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16. Abstract In response to both natural and man-made disasters, more and more emergency evacuation plans have been put forward and consistently aims to move a large disaster affected population through a highway network towards safer areas as quickly and efficiently as possible. The objectives of this study are 1) to verify the feasibility of applying the DYNASMART-P model to simulations of traffic characteristics in both normal and emergency conditions for the urban transportation system in the Greater Jackson metropolitan area in Mississippi and 2) to evaluate the effects of possible traffic management strategies on a large scale evacuation of people under emergency conditions on highway network in the Greater Jackson area. In this report, traffic network of the tri-county area including Hinds, Madison and Rankin was built through the mesoscopic traffic-network planning and simulation program DYNASMART-P based on the dynamic traffic assignment (DTA) model, and applied the model to a highway network on the routes of the evacuation. The OD demand as input for the simulation program was calibrated using observed traffic volume data collected in several critical routes of evacuation. The evacuation scenario of evacuation traffic from New Orleans was designed to study the impacts of the evacuation traffic to the Greater Jackson metropolitan area of Mississippi due to an assumed approaching hurricane disaster. Four traffic management strategies including no strategy (NS), ITS (IS), contraflow (CS), and contraflow plus ITS (ICS) were tested for their effectiveness in reducing congestion. Critically congested freeway segments under different evacuation intensity levels were identified based on the criteria of the average queue length percentage, speed, and delay. The causes for congested locations of the network were identified and analyzed.					
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EXECUTIVE SUMMARY

In response to both natural and man-made disasters, emergency evacuation aims to move a large disaster-affected population through a multimodal transportation network toward safer areas quickly and efficiently. Effective emergency evacuation depends on careful planning and adaptive real-time management from an integrated system-level perspective, calling for the coordination of transportation agencies, metropolitan planning organizations, emergency management authorities, and highway patrol centers to enable collaborative metropolitan highway network evacuation. The first objective of this study is to verify the feasibility of applying the DYNASMART-P model to simulation of traffic characteristics in both normal and emergency conditions for the urban transportation system in the Greater Jackson metropolitan area in Mississippi. The second objective is to develop and evaluate emergency evacuation strategies for a large scale evacuation of people under emergency conditions in the Greater Jackson area. This report consists of the following chapters:

Chapter 1 Introduction

- Highlights the research objectives and outlines the report.

Chapter 2 Background

- Reviews various evacuation simulation packages that were developed, using microscopic, mesoscopic, or macroscopic simulation approaches and effective traffic control strategies that were used to improve efficiency and capacity of a transportation system during emergency evacuations.
- Introduces the research background of the project and briefs the simulation package adopted in the project and its prior applications.

Chapter 3 Development of Network Model with DYNASMART-P

- Describes the network modeling with three types of data, which are geographic data, hourly traffic volume data, and origin-destination demand matrix data.

Chapter 4 Calibration and Setup for Simulation

- Calculates OD demand matrixes including background and evacuation demands.
- Presents a detailed study methodology for the research project.

Chapter 5 Case Study of Evacuation Traffic from New Orleans

- Introduces the evacuation scenario.
- Develops traffic management strategies.
- Develops simulation results.
- Highlights the causes for the most congested road links in simulations.

Chapter 6 Observations and Summary

- Summarizes the findings of the study.

1. INTRODUCTION

In response to both natural and man-made disasters, emergency evacuation aims to move a large disaster affected population through a multimodal transportation network towards safer areas quickly and efficiently. Effective emergency evacuation depends on careful planning and adaptive real-time management from an integrated system-level perspective. This calls for the coordination of different organizations including transportation agencies, metropolitan planning organizations, emergency management authorities and highway patrol centers to enable collaborative metropolitan highway network evacuation.

The Katrina evacuation of New Orleans was a wakeup call for designing comprehensive evacuation of citizens without means of personal transportation in a multimodal network environment. The extremely long queues clogged along evacuation routes in the Houston evacuation event, on the other hand, highlight the need to provide a staged evacuation plan and real-time traffic information to assist evacuees in making rational pre-trip decisions. Specifically, managing traffic operations during or after major emergency events such as terrorist attacks or hazardous weather conditions, is one of the critical components in emergency management of the transportation system in order to effectively respond to, recover from, and mitigate the impacts of a disaster. The key abilities in effective emergency operation include the determining of the best set of evacuation routes and scheduling for a large-scale movement of people under time-sensitive, hazardous conditions. Such an evacuation strategy under threats ranging from terrorists to hurricanes must reflect various resources/constraints of transportation systems network at different levels, i.e. local and regional, under dynamically changing traffic and emergency conditions.

One of the challenges in pre-evacuation planning and post-evacuation response is accurately modeling the traffic congestion evolution (queue build-up, spillback, and dissipation) in a dynamic and complex network after emergency events. It has been widely recognized that the analytic congestion functions used in static traffic assignment models are unable to realistically describe the propagation and dissipation of system congestion under time-varying traveler demand patterns. Alternatively, Dynamic Traffic Assignment (DTA) modeling tools uniquely address the needs of evacuation network performance under various traveler information and traffic management strategies. DYNASMART-P and DynusT, in particular, are among the new generation of traffic analysis tools developed under the FHWA DTA research project in support of traffic operations and planning decisions. The FHWA is currently promoting the use of DYNASMART-P and DynusT in the professional community for region-wide transportation operations planning to (1) address operational issues in the transportation planning process and (2) develop and evaluate traffic management and control strategies, e.g. in the contexts of Integrated Corridor Management and Emergency Transportation Operations.

1.1. Study Objectives

The specific objectives of this study include:

1. Verifying the feasibility of applying DYNASMART-P and/or DynusT models to simulate traffic characteristics in both normal and congested road conditions for the urban transportation system in the Greater Jackson area.
 - a. Reviewing state of the art literature and products of traffic simulation models that are capable of solving traffic problems of time-varying demands using static/dynamic traffic assignment methodologies;
 - b. Becoming familiar with DYNASMART-P and/or DynusT models in an intense learning process;
 - c. Modeling and calibrating the transportation network and traffic demand inputs using DYNASMART-P and/or DynusT with routinely collected traffic volume, speed, and density data at specific locations. Zonal demands and network mapping data are provided by the MDOT Planning Division.
2. Simulation study of impacts of large scale evacuation of people in the Greater Jackson metropolitan area of Mississippi.
 - a. Developing emergency scenarios for the network and preparing data inputs for DYNASMART-P and/or DynusT models;
 - b. Simulation study of impacts of evacuating traffic on the highway network in the Greater Jackson Area;
 - c. Evaluating the effects of state of the practice traffic management strategies on evacuation performance;
 - d. Developing and presenting research findings.

1.2. Outline of Report

The report is organized as follows: after the introduction in Chapter 1, Chapter 2 provides a wide-scoped review of the most feasible strategies that have been used to improve efficiency and maximize transportation infrastructure capacity on evacuation conditions such as contra-flow operation, evacuation-order coordination, and mass-transit utilization. Popular evacuation simulation packages developed using microscopic, mesoscopic, or macroscopic modeling approaches were reviewed. Chapter 3 describes the study area and introduces three kinds of data required in the project: geographic data, hourly traffic volume data, and origin-destination demand matrix data. The next part of the chapter presents the detail-preparation process for each category of input data including network Excel files, Node/Link/TAZ GEO files, and OD demand files. The building of a network model in DYNASMART-P and/or DynusT is introduced at the end of the chapter. Chapter 4 presents the calibration of data inputs for the simulation program. Chapter 5 studies the evacuation scenario of evacuating traffic from New Orleans to the Greater Jackson area. The OD demand matrixes including background and evacuation demand were calculated and prepared respectively. The simulation tests were run with different OD demands under varying levels of evacuation intensities. The most congested road segments were identified and the causes for the congestions were discussed based on the simulation results. In Chapter 6, the findings in the project were summarized.

2. BACKGROUND

One of the objectives of Federal Emergency Management Agency (FEMA) is to build a culture of preparedness across the nation for all hazards. FEMA will help expedite the recovery of individuals and communities from floods and other disasters through effective risk analysis and pre- and post-disaster hazard mitigation planning (1). As the evacuation traffic increases exponentially, disruption can cascade and significantly impede the traffic operations at urban areas. The disruption in our transportation systems may cause economic and societal dislocations if the impacts are not adequately estimated. Hence pre-planning is of a critical nature for evacuation operations. A traffic simulation program is important in the pre-planning process as it aids transportation agencies to input, execute and evaluate alternative strategies and enhance system reliability. The simulation program is also designed to unearth vulnerable points in our transportation system, to adopt precautionary measures and operational strategies to strengthen our well-laid transportation systems.

There has been an immense amount of work in modeling evacuation that led to the development of various simulation methods (2, 3, 4, 5, 6, 7, 8). Generally these evacuation simulation packages fell in the microscopic, mesoscopic, and macroscopic simulation approaches. The most feasible strategies that have been used to improve efficiency and maximize transportation infrastructure capacity on evacuation conditions are contra-flow operation, coordinated or staged evacuation, and mass transit utilization.

2.1. Evacuation Strategies

Contra-flow Operation

The contraflow strategy involves the reversal of flow in one or more inbound lanes of a freeway as traffic in the outbound direction. Contraflow operation significantly increases the outbound capacity by taking advantage of the untapped capacity of the inbound lanes without the need to construct additional lanes. This method has been widely used in the coastal states that are threatened frequently by hurricanes (6).

An approach was introduced by Tuydes and Ziliaskopoulos (8) who used a modified cell transmission model (9, 10) to optimize the system travel time and calculate the optimal capacity reversibility on a traffic network under unusual demand patterns. The proposed model addresses some of the problems including representation of vehicle-level movements, spatio-temporal changes in the disaster conditions, and optimal capacity reversibility calculation capabilities. One shortcoming of the model is the high computation cost of its analytical nature which prevents its use for actual urban networks. In (11), they developed a simulation-assignment tabu search-based heuristic algorithm to compute optimal reversibility designs for large scale networks in order to reduce total system time.

Wolshon et al. (12, 13, 14) compared two alternative scenarios for a same segment using a CORSIM microscopic traffic simulation program to model the freeway configuration. The results show the critical role played by the entry point and the plan to

load vehicles into contraflow lanes. They also give suggestions to significantly improve the effectiveness of the contraflow operation using design of contraflow entry points.

Lim and Wolshon (15) conducted a study to evaluate the effects of the various contraflow termination designs planned for the Atlantic and Gulf Coast states. Six generic configurations capable of representing traffic operations in the vicinity of the termination point were developed using CORSIM as the analysis tool. The network performance measures were used to rank the configurations. The study revealed important trends in the use of the contraflow evacuation strategy.

Coordinated or Staged Evacuation

Inefficient issuance of evacuation orders results in a high rate of loading from all origins leading to avoidable congestion and putting people most vulnerable to disaster at a greater risk. There is a definite need to co-ordinate the issuance of an evacuation order for efficient evacuation operations.

Ozbay et al. (16) conducted a critical analysis on demand generation and network loading models for determining optimal evacuation staging (scheduling) schemes. They reviewed three widely used models: S-curves, Tweedie's, and Sequential Logit Models. Using the system optimal traffic assignment, they concluded that the S-curve and Tweedie's demand generation resulted in unrealistic delays and the Sequential Logit model provided more realistic results. Mitchell and Radwan (17) evaluated various heuristic strategies to improve evacuation clearance time of people evacuating from Ormond Beach. This research showed the advantage of staging demand during evacuation. Liu et al. (18) proposed a cell based network model using Tweedie's demand generation model in order to determine optimal staging schemes. In light of the research conducted by Ozbay et al., there was a need to incorporate Sequential Logit Models as a demand generation model for determining optimal staging schemes during hurricane evacuations. A major drawback was the assumption that the demand from an origin was generated only after the issuance of the evacuation order. Sbayti and Mahmassani (19) realized that by staggering the evacuating load onto the network, the onset of congestion may be delayed, and people can be evacuated faster. Hence, they considered the problem of scheduling evacuation trips between a selected set of origin nodes and destinations, with the objective of minimizing the network clearance time. Shen et al. (20) proved that an optimal traffic pattern always exists that contains no holding in the context of evacuation planning. They proposed a dynamic network simplex method for solving the simplified SO-DTA model which represents traffic flow propagation by a point-queue model. For the original cell-based SO-DTA, they suggested an iterative procedure that can effectively eliminate holdings in a solution obtained from a conventional linear programming algorithm. Dixit and Radwan (21) proposed an optimization model based on the cell transmission model to determine optimal scheduling of evacuation orders. This model used a Sequential Logit model and did not require a closed form for the evacuation demand as part of the optimization model. It only required that the demand be generated for every possible evacuation order. For the numerical problem the scheduled evacuation order provided an improvement of 11% in total vehicle hours. Chen (1) studied the simultaneous staged evacuation for a road network. The results showed that the effectiveness of staged evacuation depends upon the type of roadway network

available and the population density of the area. The results also confirmed that if there is no congestion on the roadway, simultaneous evacuation would be a good option.

Transit Utilization

Although several previous studies have been done to improve the capacity of existing road network during evacuation conditions, it is not always enough to use the contra-flow and other general traffic control strategies in many metropolitan regions. This is true because there are some high population-density areas with limited capacities in existing road networks. Therefore, a specific emergency response plan based on the existing transit system was studied to deal with the difficulties of evacuation in these regions.

