementing evacuation shutdown conditions on evacuation routes, specifically I-95 and I-10 (PBS&J 2002). Shutting down the roads involves advising evacuees to stop entering the highways. Determining the time to shut down the roadways is important so that evacuees are not stranded on the roads when the storms arrive. It is important to note that strong winds occur far ahead of the actual landfall of the eye of the storm. Therefore, during an evacuation, officials will need to determine when to shutdown the evacuation routes. The current planning models are static and do not take into account driver behavior when calculating clearance times. However, it is important to base the shutdown decision on actual traffic conditions and not on modeled predictions (PBS&J 2002).

Since 2000, Florida has worked toward the development of a "next generation" version of the Emergency Transportation Information System (ETIS) Program (Collins 2003). This program is called the Hurricane Evacuation Analysis and Decision Support Utility Program (HEADSUP) and it is much more detailed than the traditional ETIS program. The goal of the program is to proactively manage traffic during an evacuation.

HEADSUP records real-time traffic data from the traffic counters on Florida's highways to analyze traffic conditions during evacuation and aide emergency managers in making decisions (FHWA 2005). Features of the HEADSUP program include hourly dynamic travel demand forecasts, the impact of reverse-laning procedures, and a map-based user interface. HEADSUP can be used to support the timing of evacuation decisions, especially in multi-regional events. It can recommend alternative routes to drivers to avoid congestion and can also be used to predict demand on shelters. HEADSUP can test how effective various evacuation scenarios are before implementation and support recommendations to the governor by emergency managers. It can also help determine when to start evacuation shutdown procedures (FHWA 2005).

Hurricane Floyd in 1999 forced approximately two million Florida residents to evacuate. Although, fortunately, no Florida residents were injured, the mass evacuation resulted in the forming of a Governor's Hurricane Task Force (Clark and FDOT 2003). The assignments set forth for the task force were to identify bottlenecks in the evacuation routes and to assess the need and feasibility of reverse-laning. As a result of the meetings, possible contra-flow routes were determined, bottlenecks were identified, and other evacuation issues, such as shelters and public information, were addressed (Clark 2003).

Certain decision-making criteria were established to access the need for reverse-laning. First, it must be determined whether the regional evacuation plan would be sufficient without reverse-laning operations. It was agreed that a sufficient hurricane threat for considering contra-flow traffic is a category 4 or 5 hurricane impacting at least one region of the state. There should also be sufficient time to implement the plan, meaning the tropical-storm (TS) winds would be at least 25 hours from the coast of Florida. State and local emergency managers together must make the decision that a greater number of residents will be threatened by not implementing the reverse-laning procedure (Clark 2003).

Six routes were determined suitable for reverse-laning. These routes represent portions of highways from across the state (FDOT 2007):

- I-75 from Ft. Myers to Sarasota
- SR 528 from SR 520 to SR 417
- I-10 from Jacksonville to Tallahassee
- Florida's Turnpike from Ft. Pierce to Orlando

- I-4 from Tampa to Orlando
- Alligator Alley from coast to coast, east and west

Several steps were taken to prepare the state for the contra-flow procedures. A detailed timeline was developed for contra-flow operations in the state. The timeline determined for contra-flow operations is as follows (Clark 2003):

- Forty-nine (49) hours before TS-force winds reach the state, the Florida National Guard and other agencies will be notified to prepare for contra-flow operations.
- Twenty-five (25) hours prior to TS-force winds, recommendations from several agencies, including FDOT, are presented to the governor. The governor then finalizes the decision, and state agencies begin to implement the plan.
- Seventeen (17) hours before TS-force winds, contra-flow must be implemented for maximum benefit.
- Four (4) hours prior to TS-force winds, the termination of contra-flow must begin for people to seek shelter. It is the absolute latest time for termination.

Emergency crossovers were constructed to cross medians into contra-flow lanes. In-place signage was installed. Real-time traffic counters were used for monitoring contra-flow. Items such as cones, barricades, portable signs, DMS, and portable light towers were also used (Clark 2003). Having to address issues of hurricane evacuation relatively frequently, the state of Florida serves as a good case study when preparing a hurricane evacuation plan.

2.2.2 North Carolina

The North Carolina Department of Transportation (NCDOT) has also emphasized developing and improving its emergency-management practices. Detailed evacuation plans and reverse-laning procedures have been designed for evacuation of the coastal areas. These efforts have been coordinated with other states, including Florida, Georgia, South Carolina, and Virginia (Hutchinson 2003). Such coordination becomes especially important when a hurricane's projected path is large or the hurricane itself is so large that it affects multiple states.

Citizens are informed using traditional and ITS methods. Local television and radio broadcast information to the public. Press releases are used to inform citizens of upcoming evacuations and of reverse-laning implementation. Brochures and posters are used to educate citizens ahead of time, using illustrations and providing information needed during an evacuation, such as routes and shelters. Moreover, portable DMS and HAR are used for distributing information. The use of CCTV and weather stations is planned. These technologies can be used for the determination and evaluation of evacuation and re-entry plans (Hutchinson 2003).

North Carolina operates reverse-laning during evacuations on I-40 away from the coast. The decision to reverse lanes must be made and coordination among agencies must begin at least 48 hours prior to an expected mandatory evacuation (Hutchinson 2003). A firm decision of whether to reverse lanes must be made at least twelve hours before the reversal begins. To determine when to reverse the lanes, emergency management models are used. These models predict a storm's characteristics, including expected intensity and landfall location and time (Hutchinson 2003).

Criteria for contra-flow have been determined by the NCDOT. First, it is preferable that reverse-laning occur during daylight hours. Police officers and NCDOT officials shall be present at each interchange. NCDOT employees are also expected to be present at rest areas to assist motorists. Incident Management Assistance Patrols should be active and patrolling the areas. Finally, reverse-laning must end at least two hours before gale force winds begin (Hutchinson 2003).

2.2.3 Georgia

Georgia has also implemented techniques to enhance emergency-management and evacuation procedures. There are 33 designated evacuation routes in Georgia. These marked routes direct drivers inland, away from the danger of a hurricane (Poole 2003). Reverse-laning is used on a portion of I-16, a major interstate in the state, to move traffic from the coast more efficiently. The Georgia Department of Transportation (GDOT) has also recognized the need to coordinate for hurricane preparedness with the railroads (Poole 2003). Not only are the railroads also vulnerable to hurricanes, but they can be used for emergency-management purposes.

Another feature that the state of Georgia uses to make evacuation more efficient is push-button traffic-control devices (Poole 2003). Each district in the state's evacuation route has identified the critical intersections that are signalized where traffic flow is heavy and in both directions. Local law enforcement officials manually control the signal timing through the push-button apparatus.

Disseminating needed information to the public is also a priority of GDOT. For that purpose, evacuation routes are clearly marked with signage. Also, Georgia public radio provides motorists with information regarding evacuation routes and road conditions. Furthermore, DMS are used to indicate closures and openings of roadways and exits, as well as to advise on locations for gas, food, and other necessities (Poole 2003).

Definition of the re-entry criteria is as important as a well-managed evacuation. Re-entry must be controlled and planned for carefully. Roads and bridges must be evaluated for safety and damage before allowing motorists to use them. Also, ferry boats might be useful in a situation where a bridge has been too heavily damaged for use (Poole 2003).

Georgia also uses reverse-laning techniques on I-16 from the Atlantic coast during evacuations. Median crossovers have been installed along the route to move vehicles into the contra-flow lanes. The GDOT also uses drop-gate barriers placed at ramp locations along the interstate. These gates are similar to railroad-crossing gates and are used to prevent vehicles from entering the interstate during contra-flow operations. Using these gates reduces the amount of manpower needed to control reverse-laning operations, thus freeing these personnel to assist in other emergency-management tasks.

2.2.4 South Carolina

South Carolina set out to improve evacuation plans after Hurricane Floyd in 1999. It should be emphasized that South Carolina's evacuation plans are not designed to move the entire coastal population. Instead, they are intended for the evacuation of those citizens on the coast and along inland waterways who are most vulnerable to storm surge and of those living in mobile and manufactured homes, which are the most susceptible to wind damage. The goal is to move the citizens most at risk to the nearest safe location. Evacuations should be timed to clear the evacuating population before sustained 40 mph winds arrive (Dorchester County ESD 2004). It is important not to time the evacuation for the landfall of the eye of the hurricane, since half the hurricane will have already made landfall at that point. It is also important to take into account the tourist population along the coast when modeling and predicting evacuation times because the coastal population of South Carolina increases nearly 40% during tourist season (Bowman and Harrelson 2003).

ITS technologies are used by the South Carolina Department of Transportation (SCDOT) during evacuations. Incident-management trucks are dispatched for incident response. Both portable and permanent DMS are used for information dissemination. HAR is also used in numerous locations. Many CCTV cameras are used to monitor roadway conditions, and some are equipped with side-fire radar to detect speed. Automatic traffic recorders are also used. A state and four district traffic-management centers (TMCs) and a state Emergency Operations Center (EOC) all coordinate to collect, share, and use transportation and emergency data (Bowman 2003).

SCDOT found that their modeled evacuation routes tended to underestimate the clearance time of the network. One of the factors contributing to increased evacuation clearance times, above modeled predictions, is the occurrence of "shadow evacuations" (Dorchester County ESD 2004). Shadow evacuations occur when more people than those determined as vulnerable to the hurricane threat attempt to evacuate. The unexpected increase in traffic can lead to heavy congestion.

To prepare for future evacuations South Carolina developed a system to monitor hurricane-evacuation traffic conditions in real-time called the Intergraph System. This software can extract traffic information from counting stations throughout the state and monitor actual traffic conditions (FHWA 2005). This can help determine how successful an evacuation is while it is progressing. If an area of congestion is identified, officials can intercede with traffic to divert flow to alternate routes. The system can also be used to compare evacuation data to normal conditions to aid in developing evacuation plans. The Intergraph System can also access weather information and camera shots for some roadways. As of 2005, South Carolina had plans to make the Intergraph System accessible over the internet during evacuations to emergency response officials on all levels to enhance information sharing and planning (FHWA 2005).

South Carolina also uses lane reversal in certain instances to increase the capacity of evacuating roadways. Interestingly, not all of South Carolina's evacuation routes use all the lanes. In several of the reverse-laning evacuation routes lanes are left to normal operation to accommodate traffic flow in both directions (SCDOT 2007). Reversing the lanes on the interstate is considered a high priority for category 2 or greater hurricanes. Upon implementing reversal, it takes two hours to place the barricades and another two hours to flush the traffic on the roadway. The entrances and exits should be limited.

SCDOT uses SIM Traffic Animation to model evacuation traffic. Using reverse-laning for return traffic is also an option considered by SCDOT (Bowman 2003). Folded signs are used on the contra-flow side of the highway. These signs can be unfolded during reverse-laning to inform and direct traffic (Bowman 2003). SCDOT also provides extra portable toilets and bottled water at rest areas and weigh stations when lanes are reversed (Dorchester County ESD 2004).

2.2.5 Alabama

The current Alabama evacuation routes are designed to evacuate Alabama residents from Mobile and the Gulf coast, as well as to accommodate evacuees from Mississippi and Florida. Alabama's evacuation routes are published on the Alabama Department of Transportation (ALDOT) website and on informational brochures available at state rest areas.

In response to the needs of the traveling public in emergency evacuation situations, ALDOT has developed a detailed reverse-laning plan that details the logistics involved in reversing one lane of traffic on Alabama State routes to facilitate evacuation traffic flow (ALDOT 2008). Alabama established contra-flow procedures on I-65 in 2000, and ALDOT continues to perform tabletop exercises and to refine its plans. The plan has been successfully implemented twice: during Hurricane Ivan in September 2004 and Hurricane Dennis in July 2005. ALDOT officials intended to time the contra-flow operations based on predetermined traffic-flow thresholds. However, the policy was changed in response to Hurricane Ivan and is now a schedule-based plan of operations. The schedule-based option allows for better preparations by ALDOT staff and limits reverse-laning to daylight hours (Ballard 2006). This increases safety due to the unavoidable unfamiliarity of the route to drivers.

Several evacuation routes were considered for reverse-laning, but it was determined that I-65 was the only suitable route (ALDOT 2006). I-65 is a limited-access interstate, and therefore traffic entering and leaving the roadway is easier to control than on an open-access route (Figure 2-1). The southern terminus of the contra-flow is just north of Mobile – between the Delta River Bridges, which span the Mobile and Tensaw Rivers – and the intersection of Alabama Route 225 and I-65. The northern terminus is located just south of Montgomery in the area encompassing the US 80 West Selma (Exit 167) interchange and the US 82/US 80 East (Montgomery Southern by-pass) (Exit 168) interchange with I-65 (ALDOT 2006). Figure 2-2 shows the crossover at the northern terminus of I-65 contra-flow operations. Flip-down signs located on the southbound side of the interstate open to direct evacuating traffic.