In order to enhance the evacuating ability of rescue vehicles (i.e. to increase their load factors), conserve capacities of existing road networks, avoid potential traffic chaos and congestion during the evacuation, and take care of the requirements of disabled and poor citizens, an initial framework of transit-based evacuation plans was developed by Chen and Chou (22). Based on the research results, Chen and Chou (23) used a bi-level optimization model to determine the waiting locations and corresponding shelters of the transit-based emergency evacuation plan and also dispatch rescue buses toward the combinatorial locations. Furthermore, a contra-flow simulation was elaborated to disperse the inside and ambient traffic of the target area. They found the transit-based evacuation plan with the contra-flow operations to be superior to those without the contra-flow operations. If more people should choose to evacuate via transit systems, that plan would reduce the difficulties of dispersing traffic and improve the system performance remarkably. ElMitiny et al. (24) used VISSIM traffic simulation tool to evaluate alternative plans for the deployment of transit during an emergency situation in a transit facility such as a bus depot. A total of nine evacuation scenarios were simulated and analyzed to find the best evacuation strategy for the local transit company's main bus depot. Evacuation strategies evaluated included traffic diversion, bus signal optimization, access restriction, different destinations, and pedestrian evacuation. Mastrogiannidou et al. (25) used a dynamic network model in their study of transit-assisted emergency evacuation procedures. They considered three different scenarios with different numbers of available evacuation transit vehicles for the design of the evacuation container terminals in the Port Elizabeth-Newark area of the Port of New York and New Jersey.

2.2. Evacuation Traffic Simulation Programs

The modeling and design of a more effective emergency evacuation plan has been rigorously investigated (3, 4, 5, 6, 7, 26) since the early studies dealing with traffic management under emergency conditions. The previous research has identified that the most feasible operational strategies to maximize the efficiency and performance of transportation infrastructure under evacuation conditions were contraflow operation (11, 12, 13), coordinated evacuation operation (18, 19, 21) and mass-transit utilization (23, 24, 25). Meanwhile, several evacuation simulation packages were also developed using microscopic or macroscopic simulation approaches. For example, NETSIM (27), NETVAC (28), DYNEV, MASSVAC (29), HURREVAC (30), OREMS (31) and TransModeler (32).

Several simulation models of different degrees of granularity of network representation were developed in the last decades. The main disadvantage of a microscopic model is the extensive data and computer resource requirements. However, macroscopic models do not have the capability of keeping track of individual driver decisions. Therefore, the mesoscopic dynamic traffic assignment (DTA) simulation package, namely the DYNASMART-P and its update version DynusT, were used to establish the simulation network models for the study (Meso models denote a greater geographic area than micro models and enables for precise results than macro models as they track each vehicle when it traverses through links between specific origin and destination) (33).

NETSIM (KLD, 1980)

The network simulation package of NETSIM was developed by KLD Associates, Inc. It is a microscopic, stochastic highway traffic simulation model and can be used to simulate traffic performance under different control strategies and under heavy traffic demand. The vehicles simulated in the network are processed for each time interval subjected to the imposition of traffic control systems.

HMM Associates (34) and Urbanik (35) first used NETSIM to estimate evacuation time for a nuclear plant area. Though the NETSIM model is a widely-validated procedure and found to perform reasonably well, the application of NETSIM to evacuation analysis has some drawbacks, including limited capacity to handle large regional networks and lack of a dynamic route selection model (every turning movement at an intersection has to be specified).

NETVAC (MIT, 1981)

The NETVAC was developed by Sheffi et al. (28) specifically for nuclear evacuation analysis. NETVAC is a fixed-time macro traffic simulation model using established traffic flow models and relationships to simulate the flow of vehicles through a network. NETVAC was used to estimate network clearance time for areas surrounding nuclear power plant sites. It was specifically designed to model evacuation traffic patterns including queue formation processes, dynamic route selection, and a wide variety of options designed to simulate alternative evacuation scenarios.

The major disadvantages of the model include 1) It is insensitive to evacuees' behavior; 2) It is structured in a descriptive mode rather than designing and planning; and 3) It is a deterministic model rather than a probabilistic and dynamic simulation model. In addition, as indicated from the input requirements, NETVAC is not given the capability of estimating the travel demand associated with evacuations, and the spatial and temporal loading pattern has to be input to NETVAC as given information.

DYNEV (KLD, 1982)

The DYNEV model was developed by KLD Associates, Inc. It is a macroscopic model for simulating evacuation from sites around a nuclear power plant which employs the principles of flow continuity and flow dynamics. In the DYNEV model, the road network is represented as a series of links connected at nodes representing the intersections of these segments. The outputs can help identify the bottlenecks on the evacuation route so

that appropriate measures can be taken to improve the operations. The improved computational efficiency serves to substantially reduce the computing time and storage. The number of trips entering and leaving the roadway system is required as input data for the DYNEV model.

MASSVAC (VP, 1985)

The MASSVAC was developed by Hobeika et al (29). It is a macroscopic model for the evacuation process and utilizes the all-or-nothing traffic assignment or Dial's algorithm to simulate the traffic movements during evacuation. The inputs to the program include the trip production at each origin node, loading rate curve factors as well as link characteristics such as link length, road capacity, number of lanes, free-flow speed, link type, and coordinates of each origin and destination point. The program loads evacuating vehicles onto the highway network according to loading rate curves, determines their best evacuation routes, estimates network clearance time, and identifies highway bottlenecks. This program includes a trip distribution model. Because people need to be evacuated as quickly as possible from a nuclear disaster area, the model has been developed so that the evacuees choose the shortest routes to get out of the at-risk area first and afterwards seek the proper destination shelter. This is completely different from hurricane evacuation trip distribution, which is usually well-planned before the evacuation begins.

MASSVAC was applied to develop a hurricane transportation evacuation plan for the city of Virginia Beach (36). In this study, four scenarios with different hurricane intensity levels and operational strategies were evaluated. The factors significantly affecting the overall evacuation times under hurricane/flood conditions were found to be the size of the population to be evacuated, the location and number of shelters, the capacity of the evacuation routes, the time available for evacuating from the threatened areas, and the specific traffic operations strategies used for alleviating the congested links.

HURREVAC (COE, 1994)

The HURREVAC program was developed by Sea Island Software, Inc. beginning in 1988 in response to a need for computer-based management of data produced by various federal hurricane evacuation studies. It assists government emergency managers in making decisions for their states/communities when under a hurricane threat. First major use of the program came with Hurricane Hugo (30) in South Carolina and Georgia. Subsequently, the program was developed for 13 states, the US Virgin Islands and Puerto Rico.

HURREVAC tracks hurricanes on computer plot maps using information from the National Hurricane Center (NHC) and estimates when various evacuation decisions should be made using data from the federal hurricane evacuation study for the area. The process works as follows: a) The arrival of gale-force (34 knots or 39mph) winds in the area is computed using the NHC projections with adjustment for a direct-hit or worst-case approach to the community; b) Clearance times are computed using Saffir-Simpson scale category of storm, response of the public, and occupancy readings for the area. The basic data for the clearance times is produced by a local hurricane evacuation study usually performed by the Corps of Engineers, National Weather Service, and Federal Emergency Management Agency (FEMA). The clearance time is subtracted from the

gale arrival time to reach a suggested evacuation decision time. This approach is based on the need to have the at-risk population out of vulnerable areas before gales reach the coast.

OREMS (ORNL, 1999)

Another simulation model is the Oak Ridge Evacuation Modeling System (OREMS) (31). This microcomputer-based system was developed by the Center for Transportation Analysis at the Oak Ridge National Laboratory (ORNL) to simulate the traffic conditions of a highway network as evacuation progresses. It is an integrated system consisting of three major components: a data input manager, a traffic simulation model, and an output data display manager.

The analytical core of OREMS is a FORTRAN program ESIM (Evacuation SIMulation), which combines the trip distribution and traffic assignment sub-model with a detailed traffic flow simulation sub-model. The combined trip distribution and traffic assignment sub-model was developed by the researchers at ORNL, and the traffic simulation model was derived primarily from the TRAF simulation system developed by FHWA and therefore has many similarities to that system. The combined algorithm of trip distribution and trip assignment expands the original network by introducing super-destination nodes and adding a set of pseudo-links which connect the super-destination nodes to the original destination nodes.

Each super-destination node is connected to a subset of destination nodes. These subsets of destination nodes are designed in such a way that the flow needs to be assigned from any origin to a single super-destination node. The algorithm solves this problem by using the assignment model on the expanded network. The flows on the expanded network are converted into flows on the original network by deleting the super-destination and the pseudo-links.

Given evacuation travel demand, ESIM determines the destinations selected by evacuees and the routes taken to reach the selected destinations through traffic distribution and assignment. It then performs a detailed simulation of vehicular traffic operations on the evacuation network using these projected flows and routes under prevailing roadway and traffic conditions. The model can pinpoint evacuation routes, estimate service rates in the evacuation network by location and time, identify traffic operational characteristics and bottlenecks, estimate evacuation times across various categories, and provide information on other elements of an evacuation plan.

It also allows the analyst to experiment with alternative routes and destinations, various alternative traffic control and management strategies, and different evacuee participation rates.

TransModeler (Caliper, 2000)

TransModeler is a powerful and versatile traffic simulation package applicable to a wide array of traffic planning and modeling tasks (32). TransModeler can simulate all kinds of road networks from freeways to downtown areas and can analyze wide area multimodal networks in great detail and with high fidelity. It can model and visualize the behavior of complex traffic systems in a 2-dimensional or 3-dimensional GIS environment to

illustrate and evaluate traffic flow dynamics, traffic signal and ITS operations, and overall network performance.

TransModeler breaks new ground in ease-of-use for complex simulation applications and integrates with TransCAD, the most popular travel demand forecasting software in the U.S., to provide a complete solution for evaluating the traffic impacts of future planning scenarios. Moreover, the TransModeler mapping, simulation, and animation tools help present study findings to decision-makers in a clear and compelling fashion.

Based upon the latest research, TransModeler employs advanced methodological techniques and software technology to bring traffic simulation into a new era. TransModeler models the dynamic route choices of drivers based upon historical or simulated time-dependent travel times, and it also models trips based on origin-destination trip tables or turning movement volumes at intersections. It simulates public transportation as well as car and truck traffic and also handles a wide variety of ITS features such as electronic toll collection, route guidance, and traffic detection and surveillance. TransModeler works with travel demand forecasting software to provide an integrated capability to perform operational analysis of transportation projects and plans. Traffic simulation results can also be recalled for use in travel demand forecasting.

DYNASMART-P (FHWA, 2002)

DYNASMART-P, or the Dynamic Network Assignment-Simulation Model for Advanced Roadway Telematics supports transportation network planning and traffic operations decisions, including evaluation of ITS deployment options, through the use of simulation-based dynamic traffic assignment. This tool combines dynamic network assignment models, used primarily in conjunction with demand forecasting procedures for planning applications, and traffic simulation models, used primarily for traffic operational studies (33). DYNASMART-P provides the capability to model the evolution of traffic flows in a traffic network which result from the decisions of individual travelers seeking for the best paths en-route over a given planning horizon. It overcomes many of the known limitations of static tools used in current planning practice. These limitations pertain to the types of alternative measures that may be represented and evaluated and the policy questions that planning agencies are increasingly asked to address.

2.3. DYNASMART-P Applications

Brown et al developed a hurricane evacuation model for the Greater Houston Area that incorporated the development of a dynamic traffic assignment module for evaluating the performance of major evacuation routes. A strategic model (using super-zones) and a detailed model (using the regional network and zone system) were together employed for screening and evaluation of evacuation plans based upon system-wide performance and zone-specific clearance times (7).

For the study “Evaluating Regional Contra-flow and Phased Evacuation Strategies for the Central Texas Area,” a large scale regional traffic simulation modeling approach was incorporated by the employment of DYNASMART-P. The study provided detailed aspects of benefit and impact from contra-flow and phased evacuation with respect to

various performance measures such as travel time, cumulative safe arrival, and space-time speed profile. Thus DYNASMART-P was instrumental in ascertaining that the phased evacuation strategy in conjunction with the contra-flow operation significantly benefitted evacuees from the coastal areas at the cost of slightly increasing travel time for evacuees from other flood zones (37).

The Daytona (Florida) Speedway Evacuation Modeling project applied the DYNASMART-P simulation model to the evaluation and development of a new evacuation plan for the speedway. An advanced dynamic traffic assignment model was needed for the research due to queues that develop during evacuations, unstable traffic flow, the need to examine ITS strategies and devices, and the desire for a graphic simulation and presentation capability. DYNASMART-P was chosen due to its ability to meet these requirements. The model results showed that the proposed emergency evacuation routing with road/lane closures, elimination of vehicle-pedestrian conflicts, additional one-ways and added capacity of US 92 via De Land reduces network clearance time by 25 percent (90 minutes) and clears the Speedway 40 minutes early (37).

A case study using DYNASMART-P was done in Knox County, Tennessee, for the study entitled “Does Non-compliance with Route/Destination Assignment Compromise Evacuation Efficiency?” The purpose of this study was to examine whether the rate of evacuees’ compliance with pre-determined route/destination assignments would have an impact on the efficiency of evacuation operations. The Knox County roadway network was geo-coded in DYNASMART-P with detailed geographic representation, including on-ramps, off-ramps, and interchanges as well as control information. The results proved that unexpected improvement resulted from a reduction in congestion along designated evacuation routes as evacuees spread out to less prominent parallel streets and other non-congested outbound routes. The study suggested that it appears that rethinking traditional approaches in this field could yield substantial benefits to evacuees in future crises (38).

2.4. Summary

The literature review has indicated that the potential impacts of traffic evacuating from a disaster area due to an approaching hurricane on the network performance of area passed by have not been underscored and estimated so far. The fact that Jackson is the only major metropolitan area in Mississippi which is located on the evacuation route of New Orleans, Louisiana, and that Mississippi is among the gulf coast states that are frequently affected by hurricanes has justified an emergency evacuation simulation study to be carried out for the area. There are two main categories of evacuation simulation packages: microscopic and macroscopic simulation based models. The main disadvantage of the microscopic model is the extensive data and computer resource requirements, while the macroscopic models do not have the capability of keeping track of individual driver decisions. Given the size of the simulation area and the level of traffic demand involved in the study, the mesoscopic simulation model – namely DYNASMART-P – was used (meso models denote greater geographic area than micro models and enable for precise results than macro models as they track each vehicle when it traverses through links between specific origin and destination). Additional reasons for choosing this model was based mainly on its wide acceptance within the transportation community as well as the fact that it produces a wealth of detailed measures of effectiveness.

3. DEVELOPMENT OF NETWORK MODEL

3.1. Study Area

The study area is located in the southwest geographic center of the state of Mississippi east of the Mississippi River and north of New Orleans. The area is trisected by the Pearl River which divides Madison, Hinds, and Copiah counties on its west bank from Rankin and Simpson counties to the east and the Big Black River which divides Yazoo and Warren Counties to the west bank from Madison and Hinds counties to the east.

The study area includes substantial portions of the Greater Jackson area of the tri-counties including Hinds, Madison, and Rankin counties. The estimated population and the area of the study area as recorded by the 2000 census were 440,801 and 2,400 square miles.

The study area, a radial system of major through-routes including I-20, I-55 and US 49 is bisected east and west by Interstate 55 (I-55) and north and south by Interstate 20 (I-20). Interstate 220 (I-220) provides an additional connection between I-20 and I-55, establishing a closed loop around the core study area. In addition to US 49, there are two other federal highways in the study area that have been partially displaced by newer interstate routes; US 51, which runs roughly north and south just east of I-55, and US 80 which runs east and west primarily north of I-20. The principal state-maintained routes that link the study area to other parts of Mississippi are highways 18, 25, 463, 468, and 469. The scenic Natchez Trace Parkway also runs north and south in the study area.

3.2. Data Collection and Preparation

In this study, three kinds of data are required: geographic data, hourly traffic volume data, and origin-destination demand matrix data.

Geographic Data

The geographic data which includes an amount of basic network characteristics for the tri-counties in the Greater Jackson area are used to create the highway network model. The “shapefile” format, developed by ESRI (Environmental Systems Research Institute) for spatial data in a geographic information system (GIS), features the shape files for nodes, links, and traffic analysis zones (TAZ) which were provided by MDOT. There are in total 4607 nodes, 10288 links, and 691 TAZ zones in the study area.

Traffic Volume Data

The hourly traffic volume data refers to the number of vehicles that pass a point on a highway facility during a specified time period. The data is needed for calibrating the traffic flow model in DYNASMART-P and was collected by the research team.

Origin-Destination Demand Data

The origin-destination demand matrix as a necessary input data for DYNASMART-P was provided by MDOT and stored in TransCAD data format.

In this study, the graphic user interface (GUI) program Nexta developed specifically for DYNASMART-P by the University of Utah team was used to build the network model. There are three types of data files to be imported: network definition files, node/link/taz geographic property files, and origin-destination (OD) demand files. The network definition file includes 4 spread sheets named NODE, LINK, ZONE and SIGNAL in Excel. The Node/Link/TAZ.GEO files can be produced directly from the TransCAD data files. The OD demand file contains daily traffic trip demands which need to be converted into a peak hour demand matrix by multiplying the daily trip demands by peak hour percentages. These data were contained in the MDOT data set provided by MDOT's Planning Division.

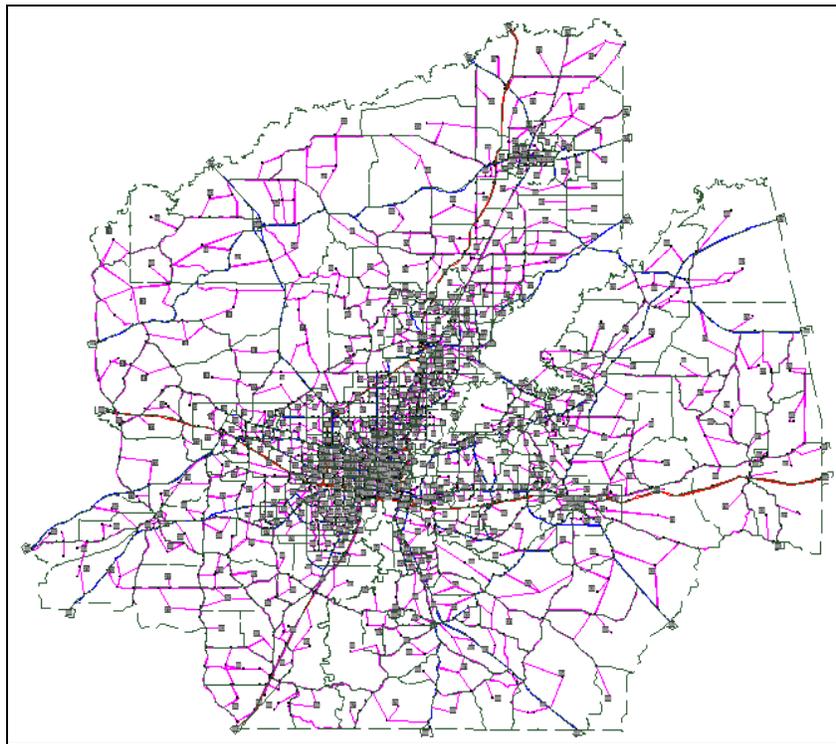


Figure 1 Road Network in Nexta

3.3. Network Modeling with DYNASMART-P

The program Nexta provides an import wizard to allow the users to create a network model. The steps are shown below.

- 1) Start Nexta and choose *File, Import Files, Import GIS Data Set, and Import Network Table* to display the Open dialog box
- 2) Choose the network Excel file prepared in 3.2 and click Open
- 3) Choose *File, Import Files, Import GIS Data Set, and Import Node/Link/Zone Geo Files* to display the Open dialog box
- 4) Choose node.geo, link.geo and zone.geo in order and click Open.

An example highway network model built in the Nexta program is shown in Figure 1. In the figure, red solid lines are used to represent freeways. Arterials highways are represented with blue solid lines and the collector roads by pink solid lines. The grey solid lines represent local roads, and traffic analysis zones (TAZ) are shown with green broken lines in the network for the Greater Jackson area.

4. CALIBRATION AND SETUP FOR SIMULATION

4.1. Calibration Method

To evaluate the accuracy of the dynamic traffic assignment model in DYNASMART-P and to determine input parameters of hourly volume percentages, the calibration comparison method was used. The calibration method is an iterative process of determining the optimum input parameters and making output results meet predefined tolerance criteria under specified traffic conditions by comparing simulation output results with corresponding observed traffic volume data. The MAPE (Mean Absolute Percentage Error) formula was adopted for the calibration. MAPE is one of the most popular equations and mostly utilized in engineering practice. The complete calibration process is shown in Figure 2.

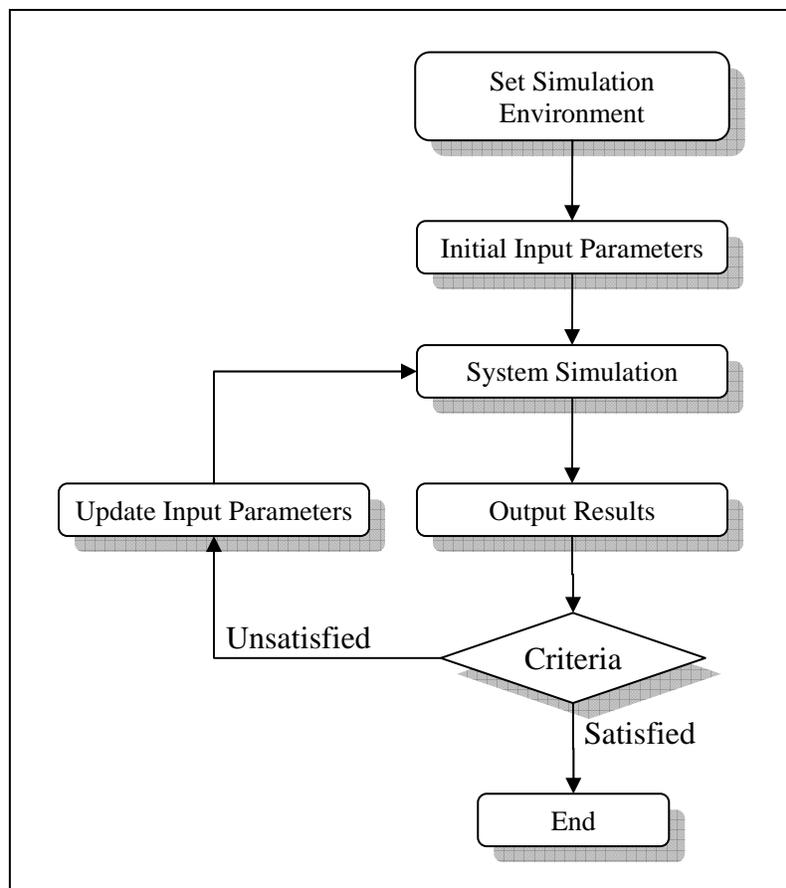


Figure 2 Calibration Flow Chart

The above figure shows that the calibration process is a set of operations which evaluate the difference between the simulation output results under specified simulation environment conditions and the corresponding measured values. The model input parameters (simulation environment conditions) were adjusted to make the simulation results to be as close to the observed traffic characteristics as possible at selected

locations. A comparison indicator computed from the simulated and observed traffic characteristics using the selected MAPE model was used as the goodness-of-fit criterion.

Traffic Volume Data Collection

Since the calibration is a comparison between two different quantities, traffic volume data needs to be collected (observed) and compared with the simulated traffic volume results. Traffic volume data was collected by watching the online images of the ITS cameras owned by MDOT’s Traffic Division (39). The first step in this process was to record videos at selected locations within the network as shown in Figure 3. In this figure, 12 video camera locations were chosen and their positions were described in Table 1. The videos were recorded for 20 minutes during each of the morning peak hours from 7 to 10 AM.

Then the videos were played back and counted for 15 minutes to determine the 15-minute vehicle volumes. After the 15 minute interval, the count of the vehicles that passed by was recorded along with the location of the camera and the time the video was recorded. This process was repeated for every location within each of the peak hours. The 15-minute volumes were then multiplied by 4 to estimate the corresponding hourly vehicle volumes. The final results were then input into the calibration worksheet. The data collection was a very laborious and time consuming process which was extremely important to the accuracy and quality of the simulation results of the study.

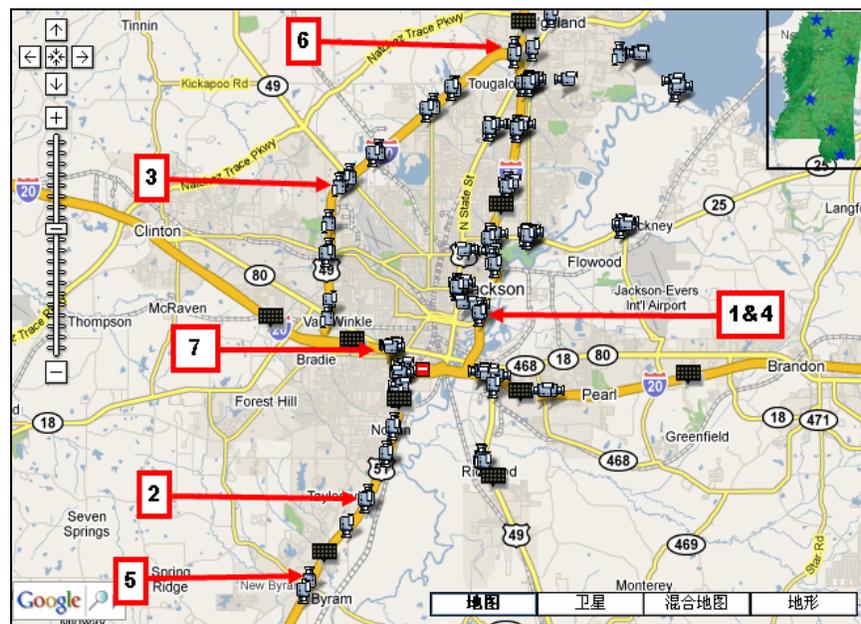


Figure 3 Camera Locations in Jackson Area (Source: MDOT)

A seemingly trivial step was to match the data collection locations to the exact locations in the network model. This allowed for readings from the simulation at the exact network locations where the vehicle volumes were manually counted. The locations were found on the network model and the identified link IDs were then recorded. The results are shown in Table 1.