Each crossover and access point has strict checklists that must be followed when contra-flow operations are ordered by the governor. The plan is implemented during daylight hours for a specified time period that is announced to the public in advance via radio and television broadcasts. Local officials also disseminate the information to the coastal public. At the beginning and end of contra-flow operations, a patrol car follows the last car to be sure that all traffic headed in the opposite direction has cleared. More details on the Alabama reverse-laning plan are available in Chapter 4.

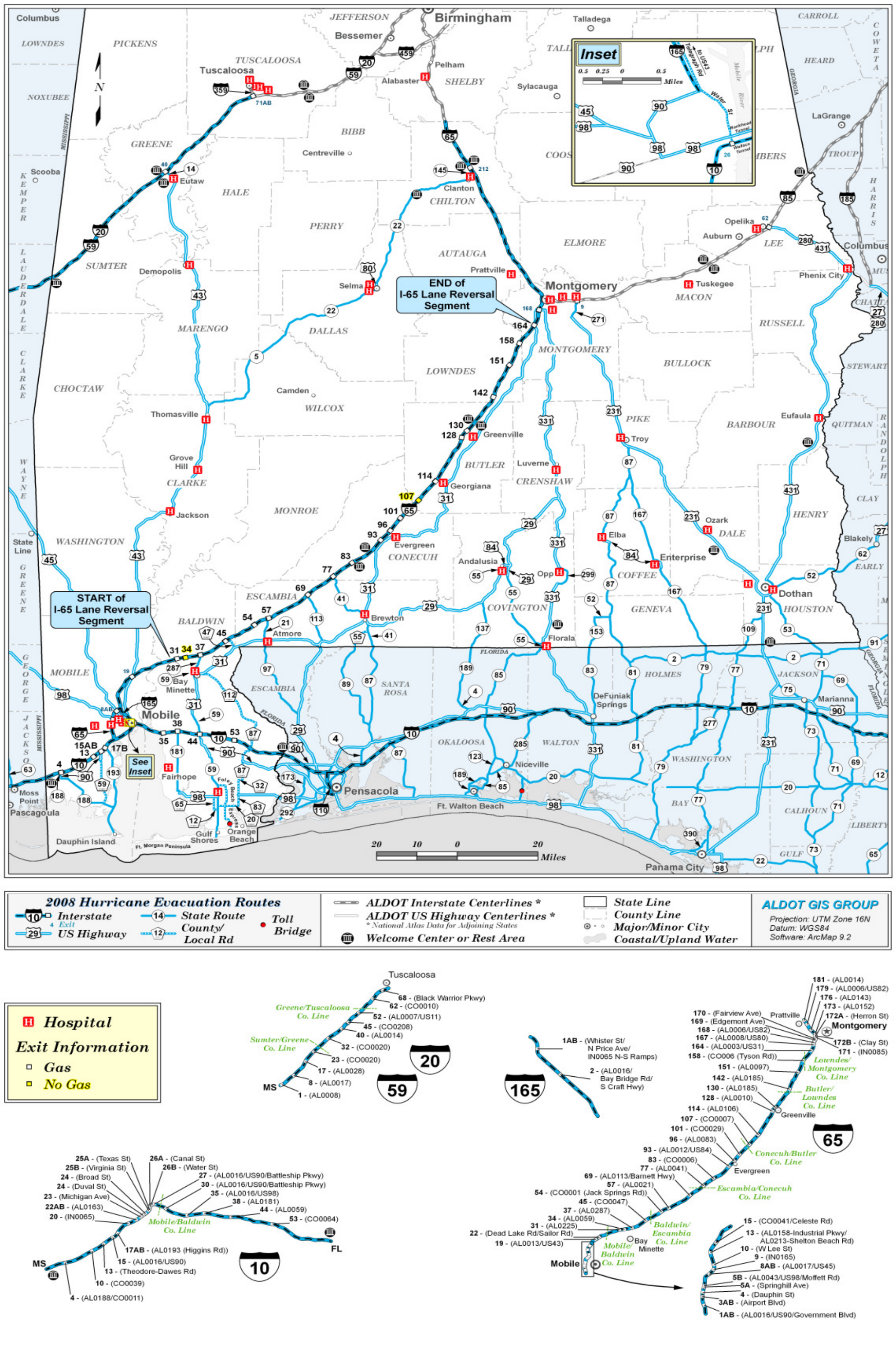

Figure 2-1. 2008 hurricane evacuation routes in Alabama (ALDOT)

Figure 2-2. I-65 northern terminus crossover under contra-flow operations in Alabama

2.2.6 Lessons Learned

In the process of examining these case studies, it is important to note the lessons learned. First, targeted evacuations are important, meaning only citizens who are directly affected should evacuate and others should not be on the roadways. Increased congestion in evacuations is often a result of citizens not directly in harm's way unnecessarily evacuating. Having a detailed plan, set evacuation zones, and adequate public information dissemination are keys to avoiding this type of congestion problem.

Another important consideration is to time the evacuation properly. Strong winds from a hurricane occur long before the eye of the storm reaches land, which is designated the official landfall of the storm. In fact, half the hurricane has already passed by the time a hurricane makes "landfall." Therefore, evacuations should be timed such that clearance times are expected to occur well before damaging winds arrive.

It is also important to take into account the tourist population along the coast when modeling and predicting evacuation times. Tourist populations can be predicted based on the time of year and week. This increase in population cannot be overlooked because most coastal areas have tourists. These drivers are also more unaware of the area and are less likely to know about alternative routes without being informed.

ITS technologies are important to both the collection and dissemination of information to the public during hurricane evacuations. ITS applications have been heavily researched and expanded in the past decade. These functions provide excellent ways to collect information on the road and traffic conditions, as well as to provide invaluable ways to get the information to the public in a timely manner. Georgia's concept of push-button traffic-control devices at critical intersections activated manually during evacuations by local law-enforcement officials should be considered in an evacuation plan. This is a fairly simple way to increase capacity and to improve traffic flow.

Sometimes overlooked but just as important as evacuation procedures are the re-entry criteria. Re-entry must be planned for and controlled. Roads and bridges must be evaluated for safety and damage before allowing motorists to use them.

One of the most persistent problems observed in numerous evacuations in many states is that transportation professionals have stepped aside and waited while emergency managers, first-responder agencies, and others have developed and managed evacuation plans. While these various groups are extremely knowledgeable and in most cases are excellent at their jobs, they are rarely experts in understanding and accounting for many of the more subtle nuances of traffic planning, engineering, and operations. Highway agencies need to take a proactive management role in evacuations.

Another valuable lesson is understanding that no two evacuations will be the same with respect to the scope, size, and movement or location of the threat. Plans must be flexible so they can be adapted to meet a variety of conditions. From a traffic-planning and engineering perspective it has been shown that evacuation demand may change but roadway capacity is relatively fixed; and for plans to be effective, they should fully utilize whatever capacity exists. Contra-flow is one method to accomplish this goal; however, it will not solve all problems. When using contra-flow all management decisions at origins and destinations are linked and contra-flow segments cannot operate properly without efficient loading and unloading points. Strong evidence from the Ivan and Katrina evacuations indicates that contra-flow operations should begin as soon as possible. Some agencies in other states have stated that contra-flow would be used only when traffic volumes justify its use.

Last but not least, coordination among states is often essential, especially when implementing reverse-laning. Although reverse-laning may increase capacity on one route away from the coast, it may not be feasible to operate contra-flow under a large-scale, multi-state evacuation unless there is good coordination among the states. In addition to promoting communication among states and agencies, integration among transportation modes is also important. In cases where the capacity of an evacuation is more than the highway system can handle, other forms of transportation – such as railroads, airplanes, and ferries – can be used to transport people from harm's way (Waid, *et al*. 2008).

2.3 Contra-Flow Operation Reservations

Despite the advantages that contra-flow operations can bring to an evacuation, their disadvantages also need to be considered. Highway agencies agree that reverse-flow operations will likely be inconvenient and confusing for drivers. They expect contra-flow to be labor intensive to initiate and difficult to enforce. Decisions also should be made to determine managerial strategies such as who will decide when to use contra-flow? under what conditions will it start and end? how long it will last? and how safety, accessibility, convenience, enforcement, and cost be addressed?

Another issue of concern relates to the coordination of lane-reversal evacuation plans that cross state lines. For example, in Louisiana, plans for an evacuation of New Orleans call for contra-flow on I-59 leading north into Mississippi. To prevent a bottleneck from occurring at the Mississippi line, this requires that the contra-flow operation continue into Mississippi. These plans created considerable controversy in Mississippi because the manpower required to establish contra-flow on I-59 in Mississippi, estimated at 250 people, decreases the manpower available to provide services to Mississippi residents. To put this manpower demand in perspective, the Mississippi Highway Patrol has only about 350 officers. A second concern was related to the costs of implementing contra-flow in Mississippi. If Mississippi implements contra-flow on I-59 as a result of a Louisiana contra-flow evacuation decision but the hurricane changes course or weakens, federal funds may not be available to reimburse Mississippi for supporting the Louisiana evacuation. In this case, the State of Mississippi may be left paying part of the cost of a Louisiana evacuation (SAIC 2003).

Contra-flow increases the capacity of the evacuation route for which it is used, but it does not increase the capacity of the feeder roads for the evacuation route. In Texas, it was discovered that the feeder roads from Corpus Christi leading to the contra-flowed portion of I-37 were a bottleneck that prevented contra-flow I-37 from operating at full capacity. This finding was compounded by the fact that the Nueces River Bridge north of Corpus Christi could not be contra-flowed because it was the only viable southbound route for emergency vehicles entering the city. This meant that the primary feeder for the contra-flow portion of I-37 was the non-contra-flow portion of I-37 crossing the Nueces River Bridge (SAIC 2003).

It should be also noted that reverse-laning is still a relatively new emergency-management procedure, and thus further study is required to assess the potential effectiveness of reverse-laning under different scenarios and the helpfulness of existing strategies. Several agencies recommend that before implementing a contra-flow plan, it is important to conduct a network analysis to ensure contra-flow does relieve the traffic bottlenecks that might occur and thus is worth pursuing during evacuations.

Section 3
Evacuation Modeling Background

3.1 Evacuation Analysis Tools

One means of planning and preparing for evacuations involves the use of computer modeling. Since the 1970s modeling techniques have improved significantly, mainly as a result of faster and less-expensive computers and access to more and better evacuation data. Today, simulation programs are used to model weather, flooding, traffic flow, evacuation travel behavior, among others. The data that feed many of these programs have come from the inventory of hurricane evacuation studies (HESs). HESs were initiated in the 1980s by the Federal Emergency Management Agency (FEMA) to integrate key aspects of hurricane evacuation planning and to assist in disaster preparedness. An HES typically consists of the following:

- A storm-hazard and vulnerability analysis.
- An evacuee-behavior analysis.
- A sheltering analysis.
- A transportation analysis.

The hazard analysis identifies the areas that would need evacuation based on various storm tracks and intensities. The vulnerability analysis identifies the number of people and households occupying the threatened area and the structures that need to be evacuated. The behavioral analysis projects how the public will respond to the hurricane threat. The shelter analysis evaluates structures for safely housing the evacuees. The transportation analysis assesses street and road capacities and identifies critical links in the evacuation network (Wolshon, *et al*. 2001).

Several models have been developed for hurricane-evacuation traffic-flow analysis. It is interesting to note that many early models were initially developed to plan for other civil-defense emergencies, such as nuclear-missile attacks and nuclear-power-plant accidents. One of these programs, MASS eVACuation (MASSVAC), is a macro-level model developed to model nuclear-power-plant evacuations that was also applied to test operational strategies for hurricane evacuations in Virginia (Hobieka, *et al*. 1985). Another model of this type is the Hurricane and Evacuation (HURREVAC) program. HURREVAC uses geographic-information-system (GIS) information to correlate demographic data with shelter locations and their proximity to evacuation routes to estimate the effect of strategic-level evacuation decisions (Wolshon, *et al*. 2001).

One of the most robust evacuation-analysis tools is the Oak Ridge Evacuation Modeling System (OREMS). Developed by the Center for Transportation Analysis at the Oak Ridge National Laboratory (ORNL) using the CORridor SIMulation (CORSIM) platform, OREMS was developed to simulate traffic flow during various defense-oriented emergency evacuations. The model can be used to estimate clearance times and to identify operational traffic characteristics and other information such as evacuation routes and times necessary to develop evacuation plans. It also allows users to experiment with alternate routes, destinations, traffic-control and management strategies, and evacuee-response rates (ORNL 1995). More recently, researchers from ORNL have identified the need for a decision tool capable of modeling hurricane evacuation activities in more timely and accurate ways.

Another recent macro-level evacuation modeling-and-analysis system is the Evacuation Travel Demand Forecasting System (PBS&J 2000a). This system was developed in the aftermath of Hurricane Floyd, driven by the need for a capability to forecast and anticipate large cross-state traffic volumes. At the heart of the model is a web-based travel-demand forecast system that anticipates evacuation traffic congestion and cross-state travel flows for North Carolina, South Carolina, Georgia, and Florida. The Evacuation Travel Demand Forecasting System model was designed so emergency management officials can access the model online and input category of hurricanes, expected evacuation-participation rate, tourist occupancy, and destination percentages for affected counties. The output of the model includes the level of congestion on major highways and tables of vehicle volumes expected to cross state lines by direction (Wolshon, *et al*. 2001).

A more detailed discussion on evacuation models is available from Gwynne, *et al*. (1999), who identified 22 evacuation models and compared them on network enclosure, population perspective, behavioral perspective, and the nature of model applications.

3.2 Traffic-Simulation Tools

3.2.1 Traffic Simulation for Evacuation Modeling

Traffic simulation is widely used to evaluate the impacts of highway projects, signal-timing changes, and new developments. Traffic-simulation tools may also be employed in the study of evacuations to study emergency-management plans without the need of actual execution of such plans.

Many simulation-based evacuation studies deployed the PARAMICS for traffic analysis. Examples include the works of Church and Sexton (2002) and Chen (2004). Other researchers used the popular CORSIM package to study evacuation-traffic operations. Sisiopiku, *et al*. (2004) used CORSIM to test and evaluate various emergency-management strategies in response to natural or human-caused disasters in the Birmingham area. Examples of such strategies include evacuation routing, emergency-response routing, and traffic-control strategies for expediting evacuation. In another effort, Williams, *et al*. (2007) undertook a study to test the efficiency of contra-flow operations under various evacuation scenarios using CORSIM. Theodoulou and Wolshon (2004) modeled contra-flow implementations for evacuation in New Orleans in CORSIM. Santos and Aguirre (2004) summarized available simulation models for emergency evacuation by modeling approach and discussed the advantages and disadvantages of each from the perspective of evacuee behavior.

3.2.2 Traffic-Simulation Options

Depending on the level of modeling detail, traffic-simulation models are classified as microscopic and macroscopic. A detailed discussion about micro- and macro-simulations and their relative advantages and disadvantages is provided by Pidd, *et al*. (1993). It should be noted that microscopic models such as CORSIM and Synchro/SimTraffic provide more realistic estimates of traffic performance than traditional traffic-analysis methods because they simulate the performance of individual vehicles and incorporate the influence of traffic controls and roadway geometry. They can also provide detailed outputs such as estimated travel times, delays, and travel speeds. These measures are useful for evaluating traffic performance and are more easily understood by non-transportation professionals. However, the available models vary in their sophistication and capabilities to realistically model driver behavior and can become very complex when simulating large-scale networks.

The majority of models in use are static models, meaning vehicles are assigned to specific travel paths at the beginning of a simulation and remain on those paths regardless of prevailing traffic conditions. At the lowest level are models such as SimTraffic, in which vehicle movements are defined by the user at the beginning of the simulation. Vehicle paths are generated stochastically based upon inputted turn movements and may not necessarily reflect realistic vehicle movements. This is ordinarily not a problem for small networks and stochastic models like SimTraffic function very well for evaluating signal timings or localized traffic impacts.

At the next level are models that permit traffic assignment, such as CORSIM. In CORSIM, instead of entering turning movements for each intersection, the user can input origin-destination trip tables that specify trip generation and attractions at various points along the network. The model generates traffic volumes using these tables and assigns each vehicle an origin, destination, and optimum path as it enters the network. This tends to generate more-realistic vehicle movements across the network and is useful for larger planning models. The limitation of CORSIM is that once a vehicle enters the network it is committed to the path to which it has been assigned, regardless of any traffic congestion or incidents. Over smaller networks this limitation may not be significant, but across larger networks where a vehicle path may require an hour or more to travel it can yield unrealistic driver behaviors.

3.2.3 Dynamic Traffic Assignment Models

Dynamic Traffic Assignment (DTA) models have evolved rapidly over the past two decades and represent the new generation in traffic simulation. As with CORSIM, the user of a DTA model can enter origin-destination trip tables specifying traffic generation for a given network. The DTA model then assigns each vehicle an origin, destination, and optimum path when it enters the network. Unlike CORSIM, a DTA model then re-evaluates vehicle paths at regular intervals and allows individual vehicles to alter paths mid-trip to optimize their travel. This yields more realistic simulation results because it models what drivers actually do (i.e. choose a route based on available alternatives and current traffic conditions) versus what the modeler thinks they ought to do. DTA models, therefore, offer several advantages over static simulation models that may be very useful for the testing of evacuation plans, including:

- More realistic modeling of vehicle movements and driver behavior.
- Realistic modeling of incidents and disruptions to traffic.
- Realistic modeling of the effects of ITS technologies and driver information systems.
- More accurate modeling of how changes to one route can affect traffic on other routes.

Several simulation-based DTA models are available for real-world deployment and have gained sophistication and significant acceptability. Sisiopiku and Li (2006) provide a comparison of features, strengths, and limitations of three representative DTA simulation models, namely DynaMIT, DYNASMART-X, and VISTA. Chapter 5 provides a detailed description of VISTA, the model selected for implementation in this study.

Section 4
The Alabama Lane-Reversing Plan

The following sections summarize the main features of the Alabama lane-reversing plan adopted by ALDOT and form the basis for the development of an evacuation model for this study. The plan at its entirety is available in ALDOT (2008).

4.1 Reverse-Laning Route Identification

Denied-access routes, or interstates, have the best potential for use in any reverse-laning scenario. By the very nature of their denied access, the traffic control necessary to reverse normal traffic flow on interstate routes can be accomplished by concentrating on the interchange and termini areas.

The geographic area of Alabama where it is deemed necessary to provide a reverse-laning capability is south of Montgomery. In this area there are two interstate routes: I-10 and I-65. Interstate 10 (I-10) runs west from the Florida panhandle through Baldwin County and runs east from the Mississippi Gulf coast through Mobile County. Interstate 65 (I-65) originates at I-10 in Mobile and runs north through Montgomery and beyond.

A reverse-laning plan involving I-10 has been determined to be impractical and unnecessary at this point. I-65, on the other hand, has been viewed as a practical candidate for reverse-laning. Experience from Hurricane Opal and other storm events have shown the most significant traffic delays occur where evacuation traffic from Mobile County traveling north on I-65 meets evacuation traffic from Baldwin County traveling north on Alabama Routes 225, 59, and 287, and attempting to enter I-65 North of the Bay Minette area. Due to experience with traffic delays on I-65, a denied-access route, a reverse-laning plan was developed for I-65.

4.2 Reverse-Laned Route Termini

Historically, traffic congestion has occurred during hurricane evacuations on I-65 at its junction with Alabama Routes 225, 59, and 287. Therefore, it is in this area that the reverse-laning strategy was determined to begin. The southernmost of these three routes along I-65 is Alabama Route 225; reverse-laning should begin south of this route's intersection with I-65. Another factor that must be considered is that at Exit 51, just south of the Alabama Route 225 and I-65 intersection, are the Delta River Bridges over the Mobile and Tensaw Rivers. Therefore, it is anticipated that the reverse-laning plan should be implemented between the Delta River Bridges and the Alabama Route 225 and I-65 intersection. It is further anticipated that a crossover ramp must be available between these two features. This crossover would move most of the existing northbound traffic on I-65 south of the implementation point into the southbound I-65 traffic lanes.

The geographic area of Alabama where it is deemed necessary to provide a reverse-laning capability is being limited to south of Montgomery. Therefore, it is the greater Montgomery metropolitan area that is considered for ending the reverse-laning strategy. Since the greater Montgomery metropolitan area is unlikely to be heavily affected by a storm event, it would be preferable to leave Interstate 65 traffic alone through the metropolitan area itself. Therefore, to the extent practical, some location in the southern portion of the greater Montgomery metropolitan area was considered as the northern terminus of the reverse-laning strategy.

Based on the considerations stated above, the area encompassing the US 80 West to Selma (Exit 167) interchange and the US 82/US 80 East (Montgomery Southern bypass) (Exit 168) interchange with I-65 has been identified by ALDOT as the location where the reverse-laning strategy would end.

One additional consideration for the selection of this area is that US 80 West to Selma (Exit 167) interchange and the US 82/US 80 East (Montgomery Southern by-pass) (at Exit 168) interchange with I-65 are both four-laned facilities. Therefore, these facilities offer additional capacity not afforded by two-laned facilities in the vicinity. Another consideration is the fact that the US 80 West to Selma (Exit 167) interchange with I-65 can offer access to a major westbound US route, while the US 82/US 80 East (Montgomery Southern bypass) (Exit 168) interchange with I-65 can offer access to a major eastbound US route. A third consideration is the fact that US 31 runs parallel to I-65 between the US 80 West to Selma (Exit 167) interchange and the US 82/US 80 East (Montgomery Southern by-pass) (Exit 168) interchange. This allows those motorists who exit at the US 80 West to Selma (Exit 167) interchange an opportunity to take US 31 North to US 82/US 80 East (Montgomery Southern by-pass), where they may proceed either eastbound or westbound on US 82/US 80 or get back onto I-65 if they wish to proceed northbound.

Twenty interchanges are located along I-65 within the ALDOT's plan limits of the reverse-laning plan.

4.3 Southbound and Emergency-Vehicle Access

US 31 runs relatively parallel to I-65 throughout the limits of the reverse-laning plan, and therefore can serve as the general southbound detour for I-65. Under contra-flow operations, normal southbound traffic and emergency vehicles would be required to exit I-65 at US 82/US 80 East (Montgomery Southern by-pass) (Exit 168) and follow US 31 through Hope Hull, Greenville, Georgiana, Evergreen, Brewton, Flomaton, and Atmore to Bay Minette. Once in Bay Minette, normal southbound traffic should continue on I-65 South to I-10 or should use other state or county routes or city streets as necessary to reach their local destinations. Once on Interstate 10, traffic can proceed either west or east to reach their destinations. However, provisions will be made to allow emergency vehicles to take AL 59 north from Bay Minette to Interstate 65. Once at I-65 emergency vehicles could proceed over the overpass and take the outside shoulder down the onramp to I-65 southbound and proceed down the outside shoulder southbound for approximately two miles just south of the I-65/AL 225 interchange where the beginning crossover for the reverse-laning plan is located.

It must be remembered northbound traffic will use the normal southbound traffic lanes so emergency vehicles traveling on the outside shoulder of southbound I-65 will need to take necessary precautions. Again, due to the inherent dangers this procedure should only be used for emergency vehicles in necessary situations.

4.4 Crossover Ramps

In addition to the northern and southern termini crossover ramps discussed, four additional crossover ramps were constructed by ALDOT for lane-reversing evacuation operations. These additional crossover ramps were needed to allow vehicles to move from the northbound roadway to the southbound so as to ensure an equal distribution of traffic onto both roadways.

Two considerations influence where these crossover ramps should be located. The first consideration was to locate these crossovers at locations where a significant increase in evacuation traffic merging onto I-65 could be anticipated. The first location occurred at the AL 21 interchange (Exit 57) near Atmore. AL 21 (and Florida 97) is a major north-south evacuation route from the extreme western panhandle of Florida and Pensacola. A second location occurred at the AL 113 interchange (Exit 69) near Flomaton. AL 113 (and US 29 in Florida) is also a major north-south evacuation route from the extreme western panhandle of Florida and Pensacola. The third location occurred at the AL 55 interchange (Exit 114) near Georgiana. AL 55 is a major feeder evacuation route from south-central Alabama and the panhandle of Florida, including Fort Walton Beach.

A second consideration was the equal spacing of crossovers along the reverse-laning route to facilitate the equalization of traffic loading on both sides of the interstate. Previous considerations would have the initial crossover south of AL 59, and intermediate crossovers at AL 21, AL 113, and AL 55, all of which are about 20 to 45 miles apart. That leaves approximately 55 miles between AL 55 and the end of reverse-laning at US 80 West. One more intermediate crossover within these limits would logically place it at AL 10 (Exit 128) near Greenville. There is no major evacuation route feeder in this area; however, Greenville is the largest metropolitan area along this section of roadway, and could be expected to generate the largest amount of traffic onto I-65.

The intermediate crossovers were placed just south of the interchanges identified. This placement allowed the shifting of traffic from the more congested side of the interstate to the less congested side prior to the introduction of additional traffic at these interchanges. Therefore, intermediate crossovers were located at AL 21 (Intermediate Crossover A) near Atmore, AL; 113 (Intermediate Crossover B) near Flomaton, AL; 55 (Intermediate Crossover C) near Georgiana; and AL 10 (Intermediate Crossover D) near Greenville.

4.5 Traffic-Control Device Requirements

In addition to the need for traffic-control devices at the southern and northern termini and crossover ramps, variable message boards (VMS) are needed to notify southbound travelers along various interstates in Alabama of the reverse-laning and to suggest alternate routes to avoid involvement.

Variable message boards are placed along I-65 north of Birmingham, I-59 northeast of Birmingham, and I-20 east of Birmingham. Placing these variable message boards in such as way as to allow motorists to see them before reaching Birmingham will allow them the opportunity to take alternate interstate routes and to avoid the reverse-laning plan route.

Section 5
Methodology

5.1 Approach

The following five tasks were completed to accomplish the goals of this project:

1. Definition of study area
2. Model selection
3. Data collection
4. Model development and testing
5. Definition of study scenarios

Details on assumptions and activities undertaken as part of each task follow.