Table 1 CCTV Camera Locations

No	Link ID	Location
1	5768	I-55 South at High Street
2	1959	I-55 S North at Elton Road
3	2603	I-220 North at Medgar Evers
4	5761	I-55 North at High Street
5	1800	I-55 North at Siwell Road
6	6685	I-55 North at I-220
7	3508	I-20 West at Valley Street

Simulation Calibration Criteria

In the calibration process, the Mean Absolute Percent Error (MAPE) was chosen as the numerical model to evaluate the closeness of comparisons between simulated and observed traffic volumes. Each item in the MAPE equation is the absolute difference between the actual value A_t and the estimated value F_t divided by the actual value A_t , where t is a fitting (comparison) point. The summation of all absolute items over all comparison points along time and/or location divided by the number of fitted points n is MAPE, as shown in Equation 1.

$$MAPE = \frac{1}{n} \sum_{t=1}^n \left| \frac{A_t - F_t}{A_t} \right| \quad (\text{Eq. 1})$$

In this study, the calibrations were based on three different levels: the first is on an areawide basis by comparing the overall aggregate assignment volume for all links in the network model with the overall aggregate demand volume provided by MDOT with MAPE following the rule of plus or minus five percent ($\pm 5\%$) as recommended by FHWA (12); the second level is based on roadway functional classification by comparing the assignment volumes by road functional classification (freeway, principal arterials, minor arterials, and collectors) with the observed traffic volumes and the MAPE's by road functional classification are within the limits by FHWA ($\pm 7\%$ for freeways, $\pm 10\%$ for principal arterials, $\pm 15\%$ for minor arterials, and $\pm 25\%$ for collectors); the third one is on specific road links by comparing the assignment volumes for specific highways with observed results while following the MAPE's rule of thumb of $\pm 20\%$.

4.2. Simulation Calibration and Results***Initial Hourly Volume Percentages***

The background demand is related to a typical day's travel pattern. In this study, we only consider the worst case, i.e. the peak hours of a day when the evacuation also happens and simply assume that the traffic demand during each of the peak hours is a percentage of the 24-hour OD demand. The 24-hour OD demand data was available in the MDOT data set.

In order to assign the total 24-hour background traffic demand to specific hours of the day in simulations, the traffic volume percentage at each hour during a typical day would be needed. Hourly Volume Percentages (HVP) were initially characterized from the 24-hour traffic volume data (2007) in the Jackson area from MDOT. The 24-hour traffic volume data was collected by MDOT’s Traffic Division for specific locations in the area during special events, from which a 24-hour traffic pattern was depicted and shown in Figure 4 to approximately characterize the pattern of the background traffic condition.

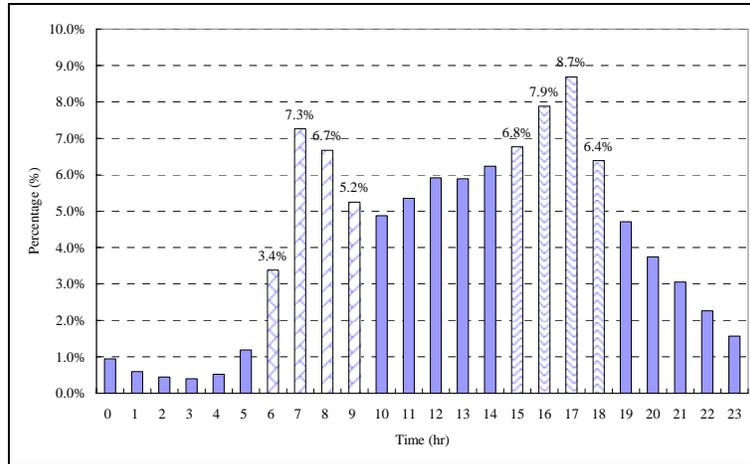


Figure 4 Traffic Volume Distribution Pattern (24-hr)

In the figure, two volume peaks appeared around 8:00 and 18:00. If a four-hour duration encompassing a volume peak is simulated in the DYNASMART program, the traffic conditions before and after the peak hour may be approximately studied. Two such four-hour durations may be from 6:00 to 10:00 and from 15:00 to 19:00 based on Figure 4. The hourly volume percentages of these two time periods are shown in Table 2.

Table 2 Hourly Volume Percentage of Daily Trip Demand

Start Time	End Time	HVP (%)	Start Time	End Time	HVP (%)
6:00	7:00	3.4	15:00	16:00	6.8
7:00	8:00	7.3	16:00	17:00	7.9
8:00	9:00	6.7	17:00	18:00	8.7
9:00	10:00	5.2	18:00	19:00	6.4

The hourly traffic volumes for the four morning peak hours for background demand in normal condition are 3.4%, 7.3%, 6.7%, and 5.2% of the 24-hour traffic OD demand.

Calibration Results

The initial hourly traffic volumes for background demand in normal traffic conditions were input to DYNASMART for the calibration simulation runs. These data inputs are

shown in Figure 5. A new set of inputs were created by systematically changing one or more of the percentage inputs.

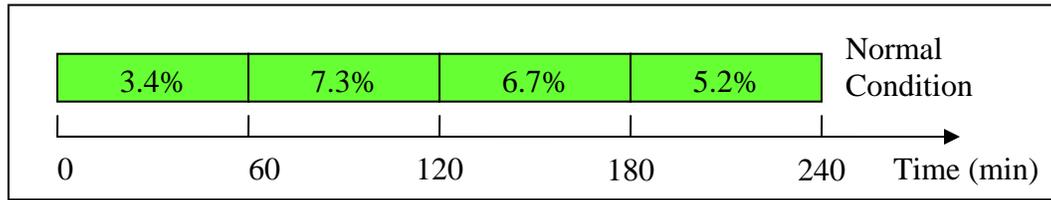


Figure 5 Volume Distribution during Simulation Time

In order to avoid the effect of randomness in individual simulation runs, each set of input parameters was simulated 6 times. For each simulation run, the result was recorded for specific links of the network and was stored in an Excel spreadsheet.

After more than thirty simulation runs, the optimum input parameters were determined to satisfy all the FHWA criteria. The optimal results are shown in Table 3 through Table 6.

Table 3 Optimal Hourly Volume Percentages

Time	6:00-7:00	7:00-8:00	8:00-9:00	9:00-10:00
HVP	6.0%	9.3%	5.6%	4.0%

Table 4 Overall Assigned Volume

Classification	Error Limit	Average Assigned Volume	ADT	Diff	PCT Diff
All	5%	363455	377169	-13714	-3.6%

Table 5 Assigned Volume by Roadway Classification: Freeway

Classification	Error Limit	Average Assigned Volume	ADT	Diff	PCT Diff
Freeways	7%	60748	65024	-4276	-6.6%

Table 6 Hourly Assigned Volumes at Specific Links

ID No	Error Limit	Error			Total
		7:00-8:00	8:00-9:00	9:00-10:00	
5768	20%	-17.1%	N/A	-1.1%	-11.5%
1959	20%	-9.0%	-7.9%	-7.1%	-8.2%
2603	20%	4.2%	17.9%	4.2%	8.7%
5761	20%	-15.0%	-16.5%	-0.3%	-12.3%
1800	20%	-7.4%	-4.2%	-13.5%	-7.9%
6685	20%	-11.7%	7.5%	6.0%	-1.6%
3508	20%	-18.7%	11.8%	1.4%	-4.7%

4.3. Study Methodology

Evacuation operations can be divided into three main networks namely Origin, Routes, and Destination (40). However, potential impacts of evacuation traffic from a disastrous area due to an emergency incident on the network performance of the destination areas receiving the evacuation traffic were not given equal attention (41). PBS&J completed a hurricane traffic modeling analysis for southeast Louisiana (42). Using socioeconomic and behavioral data, this analysis identified the potential for 84,333 vehicles to enter Mississippi on I-59, 78,652 vehicles to enter on I-55, and 19,849 vehicles to enter on I-10 for a worst case hurricane threat. As the largest metropolitan area in the state of Mississippi and 160 miles north of New Orleans, Louisiana, the Greater Jackson area in Mississippi would experience intense traffic congestions when so many vehicles entered Jackson from New Orleans. In this regard, it would be prudent and necessary for the emergency management and transportation officials of Mississippi to find the most effective ways of managing traffic and take valid measures in time to reduce congestion. As to operational strategies, contraflow operation would be more practical than coordinated evacuation and public transit utilization for a destination receiving evacuation traffic. Furthermore, the importance of implementing ITS facilities such as Dynamic Message Signs (DMS) in the Jackson metropolitan area has been increasingly recognized. The evaluation of the effectiveness of congestion mitigation by providing enhanced traveler information to evacuation traffic is of the interest of this study. To make naming easier, traffic management hereafter refers to contraflow operation and ITS deployment. Currently, the detailed possible traffic signal phasing data during emergency evacuation are not available from transportation planning and operation agencies, and therefore they are not included in the study. To enable a relatively realistic simulation process in DYNASMART-P, this study assumes that all signalized intersections are equipped with actuated signal controllers, which can automatically adjust green time allocations for different approaches depending on their incoming time-varying traffic volumes. Although this modeling strategy might slightly overestimate the available traffic capacity on arterial streets, it serves as the best available approximation for us to simulate the effects of signal control, and it can provide a starting point for traffic managers to evaluate the potential bottlenecks under idealized traffic control conditions.

In this study, observed traffic volume data from crucial evacuation route locations were collected and used to calibrate the network model and traffic demand provided by the Mississippi Department of Transportation (MDOT). The computer simulation based on the assumed evacuation scenario in which different amounts of traffic evacuated from southeast Louisiana due to an approaching hurricane examined potential impacts of these evacuation vehicles on the highway network near Jackson, Mississippi. The classic gravity model was applied to distribute evacuation production/attraction trips on the network model by using the TransCAD software in order to calculate evacuation OD demand matrix. After importing both the background and evacuation demands into DYNASMART-P for the highway network characterized with various traffic management strategies, the simulation program was run to study the effects of interest. The measures of effectiveness (MOE's) (i.e. average travel time, queue length percentage,

and vehicle speed under congested conditions, etc.) were chosen to analyze the impacts of the evacuation traffic and evaluate the effect of different traffic management strategies on the network performance of the Greater Jackson area. The program Nexta developed by the University of Utah team was used to export these MOEs and system performance statistics for the analysis of simulation results. The research helped identify effective traffic management methods and locate weak points of the highway network in the area and benefited the Greater Jackson Metropolitan area by improving the area's emergency preparedness.

5. CASE STUDY OF EVACUATION TRAFFIC FROM NEW ORLEANS

5.1. Evacuation Scenario

This study was based on the evacuation scenario in which a large amount of traffic was evacuated from New Orleans due to an approaching hurricane. The study simulated the evacuation traffic that entered or passed by Jackson, Mississippi, to analyze the effectiveness of traffic management strategies for the possible congestions caused by the evacuation traffic on the highway network of the Greater Jackson area.

To estimate the potential evacuating traffic volumes entering Mississippi for hurricanes threatening southeast Louisiana, a previous hurricane evacuation study was examined. PBS&J completed a hurricane traffic modeling analysis for southeast Louisiana in the 1990-1992 timeframe. The work was done under contract with the US Army Corps of Engineers, New Orleans District. Table 7 shows various evacuating traffic volumes exiting the southeast Louisiana area by specific route and origin parish.

Table 7 Evacuation Traffic Volumes by Route

Critical Roadway Segment	Directional Serv Vol LOS D	Cat 1/Fast Cat 2 Evac Veh Low Occ	Cat 1/Fast Cat 2 Evac Veh High Occ	Cat 2/Fast Cat 3 Evac Veh Low Occ	Cat 2/Fast Cat 3 Evac Veh High Occ	Fast Cat 3-4 Evac Veh Low Occ	Fast Cat 3-4 Evac Veh High Occ	Fast Cat 3-4/Cat 5 Evac Veh Low Occ	Fast Cat 3-4/Cat 5 Evac Veh High Occ
I-12 westbound	3,000	688	694	1,197	1,204	1,599	1,605	2,693	2,699
I-10 east over Lake Ponchartrain	3,000	7,586	8,651	22,991	24,070	56,851	57,942	94,095	95,185
I-10 eastbound into Mississippi	3,000	2,160	2,359	6,063	6,267	12,033	12,239	19,643	19,849
I-59 northbound into Mississippi	3,000	7,719	8,606	20,917	21,815	50,148	51,055	83,426	84,333
Lake Ponchartrain Causeway	2,500	4,203	4,982	12,828	13,606	40,890	41,675	69,589	70,374
US61 westbound	1,800	791	946	1,925	2,081	7,700	7,857	14,775	14,932
I-10 westbound east of I-55	3,000	9,409	10,794	27,476	28,878	72,444	73,859	122,920	124,334
I-55 northbound into Mississippi	3,000	8,092	8,900	20,126	20,955	44,135	44,973	77,816	78,652
I-10 westbound west of I-55	3,000	3,925	4,548	12,166	12,788	35,024	35,653	61,169	61,797
Louisiana Highway 1	1,000	8,783	9,510	17,750	18,564	18,402	19,241	28,692	29,528

5.2. Evacuation Traffic OD Demand

In this study, we assumed the emergency evacuation happened after the 60th minute in the four-hour period of 6:00-10:00 AM. Therefore the simulation duration was 240 minutes and two traffic demands (background and evacuation) started to be loaded concurrently at the 60th minute in simulation.