5.2 Definition of Study Area

The focus of the study was a 168-mile segment of I-65 from Mobile to Montgomery, AL. Special attention was paid to the evacuation needs of Mobile and Baldwin counties. Both Mobile and Baldwin counties are on the shore of the Gulf of Mexico. Mobile County has an area of 1,238 square miles and a population of 598,758. Baldwin County has an area of 1,590 square miles and a population of 165,100. The primary facilities of interest were marked evacuation routes from the coast, interstate highways, major evacuation routes such as US 231, US 331, US 431, US 29, SR 97, and major arterials in the Mobile region.

5.3 Simulation-Model Selection

Consideration of the desirable features for the study tasks, review of the candidate-model capabilities and limitations, and model availability issues led to the selection of VISTA as the simulation tool for this study. VISTA stands for *Visual Interactive System for Transport Algorithms* and is an innovative network-enabled framework that integrates spatio-temporal data and models for a wide range of transport applications, including planning, engineering, and operation. The client graphic user interface (GUI) is built in JAVA, so it can be used over the Internet. The database efficiently stores and retrieves spatio-temporal data by associating geographic coordinates and time stamps. The database is designed to efficiently manage a wide range of historical and real-time transportation data (Ziliaskopoulos and Barrett 2002). A unique feature of VISTA is that it runs over the internet on a cluster of Unix machines. This enables multiple users to access it anywhere anytime and to run sophisticated DTA, control, and simulation models without being limited by the computational power of the client machine.

The algorithms available in VISTA include the following:

1. Traffic simulation
2. Dynamic Traffic Assignment
3. Traffic control (isolated intersection and signal coordination)
4. Capacity analysis
5. Transit operations
6. Demand calibration
7. Routing

In addition, VISTA can be easily interfaced to existing packages, e.g. SYNCHRO and NETSIM, by outputting data from the VISTA Data Warehouse (VDW) in a format compatible with these packages and then importing the results back to the VDW.

5.3.1 VISTA Modules

The primary modules implemented in the VISTA framework include a traffic simulator (RouteSim), traditional static-planning models, DTA, network-routing algorithms, signal-optimization models, ramp-metering models, and incident-management models. The Management Module coordinates interactions among the models, and although each of these models may have different data types and structural requirements, the format and interface for the data are kept uniform.

5.3.1.1 Large-Scale Mesoscopic Simulator (RouteSim)

As a software framework, RouteSim was designed with third-party extensibility in mind. Written in C++, it uses the Abstract Factory design pattern for the creation of objects. The purpose of the Abstract Factory is to provide an interface for creating families of related objects without specifying concrete classes. This allows users to easily extend or add to the object structure without directly modifying the simulator. For instance, a new vehicle type can be inherited from the core vehicle class and the methods describing movement rules can be overridden. Each class in the simulator provides a convenient set of accessors and mutators to facilitate dynamic interactions between classes.

5.3.1.2 Planning Models

System-optimum and user-equilibrium static assignment algorithms have been implemented and can be invoked through VISTA. The algorithms are deterministic approaches based on Frank-Wolfe's convex combinations method (Sheffi 1985); a stochastic user equilibrium model is under development using a paired combinatorial logit model. The demand tables are part of the input data, since no trip generation, distribution, or mode split modules are implemented. VISTA, however, provides a convenient framework for embedding such models and for using them with DTA models.

In addition, highway-capacity analysis modules are being implemented so the level of service for intersections and street segments can be computed for the equilibrium flows. The computational procedures are done according to the Highway Capacity Manual suggestions. Existing software, such as HCS, can also be interfaced.

5.3.1.3 Signal Control Models
Although not of concern in this study, signal-timing plans can be computed for isolated intersections based on simple delay functions and offsets for intersections along an arterial. Network-wide signal optimization models are under development, although any of the already existing models (e.g. TRANSYT, and SYNCHRO) can be easily interfaced. A user-friendly graphic interface for viewing (or modifying) the intersection signal-timing plans is also available.

5.3.1.4 Dynamic Traffic Assignment
Various DTA models have been implemented within VISTA:

- A departure-based and fixed-arrival-time version of simulation-based User Equilibrium (UE) DTA approaches using RouteSim to propagate traffic and satisfy capacity constraints (Ziliaskopoulos and Rao 1995).
- A modified version of DYNASMART-X (Mahmassani, *et al*. 1998) that is capable of modeling multiple user classes including user equilibrium and System Optimum (SO) users. This version is based on departure times only and uses DYNASMART to simulate traffic.
- Two analytical DTA models: a departure-time and an arrival-time approach. Both approaches are linear programming and are solved with CPLEX.
- A combined analytical model based on departure times and arrival times that is also solved using CPLEX (Li, *et al*. 1999).

These DTA models use the same geometry, control, and demand data inputs; the demand tables need to be based on departure or arrival times, depending on the model invoked. The DTA modules access the simulator module, time-dependent least time and cost path modules, as well as other modules. Because these systems work in an iterative scheme, the computational time of sub-modules is of great importance. DTA models are the most time-consuming models, but many of these modules have operations that can run in parallel. For instance, the time-dependent shortest-path algorithms have the ability to be distributed over multiple processors (Ziliaskopoulos, *et al*. 1997).

5.3.1.5 Origin-Destination Demand Calibration
A unique capability of VISTA enables users to calibrate origin-destination trip tables based on observed link flows. This is a heuristic algorithm that allows users to adjust the trip tables so the observed 15-minute link flows are replicated on the network. Usually many adjusted trip tables can meet this requirement; the module identifies the one that deviates the list from the original target trip table.

5.3.1.6 Routing Algorithms
Various routing algorithms can be invoked through VISTA: static and dynamic shortest-path algorithms based on time or cost on the links. Versions of the dynamic algorithms that simultaneously optimize route and departure time are also being developed. The algorithms are implemented in C++. Implementation details can be found in Ziliaskopoulos and Mahmassani (1993). The routing algorithms require as input network geometry and link travel times or costs. They

have the capability to account for intersection movement delays. The output is typically a tree rooted at the origin or destination.

5.3.2 VISTA for Emergency Analysis

The VISTA system offers a framework for conducting emergency analyses in a seamless manner since most of the algorithms (i.e. DTA model, time-dependent route-planning algorithms including intermodal algorithms) are embedded into the system. The route-planning algorithms are necessary for emergency services such as EMS, fire department, towing services, police, and security agencies. In addition, these route-planning algorithms are necessary for buses and other para-transit vehicles as well as for automobiles equipped with in-vehicle navigation systems that are crucial in offering evacuation services to citizens (Chien, *et al*. 2005).

The VISTA emergency and evacuation modules can be used for off-line emergency analyses, real-time implementation, and training exercises. In addition, for each module a semi-automated self-calibration procedure is under development that will be based on data collected automatically by roadway detection devices (roadway-based sensors) and in-vehicle devices (GPS, communication), and data collected by each agency for each emergency event.

Another powerful attribute of the VISTA model is that it can allow the incorporation of real-time traffic-count data into model runs for refinement and forecasting. However, this work is still in progress and thus this project cannot take advantage of this capability. When available, VISTA will allow for a real-time evacuation module to be designed that will be able to run faster than real time, such that any changes due to the effect that a specific set of dynamic events has on roadway capacity (e.g. roadway flooding, fallen trees, signal blackout, and roadway closures due to security concerns) and operation can be emulated and a set of alternatives evaluated in real-time.

5.4 Data Collection

Geometric and traffic data were collected for the routes of interest in preparation for model development. Lane geometry and interchange configurations were inventoried along the routes, and the locations of crossovers along I-65 were also determined. As a starting point, the geometric map pinpointing the road network was obtained from Google Maps and then run through the VISTA GIS interface resulting in a one big map starting from Mobile County and ending at Montgomery County, concentrating mainly on the highways connecting the two counties. Field visits took place to confirm distances, the number of lanes, and other pertinent information.

To determine demand-related information, the South Alabama Regional Planning Commission (Mobile Metropolitan Planning Organization) was contacted and a copy of the TRANPLAN planning model for the city of Mobile obtained. As demand under evacuation conditions varies considerably (compared to normal conditions), supplemental information was obtained from previous evacuations and lane reversals to assist in determining realistic travel-demand profiles under evacuation conditions from the traffic count section of ALDOT. Figures 5-1 and 5-2 provide an example of hourly distribution of traffic demand before lane-reversal (9/12/04, 9/13/04, 9/14/04), during lane-reversal (9/15/04), during the Hurricane Ivan (9/16/04), and after Hurricane Ivan (9/17/04) using data collected at mile point MP 42 on I-65.

Moreover, demographic data for the evacuation region were used to estimate travel demand during various evacuation scenarios. Some of these data have already been compiled by the United States Army Corps of Engineers (USACE) in their Alabama Hurricane Evacuation Study (USACE 2001) and provide an excellent reference for the preparation of traffic-demand profiles for low and high hurricane-intensity conditions.

5.5 Model Development and Testing

A model of the major evacuation corridors was constructed using the VISTA platform. VISTA model zones were created that were consistent with the zoning schema in the USACE report. Each zone in VISTA was represented by a centroid, and some zones served as origins and the others as destination zones from the evacuation prospective.

Figure 5-3 shows the 23 zones considered for Mobile County. It should be noted that for category 1 and 2 storms only zones 1 to 7 evacuate whereas for category 3 to 5 storms, evacuation affects zones 1 to 13. The rest of the zones (i.e. 14-23) are destination zones that serve in-county evacuation needs. In-county evacuation refers to vehicles from zones closer to the Gulf Shore to zones far away from the shore and harm's way but in the same county.

Baldwin County is represented by four evacuation zones (Figure 5-4). For category 1 and 2 hurricanes only zone 1 is expected to evacuate. For category 3 storms, zones 1 and 2 will evacuate. Residents from zone 3 are expected to evacuate as well under a category 4 storm threat and the entire county will evacuate (zones 1 through 4) for a hurricane classified as category 5.

The evacuation model was maintained on the VISTA website and can be accessed over the internet by ALDOT personnel and any other interested parties using a simple username and password.

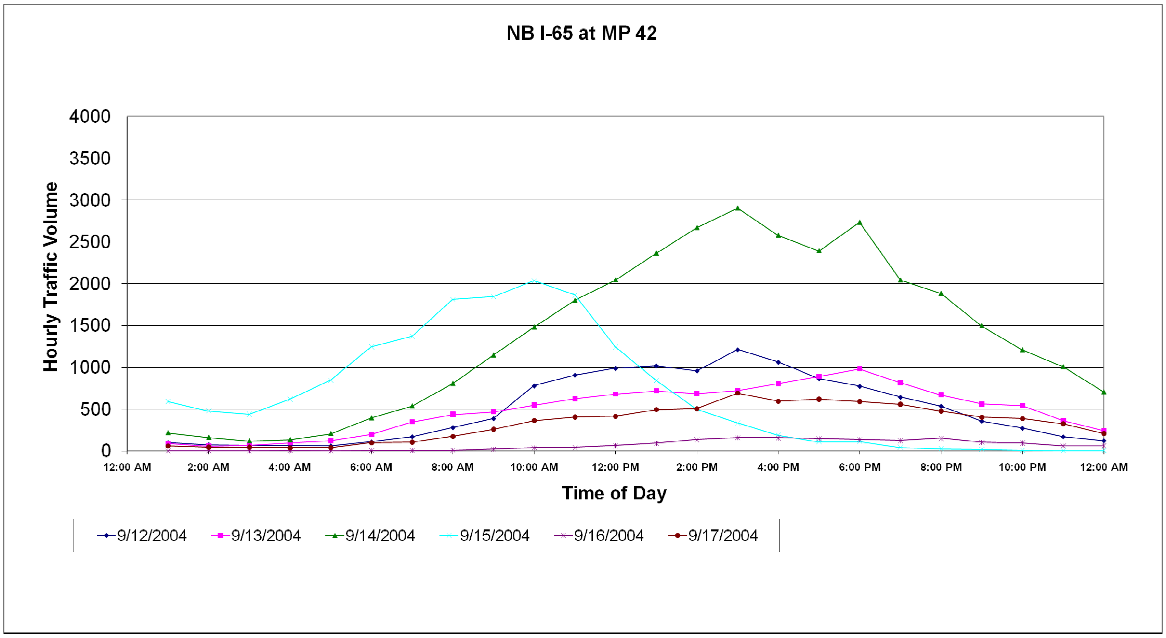

Figure 5-1. Hourly distribution of traffic demand before, during, and after lane-reversal operations for Hurricane Ivan at mile point 42 on I-65 NB

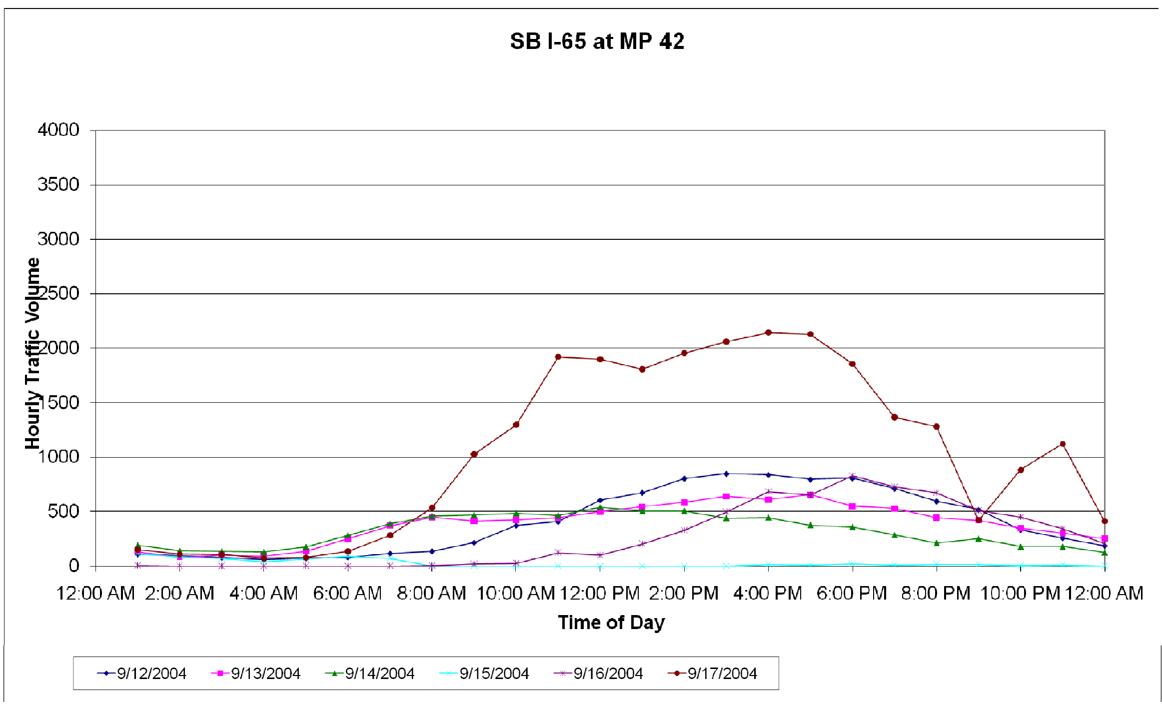

Figure 5-2. Hourly distribution of traffic demand before, during, and after lane-reversal operations for Hurricane Ivan at mile point 42 on I-65 SB

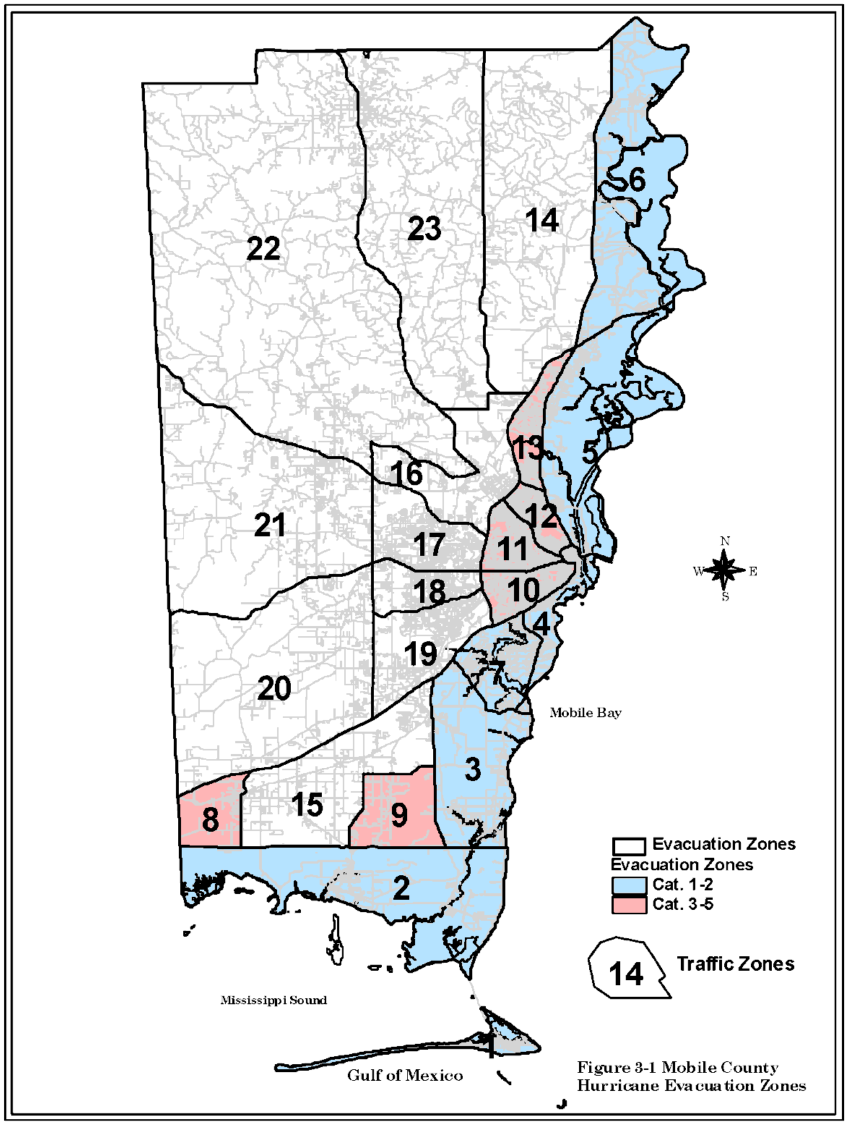

Figure 5-3. Mobile County evacuation zones by storm category (USACE 2001)

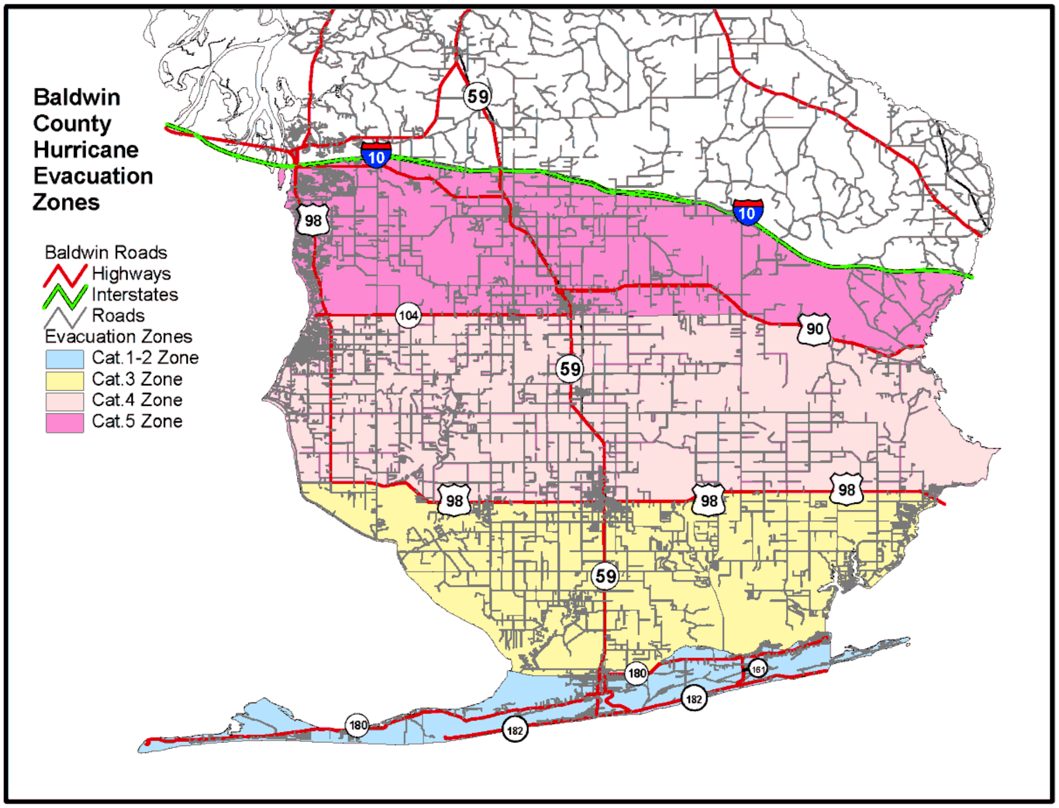

Figure 5-4. Baldwin County evacuation zones by storm category (USACE 2001)

An effort was made to model the study facilities in detail to make the simulation model realistic and to increase confidence in the model findings. Extensive reviews of ALDOT plans took place to accurately depict network operations under normal and lane-reversal conditions for evacuation. As an example, Figure 5-5 shows the crossover south of AL 21 (ALDOT 2009) and for the same location Figure 5-6 depicts the modeled network in VISTA.

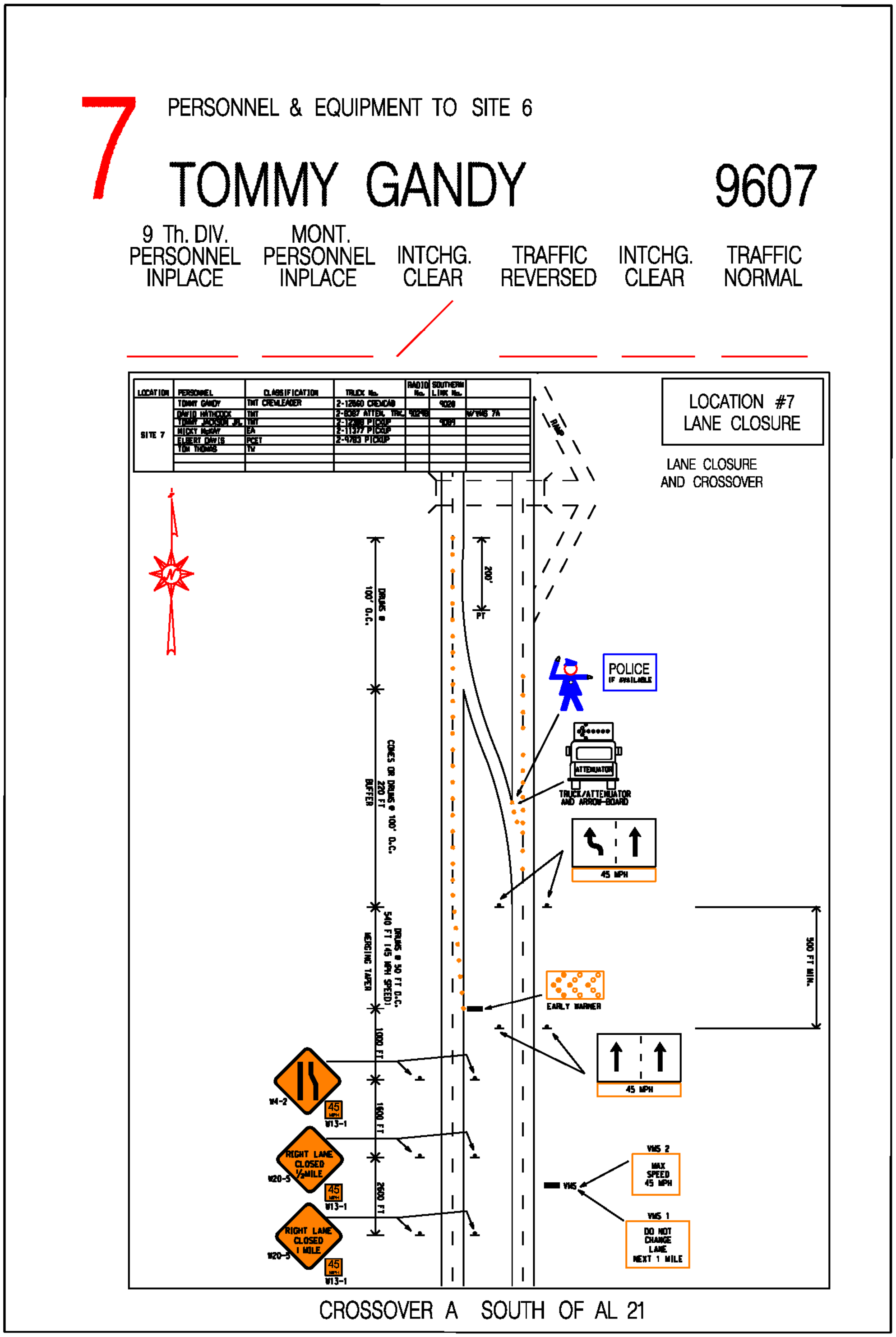

Figure 5-5. Crossover ramp south of AL 21 (ALDOT 2009)