Demand during an evacuation may be divided into two portions: the background demand and the evacuation demand. Correlation between background traffic and evacuation traffic was not considered in the study. The background demand is the traffic demand that is not related to the hazard area but occurs under normal travel conditions. Evacuation demand is the traffic demand generated from the disaster area (43). The

combination of the two types of demand was estimated in order to provide input data for an evacuation simulation.

The background demand varies in the traffic distribution pattern within a typical day. Only the worst situation of the peak hours of a day was considered and simply expressed as percentages of the 24 hour OD demand. The values for the percentages were determined in the calibration process.

The numbers of evacuation vehicles entering Mississippi under different hurricane severity categories estimated by PBS&J are shown in Table 7 (42). The numbers of evacuating vehicles from the route I-55 northbound were used based on four demand levels including “Category 1/Fast Category 2 evacuation vehicles at high occupancy”, “Category 2/Fast Category 3 evacuation vehicles at high occupancy”, “Fast Category 3-4 evacuation vehicles at high occupancy” and “Fast Category 3-4/Category 5 evacuation vehicles at high occupancy”.

Locations of Origin and Destination

For evacuation trips to be generated and distributed, the trip origin and destination zones should be determined. The origin zones were determined by experiences (42). The destination zones were determined based on the location of shelters, hotels, and/or exiting routes.

(1) Origins

In the PBS&J study, the route that would feed evacuation traffic from New Orleans, Louisiana, into the Greater Jackson area was I-55 northbound which is highlighted in Table 7. Therefore, the origins in the network would be the zones located on the southern boundary line of the study area.

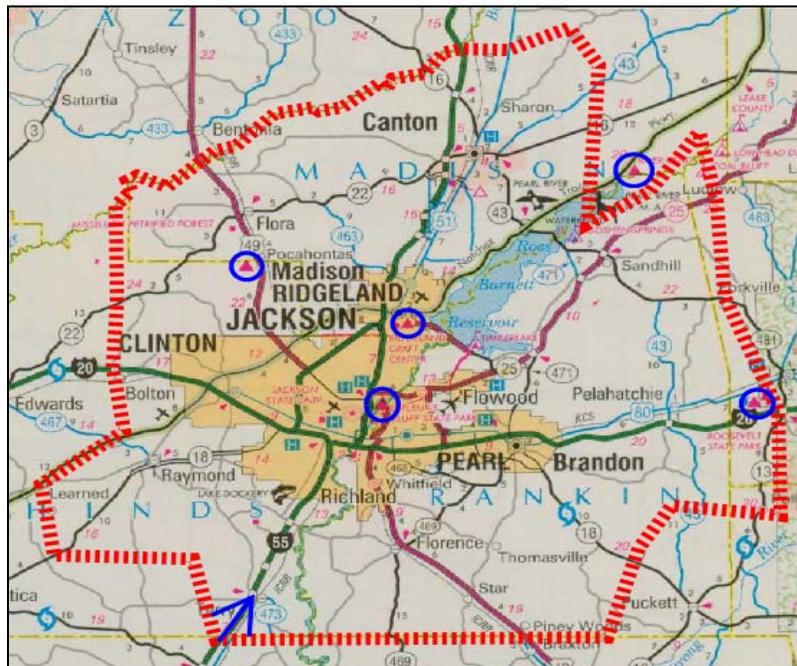


Figure 6 Origins and Destinations in Study Area

(2) Destinations

As marked in Figure 6, the total number of shelters in this study area was five: four inside the study area and one near the boundary. The hotels in every TAZ zone were considered as destinations. In addition, the traffic that passes by the study area was assumed to exit the study area at specific destination points on freeways.

Evacuation Trip Generation and Attraction

(1) Evacuation Trip Production

The temporal characteristics of evacuation travel time estimation are based on the evacuation response rate curve which predicts the cumulative evacuation demand along with time if an evacuation is ordered. Such response rate curves from a previous study are shown in Figure 7 (44). The response rate was important because it determined how many vehicles would enter the study area during the simulation period.

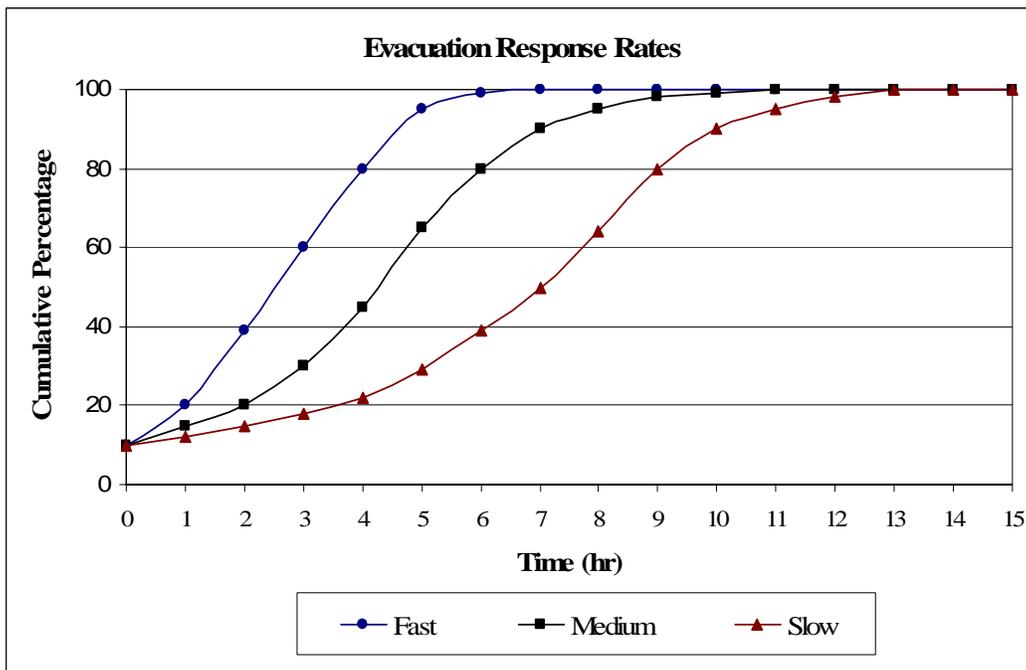


Figure 7 Response Rate Curves

In this study, the medium evacuation response rate curve was used to determine how many vehicles would enter the study area in each hour during the simulation period. In this study, only the evacuation period from hour 3 to hour 6 was simulated. This 3-hour interval was used because of the rapid increase of evacuation volume in the period, during which approximately 50% of the total evacuation volume appeared. The first hour took 15% of the total evacuation volume, the second hour 20%, and the third 15%. The total hourly demand can be calculated by summing the hourly background demand and

hourly evacuation demand. The evacuation production in a specific simulation period was calculated by Equation 2.

$$P_i = P_{Tot} \times F_{RR_i} \quad (\text{Eq 2})$$

Where:

P_i is the evacuation production in the i -th hour simulation period, vehicle;

P_{Tot} is the total evacuation production in a specific hurricane category, vehicle;

F_{RR_i} is the trip production percentage for the i -th hour in evacuation.

Based on the response rate curve, the total evacuation volume during the simulation period was computed by multiplying the coefficient 50% to the volume highlighted in Table 7 under each of the four traffic intensities respectively. The evacuation origin was chosen at the southern boundary of the study area on the evacuation corridor I-55 NB. The trip production for the origin was the same as the total evacuation volume in the simulation period, specifically 4,450, 10,478, 22,487, or 39,326 vehicles under each of the four evacuation intensity levels as shown in Table 8.

Table 8 Origin Trip Production

Loaded Link Name	zone	Production Level 1 (veh)	Production Level 2 (veh)	Production Level 3 (veh)	Production Level 4 (veh)
I-55	687	4450	10478	22487	39326

(2) Evacuation Trip Attraction

In this study, hotels, public shelters, and pass-by zones were used as evacuation destinations. The three pass-by destination points on the north, west and east boundaries of the study area were based on the assumption that evacuees seek more safe distances or shelter by traveling further up I-55 NB, or diverting to I-20 WB/EB after passing by Jackson, Mississippi. In order to determine evacuation trip attractions, the study assumed that half of the total evacuation traffic passed by Jackson, Mississippi, and the other half made their destinations to the hotels and public shelters. The trip attraction for hotels and shelters was determined, as shown in Table 9.

Table 9 Destination Trip Attraction

Destination	Trip attractions at evacuation traffic severity levels (veh)			
	Level 1	Level 2	Level 3	Level 4
Hotels and Shelters	2225	5240	11244	19663
Pass-bys	2225	5239	11243	19663
Total	4450	10479	22487	39326

(3) Evacuation Trip Distribution

With the trip production for the origin zone and trip attractions for the destination zones determined, the gravity model in TransCAD was applied to assign the evacuation traffic in equilibriums and to develop evacuation OD demand matrices over the traffic analysis zones. The OD demand matrices over the TAZ zones were then fed into DYNASMART-P for dynamic traffic assignment computation due to specific network and traffic management conditions.

5.3. Operational Strategy Development

The primary improvement methods on the most current evacuation practices and plans include the use of Intelligent Transportation System (ITS) during evacuation and operation of contraflow for evacuation which were both used in the Georges and Floyd evacuations. A more recent study focused on ITS technologies in the states of North Carolina, South Carolina, Georgia, and Florida (37). This study recommended applications such as closed circuit television (CCTV) cameras, Highway Advisory Radio (HAR), Dynamic Message Signs (DMS), count stations, and weather stations. Contraflow operation on roadways is not a new concept that is an operation of turning one or more lanes of one direction to the opposite direction. It can greatly expand the roadway capacity without building new facilities and has been used to address the issue of inadequate outbound capacity. Many cities like Washington D.C and Boston have been using reverse lane operations to improve the outflow of traffic for decades. Contraflow for hurricane evacuation was first used during Hurricane Floyd in 1999 to lessen the traffic congestion in Georgia and South Carolina.

In this study, operational traffic management methods including Intelligent Transportation System strategy (ITS), contraflow of traffic strategy (CS) and the combinational use of ITS and CS strategies (ICS) were considered and modeled in DYNASMART-P using the incident and dynamic message sign (DMS) tools available in the program, simulated based on four different kinds of hurricane categories, and evaluated using specified measure of effectiveness.

ITS Model in DYNASMART-P

There are nine existing DMS sign boards currently functioning in the study area (39). To help deploy contraflow operation in this study in addition to the nine existing DMS signs, portable DMS signs were implemented when necessary on I-55 NB between the southern end of the study area and the interchange with E. McDowell Rd. Over this freeway segment, portable DMS signs were deployed before off ramps of interchanges, in order to warn users against congestion ahead and of choosing a nearest exit.