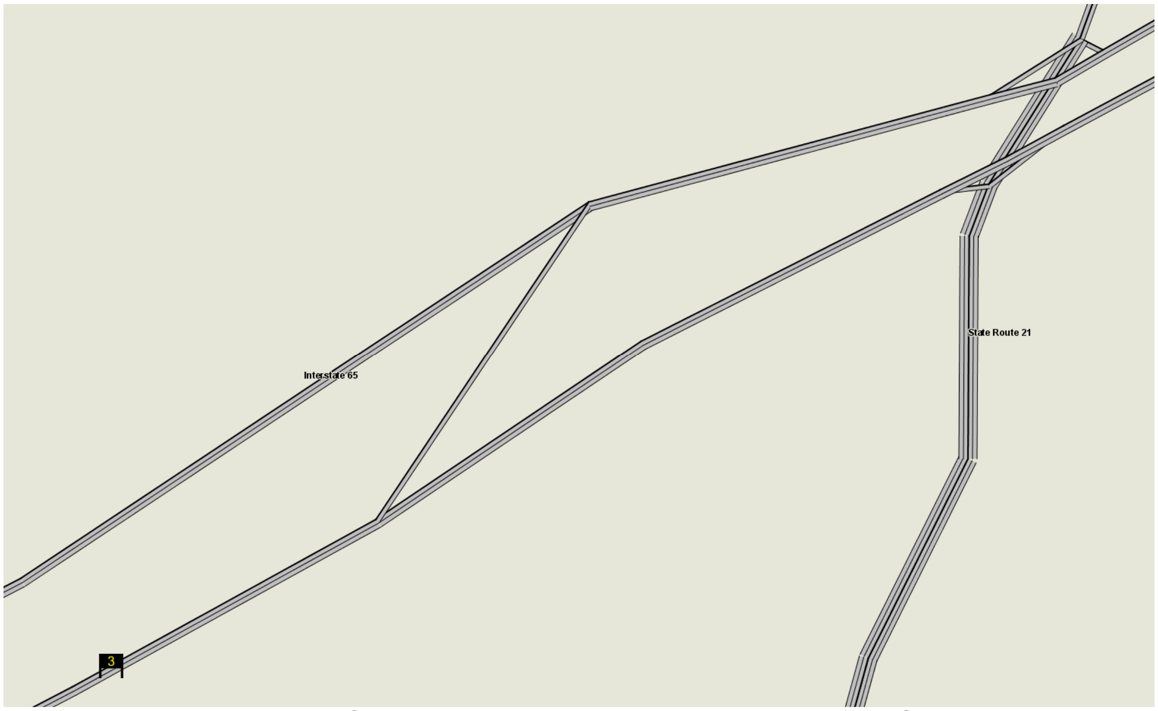

Figure 5-6. Crossover ramp south of AL 21 as modeled in VISTA

The demand required by this project presented a unique challenge. An evacuation demand was necessary to correctly model various scenario conditions, but only a limited set of evacuation trips was available. The additional demand used in the system was created from regional planning models and traffic counts on roadways parallel to I-65.

5.5.1 Evacuation Traffic

The project team obtained evacuation data from a study done by the United States Army Corps of Engineers (USACE). This study provided the project team with counts of people evacuating from multiple sub-regions within Mobile County and Baldwin County for different storm severities. The sub-regions were developed as new zones, some overlapping existing zones. These zones were then given connections to the traffic network within the boundaries given in the USACE study.

The person counts given by USACE were converted into vehicle counts using a factor of 2.5 persons per vehicle. These counts were then used as the demand originating at the respective zones. All these vehicles were given a destination in the city of Montgomery.

To prepare vehicles for simulation from this new trip table, an evacuation demand profile was created using traffic counts obtained by ALDOT during past evacuation events. These hourly counts were used to proportionally distribute the evacuation vehicles over a 24-hour period.

Origins were chosen by storm severity according to the zone boundaries defined by USACE. These acted as sources for evacuation traffic. The zones evacuated in Mobile and Baldwin Counties vary by storm severity.

Destinations were chosen by proportions defined in the USACE report. The report gave percentage of evacuees destined for locations in-county and out-of-county. All out-of-county evacuees are directed to Montgomery. All in-county evacuees are distributed randomly among non-evacuation zones within the same county.

5.5.2 Background Traffic in Mobile

The project team obtained the trip matrices for the city of Mobile. These contain trips representing an average day of travel in that city. However, an evacuation is somewhat different from an average day of travel. Under evacuation conditions, some of these trips will become evacuation trips, destined for locations outside the city. Other trips will be canceled altogether.

To bring the average daily traffic down to a level representative of an evacuation condition, the project team had to reduce demand in the Mobile trip tables by an amount related to the number of vehicles evacuating.

Using the total number of daily trips from the trip tables and the total regional population, the project determined that the average person in the region makes three trips during a 24-hour period. We therefore removed three trips from the Mobile trip tables for every person evacuating.

The resulting trip table was combined with a demand profile developed from average day freeway counts in the city of Mobile to produce the number of individual vehicles moving in Mobile.

5.5.3 Background Traffic outside Mobile

While most traffic is expected to use I-65, some evacuation vehicles may choose to divert off I-65 or travel to I-65 from a location outside Mobile. To provide a more realistic level of background traffic outside Mobile, daily traffic counts were obtained on major roads crossing I-65.

These counts were used to prepare zones straddling the interstate, allowing vehicles to flow back and forth from one side of the expressway to the other. The daily counts for these zones were combined with the same demand profile used in the city of Mobile to create individual vehicles moving back and forth under the expressway.

5.5.4 Definition of Study Scenarios

The project team simulated a series of evacuation scenarios in which different factors were adjusted to better understand the impacts of lane reversals. Such factors included evacuation severity, evacuation strategy, length of lane reversal, location of the northern terminus, and the presence of an incident during evacuation.

5.5.4.1 Evacuation Severity

Evacuation severity relates closely to hurricane intensity. Hurricane strength is categorized on a scale from 1 to 5 (5 being the maximum category of a storm). In this study, low hurricane (L) intensity referred to category 1 or 2 storms whereas high hurricane (H) intensity corresponded to category 3 to 5 storms. Each of these two categories was built based on the classification used in the USACE report and was important in determination of evacuating demand from the affected zones (Table 5-1).

Table 5-1. Number of evacuating vehicles by county and storm category (USACE 2001)

Hurricane Intensity	Total Evacuating Vehicles	Vehicles Evacuating In-County	Vehicles Evacuating out-of-County
Mobile County			
Category 1-2	34,481	20,090	14,391
Category 3-5	98,283	49,308	48,975
Baldwin County			
Category 1-2: high tourist season	23,413	8,951	14,462
Category 3-5: high tourist season	62,141	23,412	38,729

5.5.4.2 Evacuation Strategy

Based on the expected severity of the hurricane, ALDOT personnel assess whether the north-bound capacity of I-65 will reasonably accommodate evacuation traffic or whether the south-bound traffic lanes should be reversed to increase road capacity for the evacuation. There are three options:

No lane reversal (N)
Partial lane reversal (P)
Full lane reversal (F)

Full lane reversal refers to the reversal of all southbound lanes of I-65 to northbound during the course of the contra-flow operations. This is the practice used by ALDOT when an evacuation involving contra-flow operations is in place. In this case, emergency relief vehicles that need to travel toward the affected site use alternate routes (such as US 31) or the southbound I-65 shoulder lane.

This study also investigated the operational impacts from partial lane reversal to assess its feasibility as an alternate option. Under partial lane reversal only one traffic lane in the southbound direction is reversed, providing some relief to evacuating traffic while also allowing emergency vehicles access to the affected sites via the remaining I-65 SB lane(s).

The road network has been already prepared for the full reversal process and there are five crossovers present on the stretch of I-65 interstate under study ready to direct evacuee traffic traveling north to the southbound lanes when contra-flow operations are deemed appropriate. Figure

5-7 shows the first crossover in the study area near Mobile, with two lanes to facilitate the quick movement of a large number of vehicles to the reversed lanes.

Figure 5-7. First I-65 crossover for contra-flow operations (ALDOT 2009)

The project team put a lot of effort into creating the VISTA network to best resemble the ALDOT reversal plan. One of the challenges was to model the crossovers in VISTA. Under normal conditions there is no space in between the north and southbound links in a VISTA network. Typically one bidirectional link represents the two directions of travel between two consecutive nodes. The approach taken to overcome this issue and introduce the crossovers into the network was to construct a set of nodes and links parallel to I-65 serving only one direction (i.e. the northbound). Figure 5-8 shows the snapshot of the network built on VISTA depicting the first crossover.

The number of lanes open to traffic in each direction along the I-65 and the parallel network varied according to the evacuation strategy considered. More specifically, when modeling the no lane-reversal evacuation strategy the northbound traffic was served by the parallel northbound network and the southbound by the southbound I-65 links. The northbound I-65 links were not used in this case. This was done for consistency purposes even though there was no actual need for crossovers in this case.

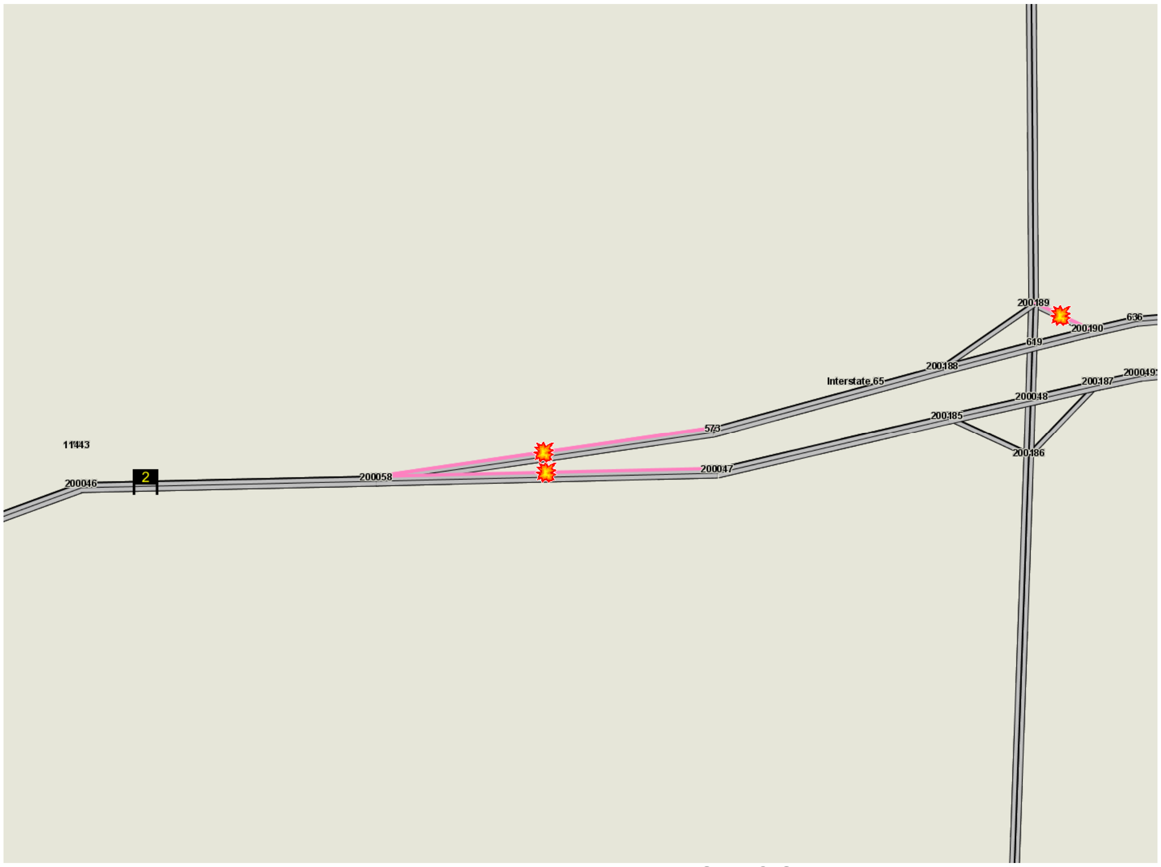

Figure 5-8. The first crossover from VISTA GIS interface

On the other hand, when modeling the full-reversal evacuation strategy all southbound lanes were reversed to accommodate the increased influx of northbound evacuee traffic. This was possible to model in VISTA by allowing evacuating traffic to use the northbound lanes along I-65 and the northbound lanes along the parallel network. Also the southbound ramps were reversed, allowing evacuees traveling north on the southbound lanes to enter or exit the I-65 anytime. Figure 5-9 shows how the intermediate southbound exits managed to be used as exits for vehicles traveling north. At the end of the contra-flow evacuees on the southbound lanes were forced to leave the interstate through a detour on US 31 at exit number 164 as shown in Figure 5-10.