In DYNASMART-P, four types of dynamic message signs can be used to model 4 types of traffic control. Type 1 DMS is the speed advisory DMS that allows users to increase/decrease speed by a certain percentage when below/above a certain threshold. Type 2 DMS is the mandatory detour DMS that advises drivers of lane closures, and mandates all vehicles to follow some user-specified sub-path in the vicinity. Type 3 DMS is the congestion warning DMS which allows users to specify percentages of DMS-responsive vehicles to evaluate the DMS information and divert if a better path exists. Type 4 DMS is the optional detour VMS, which also advises drivers with lane closure

information and gives drivers the option to follow the detour path or keep their original paths, based on the boundedly rational decision rule. In order to model ITS traffic control strategy, the third type DMS's were widely used and set on the specified I-55 NB segment upstream of exits. The detail parameters are shown in **Error! Reference source not found.**

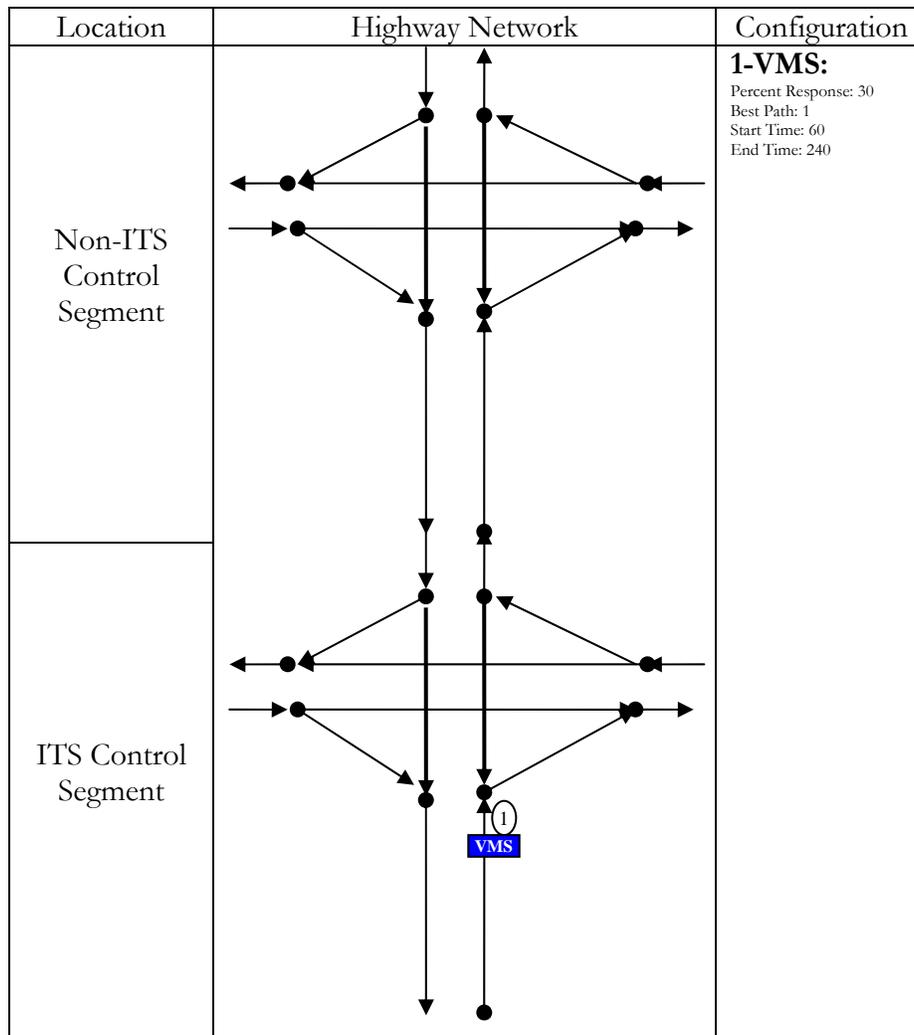


Figure 8 Evacuation Traffic from New Orleans

Contraflow Model in DYNASMART-P

In this study, the contraflow operation was tested for its effectiveness. To keep the disturbance to other traffic operations to the minimum level, the contraflow was only deployed in the suburban area on I-55 southbound between the I-55 SB interchange with Savanna St. and the south boundary end of the study area. When contraflow operation began, all off ramps and most of the on ramps in this segment were closed except for two on ramps which were reversed for evacuating vehicles to exit. The two on ramps were at the I-55 SB interchange with Siwell Rd. and the interchange with Savanna St. Meanwhile, the upstream traffic of the contraflow segment on I-55 SB was forced by a portable DMS to leave I-55 SB through off ramps at I-55 SB interchanges with E. McDowell Rd. and Daniel Lake Blvd.

Generally, the deployment of a contraflow operation includes the following three steps that are: 1) normal traffic operation, or pre-contraflow, 2) network clearance for

contraflow, and 3) contraflow operation, as shown in **Error! Reference source not found.**

Although the pre-contraflow was a normal traffic operation state, it involved setting up “Incidents” in the network model. An “Incident” is another traffic control tool provided by DYNASMART-P. In addition to the various DMS tools, an Incident can be set up to block traffic movements in a roadway direction (a link in the network model) with a starting time and an ending time to simulate traffic control of roadway closure enforced by police officers. The added northbound traffic lanes during the contraflow operation needed to be blocked using the incident tools in the pre-contraflow state as shown in Figure 10. Similarly, the network clearance state and contraflow operation state were implemented using the DMS and Incident tools.

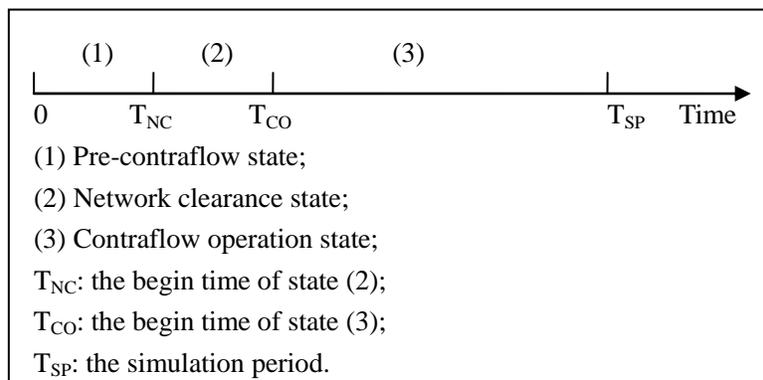


Figure 9 Contraflow Operation Timeline

The network model was prepared for the contraflow operation by adding the following tools to the network: a) DMSs were deployed on the freeway links for contraflow operation to clean up remaining vehicles; b) DMSs were used on the freeway links upstream of the contraflow segment to prevent SB traffic from entering the contraflow segment and to exit SB traffic from the nearest upstream off ramps; c) Incidents were set up on the on ramps of the freeway segment for contraflow operation to block entering traffic, and DMSs were used on the roads that feed traffic to the on ramps to divert arriving traffic, as shown in Figure 11; d) Contraflow links were operated by adding more traffic lanes to the northbound direction and using Incidents to block any SB traffic on the southbound traffic lanes, as shown in Figure 12.

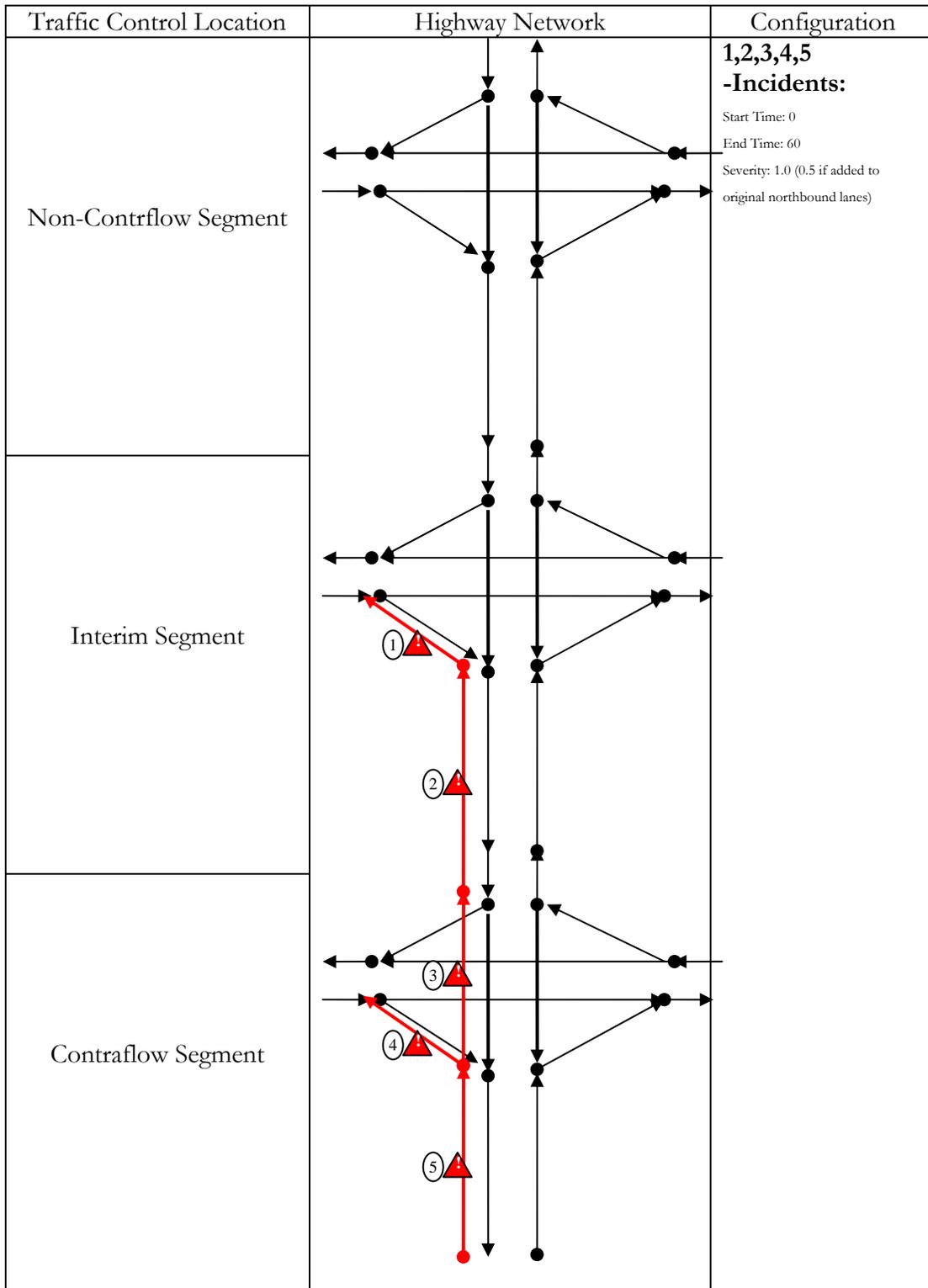


Figure 10 Setup for Pre-contraflow State

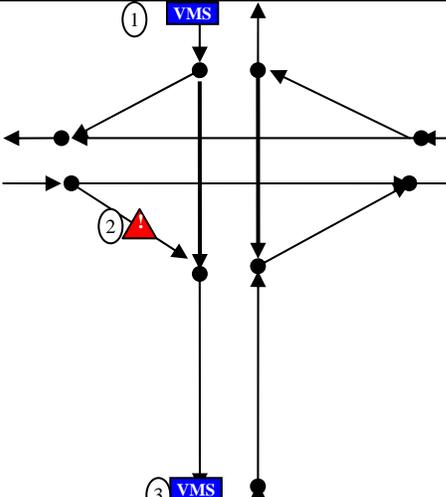
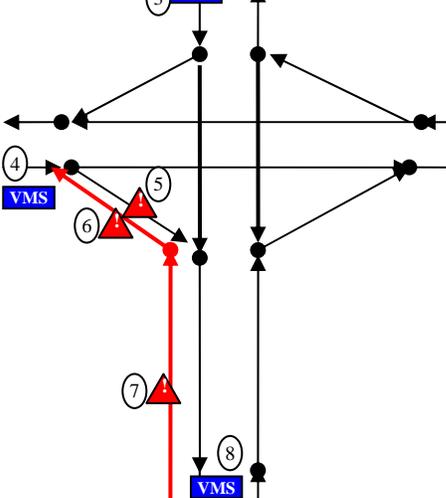
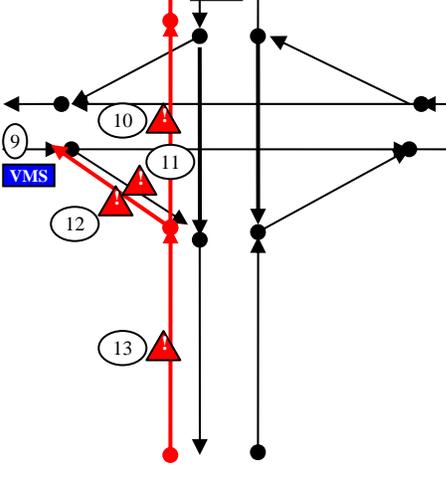
Traffic Control Location	Highway Network	Configuration
Non-Contrflow Segment		<p>1,4,9-VMS: Type: Detour Percentage Respond: 100% Start Time: 30 End Time: 240 Path: xx</p> <p>3,8-VMS: Type: Detour Percentage Respond: 100% Start Time: 30 End Time: 60 Path: xx</p>
Interim Segment		<p>2,5,11-Incident: Start Time: 30 End Time: 240 Severity: 1.0</p> <p>6,7,10,12,13-Incident: Start Time: 0 End Time: 60 Severity: 1.0 (0.5 if added to original northbound lanes)</p>
Contraflow Segment		

Figure 11 Setup for Network Clearance State

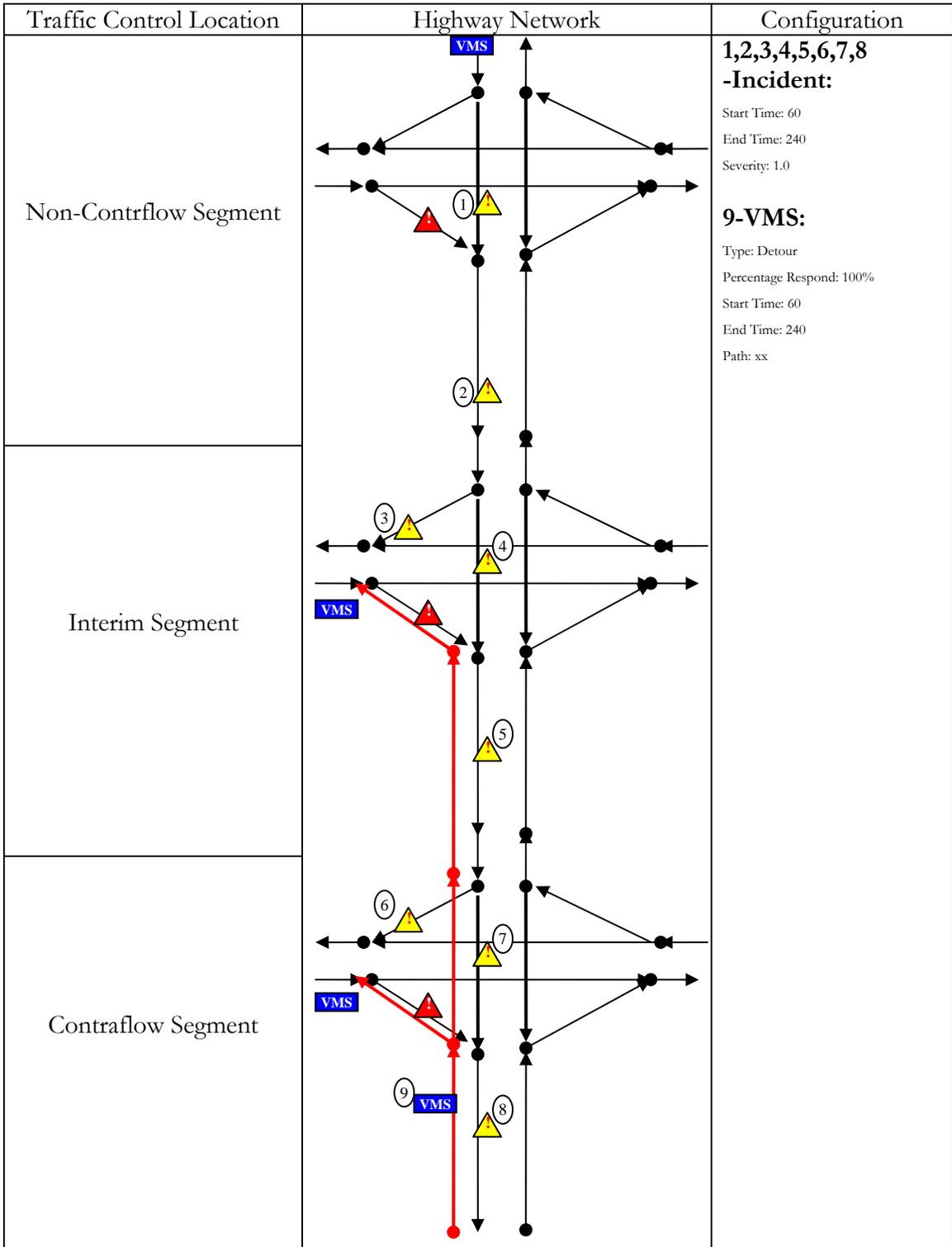
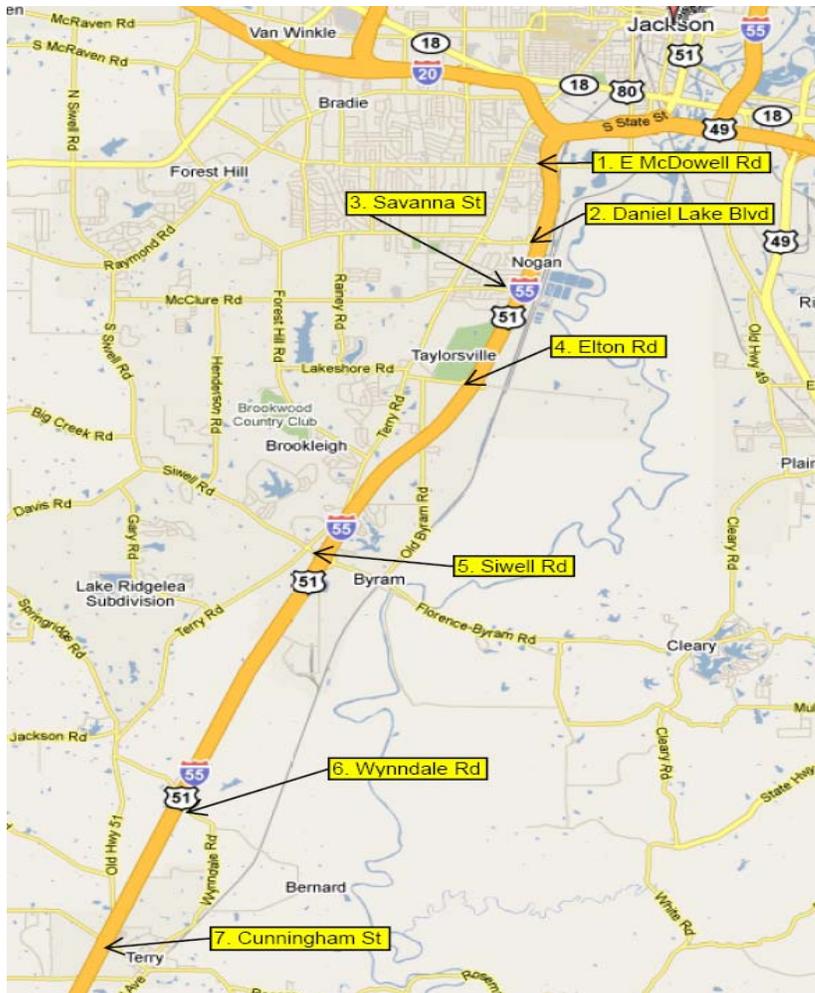


Figure 12 Setup for Contraflow Operation State

Traffic Management Deployment

Figure 13 shows traffic management deployment locations. For the ITS strategy, DMS sign boards were deployed on I-55 NB from the interchange with Cunningham St. to the interchange with E. McDowell Rd. Specifically, DMS signs were set up on off ramps of interchanges with I-55 NB at Cunningham St., Wynndale Rd., Siwell Rd., Elton Rd., and E. McDowell Rd. in order to warn evacuee drivers of downstream congestions and advise them taking the nearest exits and leaving the freeway.



Traffic management deployment locations on road interchanges with I-55, with a segment of 13.3 miles along I-55 from Cunningham St, Jerry, MS to E McDowell Rd, Jackson, MS.

- 1: E McDowell Rd
- 2: Daniel Lake Blvd
- 3: Savanna St
- 4: Elton Rd
- 5: Siwell Rd
- 6: Wynndale Rd, and
- 7: Cunningham St

Figure 13 Traffic Management Deployment Locations on I-55

For the contraflow strategy, reverse flow of traffic was set up on I-55 southbound between the interchange with Savanna St. and the southern boundary of the study area. Before contraflow was fully operative, a 30 minute pre-contraflow time was allowed to clear the freeway segment by forcing all southbound traffic to leave the freeway segment through the nearest off-ramps. All off-ramps and on-ramps on the southbound freeway segment except for the two on-ramps at Siwell Rd. and Savanna St. were then closed for traffic. The two on-ramps at Siwell Rd. and Savanna St. were reversed for contraflow traffic to exit. Meanwhile, the upstream southbound traffic on I-55 beyond the contraflow

segment was forced to leave I-55 SB through off-ramps at E. McDowell Rd. and Daniel Lake Blvd.

For the combination of ITS and contraflow strategies, ITS facilities such as DMS signs and reverse flow of traffic were deployed concurrently for the selected freeway segment mentioned earlier.

5.4. Simulation with DYNASMART-P

In this study, emergency evacuation was simulated for the morning peak four-hour period 6:00-10:00 AM, with a total of 240 minutes of simulation duration. To be more real, the evacuation traffic was not added until the second hour of the simulation period. Therefore in the first hour of simulation there was only background traffic, and in the other three hours both the background and evacuation traffic components were loaded concurrently. The background traffic demand during the 4-hour morning peak period totaled 377,776 vehicles and the 24-hr background traffic demand was 1,517,174 vehicles for the area. The hourly traffic volumes for the background demand were 6.0, 9.3, 5.6, and 4.0 percent of the daily traffic demand for the four peak hours, respectively. As mentioned, four levels of evacuation traffic demand were added to the background demand for the four intensity levels of evacuation. For each evacuation demand, emergency evacuation with four different operational strategies including NS, ITS, CS, and ICS were simulated respectively.

In the simulation tests, maximum permissible evacuation volume for each evacuation demand and traffic management strategy was estimated. The average queue length percentage and the average trip delay were used as the criteria to identify the twenty most congested freeway links and arterial links in the network in each simulation. In addition, in order to avoid the randomness effect of individual simulations, a total of 10 simulations using different random seed numbers were run for each evacuation intensity level and traffic management strategy. Therefore, for each evacuation intensity level and traffic management strategy, 200 output records including link ID, average speed, queue length percentage, delay, and density were obtained.

5.5. Results and Analysis

Maximum Permissible Volumes of Operational Strategies

The maximum permissible volume is defined as the maximum traffic volume that can effectively enter the study area in simulation during the simulation period. Due to the demanding requirements on computation resources, simulation for the whole evacuation period was not practical without using a “superzone.” Therefore, the simulation period of four hours was used and three of the four hours were for evacuation simulation. It should be noted that the maximum permissible volume estimated using the simulation method included both evacuation and background traffic components.

As indicated in Table 10 and Figure 14, the permissible volume capacity under the four traffic management strategies increased in the order of non-strategy (NS), ITS strategy (IS), contraflow strategy (CS), and ITS & contraflow strategy (ICS). The increasing tendency due to traffic management strategy was more apparent at a high

evacuation demand intensity level than at a low evacuation intensity level. The simulation results suggest that ITS facilities could add more than 20% extra capacity to the existing highway network (24.8%, 21.3%, and 21.9% at intensity levels 2, 3 and 4 respectively), and the contraflow operation could increase evacuation capacity significantly (by 37.5%, 54.4%, and 59.5% at intensity levels 2, 3 and 4 respectively). Furthermore, a contraflow operation coupled with dynamic traveler information provided by ITS facilities could most significantly increase the capacity of the highway system and be the most effective strategy to increase mobility in an emergency evacuation of high evacuation traffic demand (adding capacity by 37.9%, 74.5%, and 78.7% at intensity levels 2, 3 and 4 respectively).

Table 10 Maximum Permissible Volume in Simulation

Traffic magt strategy	Max permissible volume at evacuation intensity levels (veh)			
	Level 1	Level 2	Level 3	Level 4
NS	9582	11104	11655	11594
IS	9623	13863	14140	14131
CS	9475	15263	17994	18493
ICS	9478	15310	20343	20724

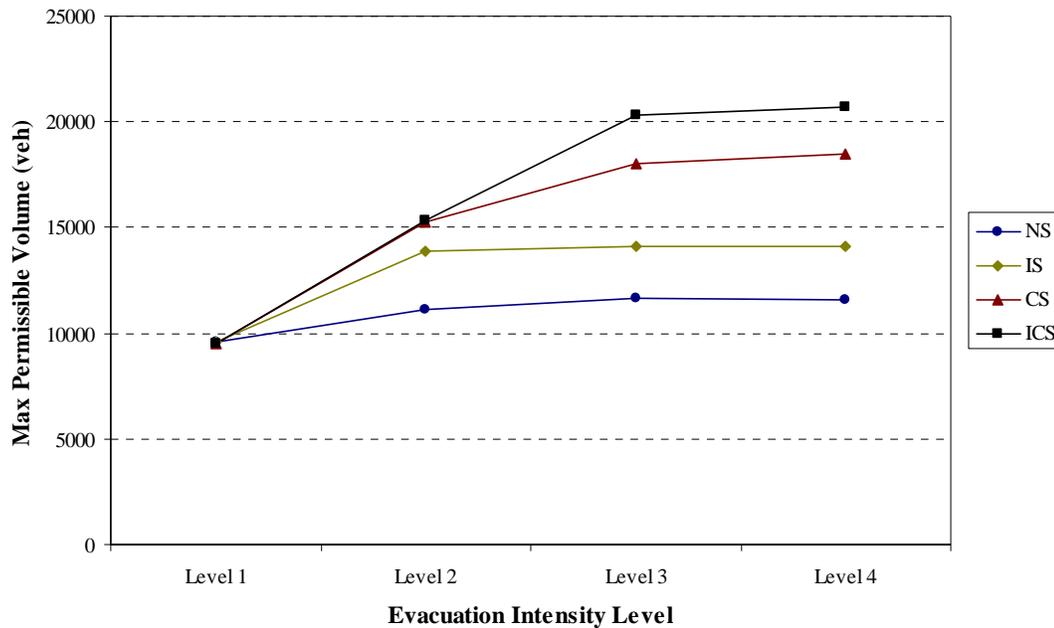


Figure 14 Max. Volume vs Evacuation Intensity & Traffic Management Strategy

Comparing the maximum permissible volume of 9,478, 15,310, 20,343, or 20,724 vehicles under the ICS strategy with the corresponding evacuation demand of 4,450, 10,479, 22,487, or 39,326 vehicles for each of the four evacuation intensity levels shows that the maximum permissible volumes were more than the evacuation demands at the first and second evacuation intensity levels, but less than the evacuation demands at the

third and fourth intensity levels. The differences of about 5000 vehicles between the maximum permissible volumes and the evacuation demands at the first and second evacuation intensity levels respectively were actually the background traffic. Therefore, the total demands for the four intensity levels including background and evacuation traffic would be 9,450, 15,479, 27,487, and 44,326 vehicles respectively.