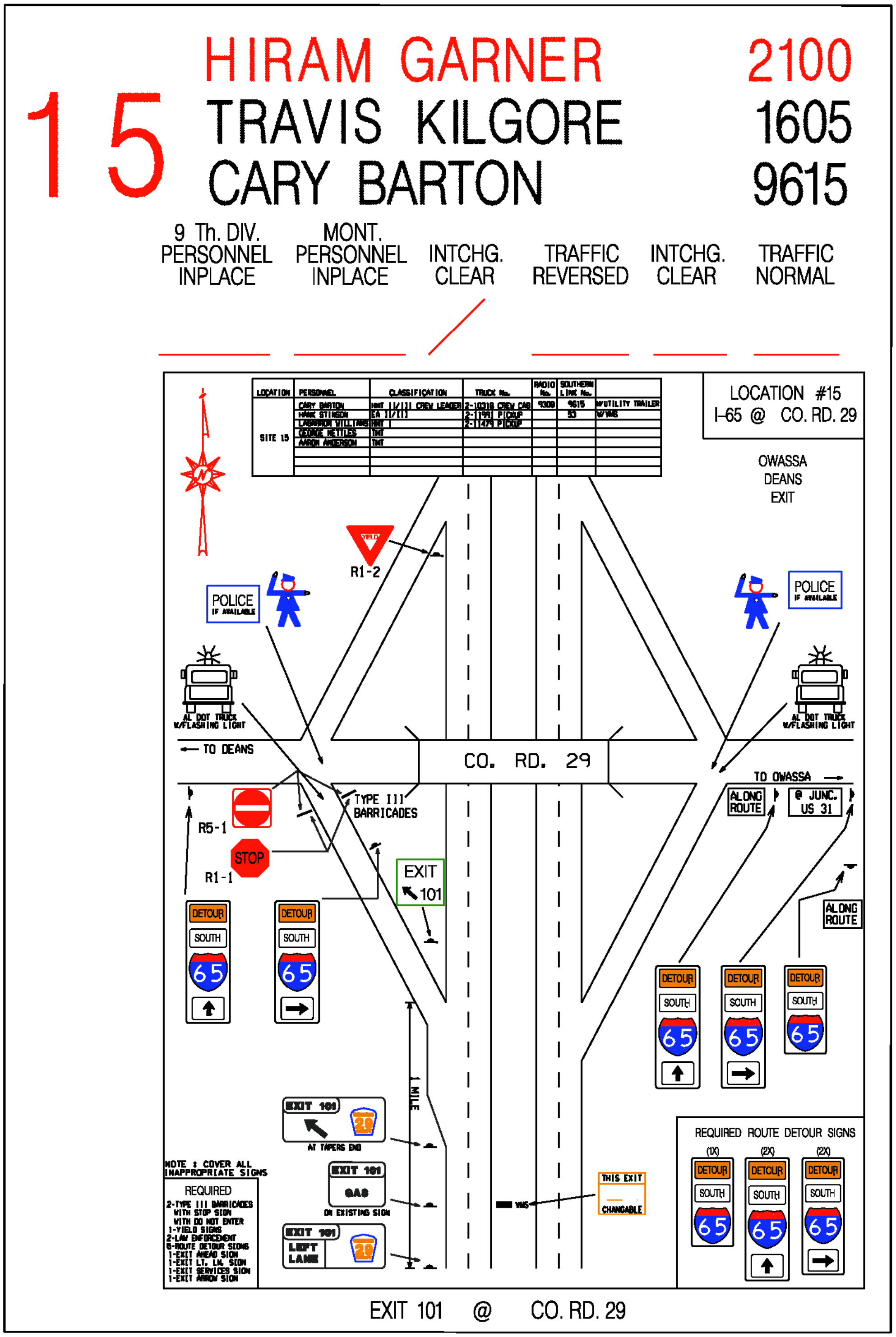

Figure 5-9. Southbound ramp managed to serve evacuees traveling north (ALDOT 2009)

Figure 5-10. Reversal end for the full contra-flow

Last but not least, under the partial-reversal evacuation strategy all northbound lanes in the parallel network in VISTA and one lane along northbound I-65 were given to northbound traffic. The southbound I-65 lanes (reduced by one) were available for emergency vehicle use. It should be noted that vehicles traveling on the reversed lanes in the partial reversal case were forced to travel all the way to Montgomery as there are no intermediate exits. Vehicles that used the regular northbound lanes were able to exit at various destinations along the way. At the end of the contra-flow operation evacuees had to merge back to the normal northbound links of I-65 as shown in Figure 5-11.

Figure 5-11. Reversal end for the partial contra-flow

5.5.4.3 Duration of Lane Reversal

When contra-flow operations are implemented ALDOT typically begins the reversal process at dawn and ends it at dusk. Another approach is to vary the duration based on the storm category and the characteristics of each county including the number of vehicles evacuating and road network capacity. This is consistent with the USACE report recommendation as summarized in 5-2 and 5-3.

In this study four reversal duration patterns were considered and tested to identify the most suitable execution. These are as follows:

Duration of contra-flow operations = 11 hrs or 16 hrs for Category 1-2 storms (low intensity)
Duration of contra-flow operations = 16 hrs or 26hrs for Category 3-5 storms (high intensity)

To model the correct reversal durations on VISTA, road closures were implemented on the crossovers and ramps leading the vehicles to the reversed lanes before and after the reversal process. shows the details involved in determining the duration of the recommended VISTA closures for the various durations of contra-flow operations considered in the study (namely 11 hrs, 16 hrs, and 24 hrs).

Table 5-2. Mobile County clearance times (hrs) (USACE 2001)

Storm Scenario (hurricane category)	Clearance Time (hours)
1-2	8 to 11
3	15 to 19
4	16 to 20
5	18 to 22

Table 5-3. Baldwin County clearance times (hrs) (USACE 2001)

Storm Scenario (hurricane category)	Clearance Time (hours)
1-2	6 to 9
3	15 to 19
4	16 to 20
5	18 to 22

Table 5-4. Closure calculations for modeling different durations of contra-flow operations in VISTA

Unit	Start	Duration	End/Start	Duration	End/Start	Duration	End
hrs	0:00	5	5:00	**11**	16:00	10	2:00 (+1)
sec	0	18000	18000	39600	57600	36000	93600
Strategy		**Normal**		**Reversal**		**Normal**	
Unit	Start	Duration	End/Start	Duration	End/Start	Duration	End
hrs	0:00	5	5:00	**16**	21:00	5	2:00 (+1)
sec	0	18000	18000	57600	75600	18000	93600
Strategy		**Normal**		**Reversal**		**Normal**	
Unit	Start	Duration	End/Start	Duration	End/Start	Duration	End
hrs	0:00			**26**			2:00 (+1)
sec	0			93600			93600
Strategy				**Reversal**			

5.5.4.4 Location of the Northern Terminus

The study considered two possible locations of the northern terminus: US 31 and US 185. The first contra-flow termination is at US 31 (referred to as option 31) at exit 164 in the city of Montgomery. This option, which provides easy access to I-85, is considered in ALDOT's current plan.

To assess the feasibility of moving the terminus location to the south, an alternate termination location was considered at US 185 (Exit 130 at Greenville) which is 41 miles away from the city of Montgomery. This location is providing access to US 31 and US 10 and is referred in the scenarios as termination location option 185.

5.5.4.5 Incident Presence

This scenario evaluated the network performance with and without lane reversal in the presence of an incident temporarily closing one lane of I-65 during an evacuation.

5.6 Summary of Alternatives Considered

For easy reference, Table 5-5 provides a summary of options considered in this study for the development of scenarios and systems analysis.

For non-incident conditions, a total of 18 studied scenarios addressed:

a) The impact of storm severity and evacuation areas on traffic operations.
b) Network performance under evacuation with and without lane reversal.
c) The impact of contra-flow operation duration on evacuation performance.
d) Alternate termini for the reversal plan and their impacts on local traffic.

Tables 5-6 and 5-7 detail the scenarios tested in this project under low (Category 1-2), and high evacuee demand (Category 3-5), respectively. Due to the large number of scenarios tested, a consistent naming scheme was devised for easy reference. The name of each test scenario starts with a letter referring to the type of lane reversal (N=no, P=partial, F=full), followed by a letter referring to evacuee demand (L=low, H=high), followed by a number representing the terminal location (31=US 31 or 185=US 185) and a number referring to the duration of lane reversal (00=no reversal; 11=11hrs; 16=16hrs, 26=26hrs). Scenarios developed for incident conditions use the letter "I" as a prefix.

Table 5-5. Summary of options considered

Consideration	Option 1	Option 2	Option 3	Option 4
Evacuation Severity	Low- Hurricanes 1-2 (L)	High- Hurricanes 3-5 (H)		
Evacuation Strategy	No lane reversal (N)	Full lane reversal (F)	Partial lane reversal (P)	
Duration of Lane Reversal	Low Severity- 11hrs (11)	Low Severity- 16 hrs (16)	High Severity- 16 hrs (16)	High Severity- 26 hrs (26)
Location of North Terminus	US 31 (31)	US 185 (185)		
Incident Presence	No incident	Incident (I)		

Table 5-6. Low-severity storms (category 1-2)

Serial	Network Name	Reversal	End Location	Reversal Information		
				Duration (hrs)	Start Time	End Time
1	NL3100	No	US 31	0	N/A	N/A
2	FL3111	Full		11	5:00 a.m.	4:00 p.m.
3	PL3111	Partial				
4	FL18511	Full	US 185			
5	PL18511	Partial				
6	FL3116	Full	US 31	16	5:00 a.m.	9:00 p.m.
7	PL3116	Partial				
8	FL18516	Full	US 185			
9	PL18516	Partial				

Table 5-7. High-severity storms (category 3-5)

Serial	Network Name	Reversal	End Location	Reversal Information		
				Duration (hrs)	Start Time	End Time
1	NH3100	No	US 31	0	N/A	N/A
2	FH3116	Full		16	5:00 a.m.	9:00 p.m.
3	PH3116	Partial				
4	FH18516	Full	US 185			
5	PH18516	Partial				
6	FH3126	Full	US 31	26	12:00 a.m.	2:00 a.m. (+1)
7	PH3126	Partial				
8	FH18526	Full	US 185			
9	PH18526	Partial				

Section 6
Results and Analysis

This section summarizes results from the analyses performed in this study using VISTA and the assumptions described earlier. The main measures of effectiveness (MOEs) include average speed, average vehicle travel time, and average delay. To obtain the desired results, two types of reports were processed. First, the General VISTA Reports were obtained and used to calculate average vehicle speeds. Queries were then processed that provided Critical Route Delay Reports, through which the average travel time and average delay were obtained for the I-65 corridor.

6.1 US 31 Terminus

6.1.1 Network-Wide Results

VISTA's General Report documents the number of vehicles (veh), total travel time in the network (TT in hrs), average vehicle travel time (AVG in min), and vehicle miles traveled (VMT). To calculate average speed, the VMT was divided by the entered travel time (TT).

Table 6-1 summarizes the network-wide impacts for the various scenarios considered under low- and high storm category evacuation conditions assuming 16 hours of evacuation and US 31 as the termination location. The information displayed is for the evacuating vehicles ("evacuees") and for the background vehicles ("car").

A review of the results shows that evacuating vehicles have a much higher travel time than other vehicles in the network in all the scenarios considered. This should not come as a surprise, as the majority of evacuees are heading to further destinations (such as the city of Montgomery) compared to the background traffic. In fact, evacuating vehicles move at a faster pace compared to local traffic (for instance, 65 mph versus 48 mph under the low storm category).

Under the low storm category, it is clear the differences in the MOEs summarized in Table 6-1 are negligible when comparing various scenarios. It can be concluded that the contra-flow type (partial versus full) has no noticeable impact on traffic operations. In fact, one can easily observe that the network shows a satisfactory performance under the baseline scenario, which modeled evacuation under category 1-2 storms without lane reversals (NL3100). This indicates existing network capacity is sufficient to handle the evacuation demand as is. Thus, lane reversal for Category 1-2 storms is not justified from a system-operation point of view.

Table 6-1. Network-wide results for low- and high-intensity hurricanes

	Loaded Vehicles	Entered Total TT (Hr)	AVG TT (Min)	Entered Veh. VMT (Miles)	AVG Speed (Miles/Hr)
Low-Intensity Hurricanes (Category 1, 2)					
NL3100- No Reversal					
All Vehicle	1087810	167547	9.24	8828190	52.69
Evacuee	35045	50156	85.87	3248543	64.77
Car	1052765	117390	6.69	5579647	47.53
PL3116 - Partial Reversal 16 Hours					
All Vehicle	1082432	163843	9.08	8668139	52.91
Evacuee	35045	49994	85.59	3250823	65.02
Car	1047387	113849	6.52	5417316	47.58
FL3116- Full Reversal 16 Hours					
All Vehicle	1082432	164057	9.09	8662865	52.8
Evacuee	35045	50038	85.67	3245882	64.87
Car	1047387	114019	6.53	5416983	47.51
High-Intensity Hurricanes (Category 3, 4, 5)					
NH3100- No Reversal					
All Vehicle	781442	472021	36.24	22376909	47.41
Evacuee	106349	398109	224.61	18862814	47.38
Car	675093	73912	6.57	3514095	47.54
PH3116 - Partial Reversal 16 Hours					
All Vehicle	778748	468251	36.08	22278233	47.58
Evacuee	106349	396090	223.47	18856652	47.61
Car	672399	72161	6.44	3421581	47.42
FH3116- Full Reversal 16 Hours					
All Vehicle	778748	391547	30.17	21300923	54.4
Evacuee	106349	319364	180.18	17880833	55.99
Car	672399	72183	6.44	3420090	47.38

Consideration of the High Storm Category MOEs show there is no statistically significant improvement in network performance from partial lane reversal under high-intensity hurricanes compared to the do-nothing scenario (NH3100), and thus partial reversal is not recommended. However, significant improvements in travel time and speed can be achieved for evacuating vehicles should a full lane reversal be implemented. More specifically, travel time for evacuating vehicles under full reversal (FH3116) reduced by nearly 25% compared to the do-nothing scenario (NH3100) and speed increased by over 15% whereas no adverse impacts were observed for the non-evacuating local traffic ("car").

It can also be observed that the increase in evacuation demand under high-intensity hurricanes (106,349 evacuees compared to 35,045 for the low-intensity scenarios) led to higher network travel times and lower speeds for all vehicles compared to low-intensity scenarios. For instance, average travel time almost tripled compared to that of the low-intensity scenarios. Moreover, average speeds for all vehicles dropped from 52.69 mph in NL3100 to 47.41 mph in NH3100. However, full lane reversal has the potential to alleviate these impacts as demonstrated by the increase in average speed for all vehicles to 54.40 mph in FH3116.

6.1.2 Corridor Results

To gain a better understanding of travel times and delays experienced by evacuating vehicles along the I-65 corridor, the VISTA Critical Route Delay Reports were obtained for the I-65 corridor under study. The main results are shown in Table 6-2.

Table 6-2. I-65 corridor results (low- and high-intensity hurricanes)

		Low-intensity hurricanes (category 1, 2)			**High-intensity hurricanes (category 3, 4, 5)**	
Scenario		**NL3100**	**PL3116**	**FL3116**	**PH3116**	**FH3116**
	Description	No Reversal	Partial Reversal 16 Hours	Full Reversal 16 Hours	Partial Reversal 16 Hours	Full Reversal 16 Hours
Normal NB Reversed Section	Path Length (Mile)	133.21	129.03	132.87	129.03	132.87
	Free-Flow Travel Time (Min)	116.3	112.3	115.6	111.1	114.4
	Simulation Travel Time (Min)	697.8	673.8	693.6	688.57	687.69
	Total Delay (Min)	581.5	561.5	578.	577.47	573.29
	AVG Delay (Min/Mile)	4.37	4.35	4.35	4.48	4.31
Reversed SB	Path Length (Mile)	-	129.56	132.61	129.56	132.61
	Free-Flow Travel Time (Min)	-	113.8	115.8	112.5	114.5
	Simulation Travel Time (Min)	-	682.8	694.8	1039.9	688.01
	Total Delay (Min)	-	569.	579.	927.4	573.51
	AVG Delay (Min/Mile)	-	4.39	4.37	7.16	4.32

Given the study conditions and a low storm, the results show that travel times along I-65 are slightly lower under lane reversal compared to evacuation without contra-flow, yet the differences are small and not statistically significant. Also, travel time on the normal northbound lanes is slightly less that on the reversed southbound lane. There was no significant delay in any of the scenarios along the I-65 corridor. These findings are consistent with those reported earlier and confirm the earlier conclusion that there is no need for contra-flow operations under Category 1 or 2 storms.

The findings for the high storm category depicted in Table 6-2 demonstrate that under partial reversal (PH3116) significant delays and increased travel times are observed on the reversed southbound lane. This shows that partial reversal is not an appropriate course of action for the study corridor under Category 3-5 storms. However, full lane reversal (FH3116) can provide full relief and allow all lanes of the reversed-lane facility to offer satisfactory quality of operations.

6.1.3 Discussion

In addition to the scenarios presented above, runs were performed for the remaining scenarios listed in Tables 5-6 and 5-7. However, the findings from these scenarios are fairly inconsistent and inconclusive. Numerous attempts were made to identify problematic spots and to intervene to unclog the network at these locations with little success. The irrationality of the results pose a concern, and the difficulty in identifying and addressing the cause is largely due to the size and complexity of the network in this study, which is unprecedented for this type of analysis.

Given limited resources and the pressure to publicize the findings of the study within a reasonable timeframe, the research team has little choice but to suspend additional efforts to refine the model and to expand the analysis.

Section 7
Conclusions and Recommendations

7.1 Study Conclusions

The concept of reversing traffic lanes for emergency evacuation has received lots of attention in recent years. The necessity and efficiency of this strategy is a topic of interest for the transportation and emergency-management agencies, the scientific community, and the public at large.

This report presents results from a project that evaluated ALDOT's hurricane-evacuation lane-reversal plan for I-65 from Mobile, AL, to Montgomery AL. A detailed traffic simulation and optimization model was developed in VISTA and used to test regular evacuation procedures along with a variety of alternative evacuation scenarios. Evacuation severity and strategy were considered, and their impacts on network operations were studied.

This work shows how a mesoscopic dynamic traffic-assignment model can be used to assist decision making for regional emergency preparedness for hurricane evacuations. Details are offered on simulation-model selection, data collection, model development, assumptions made, and scenario development and testing.

Model development and refinement is itself a tedious process due to the size of the network, the complexities introduced from changes in behavioral and travel patterns in case of emergencies, and the lack of detailed evacuation data. In this project a typical study network had over 4,300 nodes and 10,000 links. The car demand exceeded 1,000,000 vehicles. The evacuee demand was 35,000 vehicles under low-intensity storms and 106,349 vehicles under high-intensity storms. The study network ran for 26 hours to capture the evacuation patterns before, during, and after lane-reversal operations.

The results of the case study demonstrate that for the low storm categories (category 1-2) contraflow operations show no significant difference from no lane reversals. Therefore, given the study's assumptions there is no need to implement lane-reversal in the low storm category, as it appears that the existing capacity is sufficient to absorb the evacuating traffic demand. Consideration of travel times, delays, and speeds confirm that the northbound lanes of I-65 would be sufficient to accommodate the evacuating traffic from Mobile and Baldwin Counties for hurricanes Category 1 and 2.

For evacuations under severe storms (Category 3-5) the analysis shows that gains can be realized through the use of lane-reversal strategies. For example, the average travel speed of evacuating vehicles increases more than 15% for full reversal (e.g. FH3116) compared to no reversals (i.e. NH3100) and travel time drops by 25%. Such improvements in network performance are highly desirable in the event of an evacuation, and thus the implementation of full lane-reversal strategies along I-65 is both desirable and justified under high-intensity hurricane conditions (Category 3-5).

Overall, the work reported in this research study demonstrates the feasibility of the simulation approach in emergency preparedness in general and lane-reversal planning for evacuations in particular. Moreover, it highlights some of the challenges in the development of a large-scale mesoscopic model for evacuation analyses.

7.2 Study Contributions

The study contributions can be summarized as follows:

1. Because hurricane evacuations are relatively infrequent events, it is difficult for any transportation, planning, or homeland-security agency to test new procedures prior to implementation. The detailed evacuation model in this study provided ALDOT and other related agencies a useful tool that enables evaluation of alternatives, assessment of potential modifications to evacuation plans, and development of effective plans to respond to emergencies and incidents.

2. This study's regional transportation model, which was developed in VISTA, was extensive and comprised major evacuation routes from the Mobile and Alabama Gulf Coast region north to Selma and Montgomery, including 168 miles of I-65. The development of a simulation model was a major undertaking that involved extensive data collection and processing, data coding, and model refinement. The model is accessible through the internet and can be used beyond the scope of this study in future testing and evaluation studies, with minimum requirements for data collection and coding.

3. The results from the analysis provided insights on the effectiveness of existing lane-reversal operations and potential impacts from changes to used procedures. It was found that evacuation from Mobile and Baldwin counties under Category 1-2 hurricanes can be accomplished without the need of lane reversals, thus saving time and resources.

4. VISTA animation output files can be a useful tool for demonstrating the impact of a simulated strategy on transportation-network operations. This capability can be particularly useful for planning meetings to help participating stakeholders visualize the impacts associated with a particular plan.

5. The study identified and analyzed in depth existing applications of hurricane evacuations and reverse-laning procedures in the southeastern United States. Lessons learned from these studies can improve hurricane-evacuation planning in the state of Alabama.

6. The study also provided opportunities for training and technology transfer. Among those, a half-day training session on Dynamic Traffic Assignment and the VISTA model was organized and delivered in conjunction with the UTCA Symposium in Tuscaloosa, AL,

on November 13, 2006, to educate transportation professionals about the model's capabilities and available options. Moreover, three training sessions on the VISTA platform were developed and delivered as webinars (October 29, November 5, and November 12, 2008). The webinars covered VISTA basics and provided opportunities for hands-on experimentation with VISTA through tutorials focusing on Add Lane and Incident Scenarios. The webinars have been archived and are available for continuing education at the following links:

- Session 1. Introduction and Base Case Preparation
  http://uab.wimba.com/launcher.cgi?room=_uab_s_368952178011_344623_2008_1029_1026_02
- Session 2. Add Lane Scenario
  http://uab.wimba.com/launcher.cgi?room=_uab_s_368952178011_344623_2008_1105_1047_41
- Session 3. Incident Scenario
  http://uab.wimba.com/launcher.cgi?room=_uab_s_368952178011_344623_2008_1112_1040_26

7.3 Recommendations for Future Work

One of the main challenges was the lack of reliable evacuation-demand data. It is recommended that permanent counters be placed at regular intervals along the I-65 corridor under study and other strategic locations to allow for collection of regular- and evacuation-traffic data.

Additional work should refine the models developed in this study. The improved models should be used to assess the effect of incidents along the I-65 corridor during an evacuation with full, partial, or no lane reversals, as well as with and without route diversion.

In this study the developed model performed off-line analyses. Ultimately, the model should be expanded to support decision making during the course of an evacuation event. More specifically, a module should be designed in VISTA that will a) allow incorporation of real-time data into the model and b) be capable of running faster than real time. Using such a module during evacuations, effects from dynamic events on the roadway capacity (i.e. roadway flooding, fallen trees, signal blackout, roadway closures due to security concerns, traffic crashes, or other) can be emulated along with their impacts on traffic operations and alternatives could be evaluated in real-time in response to developing conditions.

Many difficulties were experienced in the development and calibration of the VISTA model for the large-scale network in this study. Other software platforms may be needed for improved modeling flexibility and performance.

ITS technologies are important to both the collection and dissemination of information to the public during hurricane evacuations. ITS applications provide effective ways to collect information on road and traffic conditions and to deliver information to the public in a timely manner. An assessment of existing ITS capabilities and future needs along Alabama's evacuation routes is recommended for improved evacuation operations.

While contra-flow is widely viewed as the best way to increase outbound flow during evacuations, it is not a cure all. In fact, the true costs and benefits of lane reversal in terms of its capacity improvements, safety, and manpower requirements remain largely unknown. It is recommended that a detailed cost-benefit analysis be performed to quantify the costs and user benefits from implementation of lane-reversal strategies and to identify options with the highest potential return for the investment.

Section 8
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Appendix

A-1. The current I-65 evacuation route

County	Location	Mile	#	Destinations
Mobile	Mobile		0	I-10 - Mississippi, Florida
			1	US-90 (Government Boulevard, SR-16)
			3	Airport Boulevard
			4	Dauphin Street
			5A	Springhill Avenue
			5B	US-98 (Moffett Road, SR-42)
	Prichard		8	US-45 (SR-13) – Prichard, Citronelle
			9	I-165 south – Prichard, Downtown Mobile
			10	West Lee Street
	Saraland		13	SR-158 / SR-213 – Eight Mile, Saraland
			15	Saraland, Citronelle
			19	US-43 – Satsuma, Creola
			22	Creola
	General W.K. Wilson Jr. Bridge over the Mobile River and Tensaw River			
Baldwin			31	SR-225 – Stockton, Spanish Fort
			34	SR-59 – Bay Minette, Stockton
			37	SR-287 (Gulf Shores Parkway) – Bay Minette, Rabun
			45	Rabun, Perdido
Escambia			54	CR-1
			57	SR-21 – Atmore, Uriah
			69	SR-113 – Flomaton, Wallace
Conecuh			77	SR-41 – Brewton, Repton
			83	Castleberry, Lenox
			93	US-84 (SR-12) – Evergreen, Monroeville
			96	SR-83 – Evergreen, Midway
			101	Owassa
Butler			107	Grace, Garland
			114	SR-106 – Georgiana, Starlington
	Greenville		128	SR-10 – Greenville, Pine Apple
			130	SR-185 / SR-10 Truck east – Greenville
Lowndes			142	SR-185 – Fort Deposit, Logan
			151	SR-97 – Letohatchee, Davenport
			158	To US-31 (SR-3) – Pintlala, Tyson
Montgomery	Montgomery		164	US-31 (SR-3) – Pintlala, Hope Hull
			167	US-80 west (SR-8 west) – Selma
			168	US-80 east / US-82 east (South Boulevard, SR-6 east/SR-8 east/SR-21) to US-231 (SR-53) / US-331 (SR-9)
			169	Edgemont Avenue
			170	Fairview Avenue
			171	I-85 north / Day Street - Atlanta
			172	Herron Street, Clay Street - Downtown Montgomery