The above comparison also showed that all the four operational strategies could satisfy the evacuation demand at the first evacuation intensity level; however, only the CS and ICS strategies could satisfy the evacuation demand of the second intensity level. For the third and fourth intensity levels, all four operational strategies failed to satisfy the evacuation traffic demands. The following analysis of traffic flow characteristics at the first and second evacuation intensity levels identifies in more details the effects of the four traffic management strategies on mobility of the evacuation traffic and the local traffic in the study area.

Effect on Mobility of Freeway Traffic

At the first evacuation intensity level, all four traffic management strategies can address the evacuation traffic demand successfully.

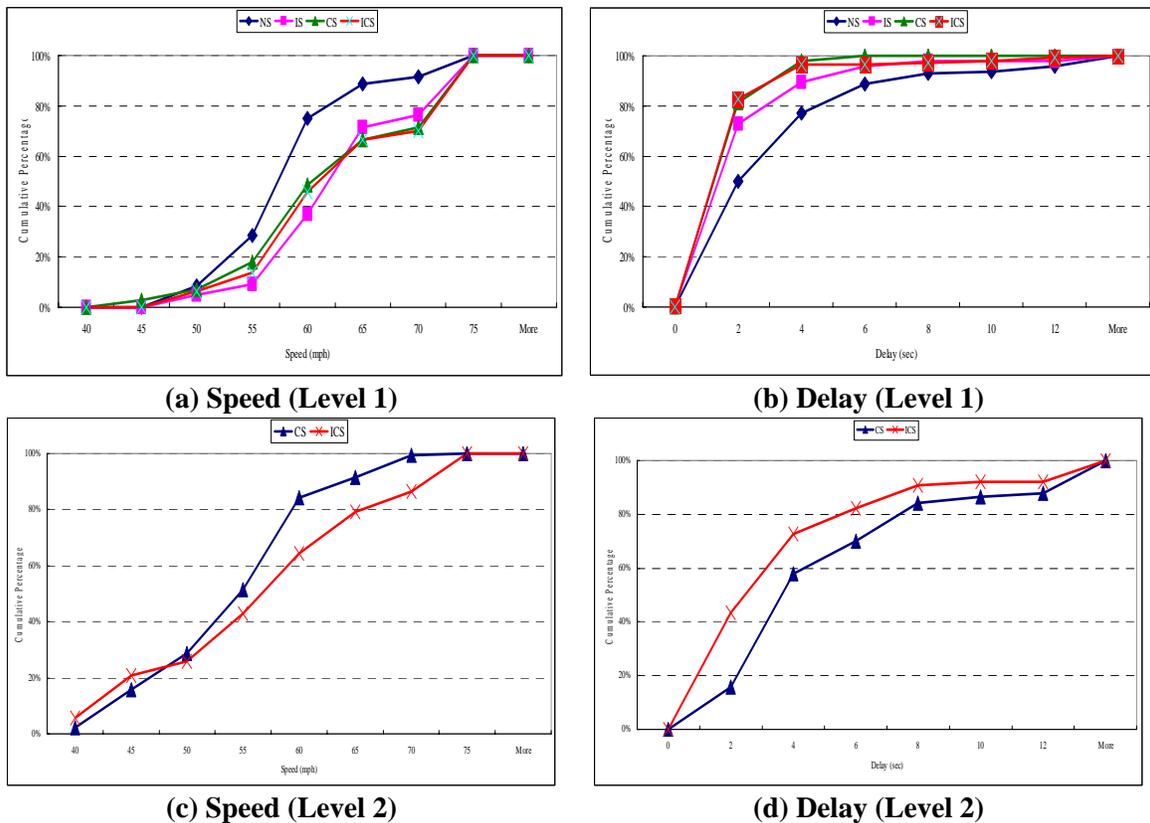


Figure 15 Cumulative Frequency Curves of Evacuation Corridor Characteristics

As shown in Figure 15, cumulative frequency curves were drawn for traffic speeds and per trip delays of freeway links under the four traffic management strategies NS, IS,

CS, and ICS. Figure 15(a) shows that the average speeds under traffic management strategies IS, CS, and ICS are significantly higher than under non-strategy NS. In Figure 15(b), the average per-trip delay under NS is significantly larger than under any of the other three traffic management strategies IS, CS, and ICS. For the second evacuation intensity level, cumulative frequency curves were drawn for the two strategies that cleared traffic successfully. As shown in Figure 15(c), the average speed at the CS strategy is lower than the average speed at the ICS strategy. In Figure 15(d), the average per trip delay under the CS strategy is greater than that of the ICS strategy. The above results show that the reversal of traffic in the direction of low demand to the opposite direction of high demand and the ITS traveler information that diverts congested evacuation traffic to alternative routes can significantly improve traffic mobility on freeways.

Effect on Mobility of Non-Freeway Traffic

The effects of different traffic management strategies on traffic mobility on non-freeway roads were examined. Cumulative frequency curves were drawn for the four strategies, as shown in Figure 16.

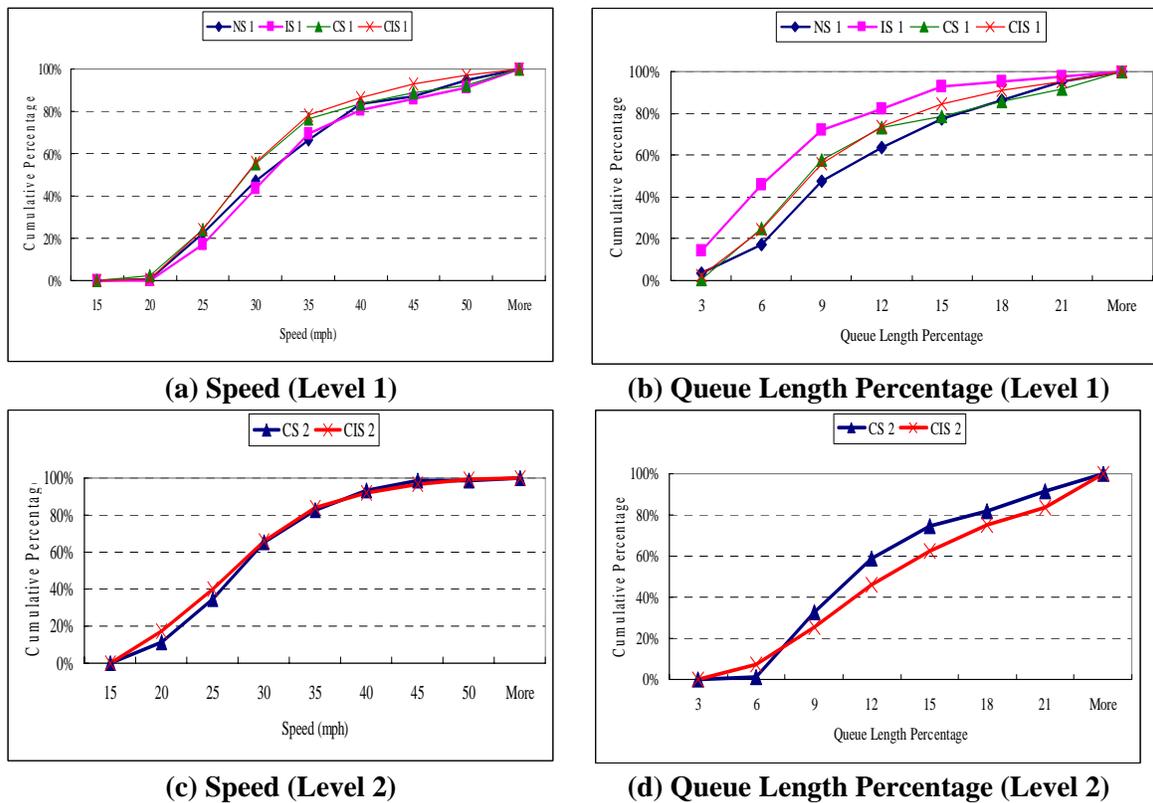


Figure 16 Cumulative Frequency Curves of Local Traffic Characteristics

Figure 16(a) shows that the average speeds for the CS and ICS strategies are lower than the average speeds for the other two strategies. Figure 16(b) shows that the queue

length percentages under the NS, CS, and ICS strategies are larger than that of the ITS strategy. For the second intensity level, cumulative frequency curves were drawn for the CS and ICS strategies. Figure 16(c) shows that the average speeds for the two strategies are approximately the same. In Figure 16(d), the queue length percentage under the ICS strategy is slightly greater than that under the CS strategy. These results suggest that contraflow operation may cause significant disturbance to non-freeway traffic in the area. Furthermore, while the traveler information of ITS strategy helps direct evacuation traffic to leave the congested freeways and take reroutes, the congestion may be transferred from the freeways to local roads in the area.

Congested Links for Each Traffic Management Strategy

For the first and second evacuation intensity levels, the most congested links were identified throughout the simulations with average trip delay for freeways and average queue length for arterial highways, which are shown in Figure 17. A sample of the congested locations was investigated in more details.



Figure 17 Congestion Locations

One congested location was the Hwy-468 interchange with I-20 eastbound. Congestion occurred on the I-20 eastbound interchange with Hwy-468 because many of

evacuation vehicles entered I-20 eastbound from Hwy-468 through the on-ramp, as shown in Figure 18. The average speed decreased from 47 mph for the background demand condition to 44 mph for the first evacuation condition and to 43 mph for the second evacuation condition. The average delay increased from 79 seconds for the background demand condition to 107 seconds for the first evacuation condition and to 130 seconds for the second evacuation condition.



Figure 18 Hwy-468 Interchange with I-20 EB

Another congested location was the West Cunningham Avenue interchange with I-55 northbound where large amounts of evacuating traffic left from I-55 northbound to West Cunningham Avenue through the off-ramp and congested West Cunningham Avenue eastbound, as shown in Figure 19. The average speed decreased from 62 mph for the background demand condition to 52 mph for the first evacuation intensity condition and to 33 mph for the second evacuation intensity condition. The average delay increased from 0.0 seconds for the background demand condition to 20 seconds for the first evacuation condition and to 104 seconds for the second evacuation condition.

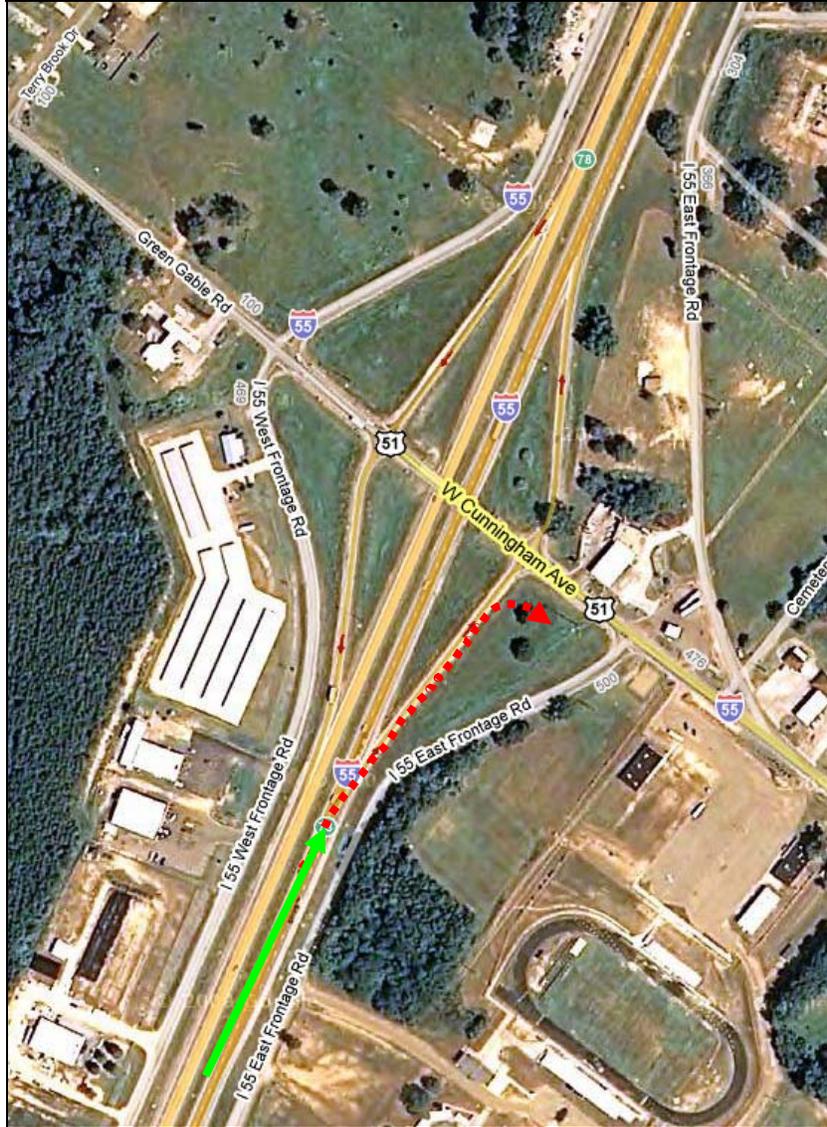


Figure 19 W Cunningham Ave Interchange with I-55 NB

A third congested location was the Natchez Trace Parkway interchange with I-55 northbound where a large amount of evacuating traffic left from I-55 northbound to Natchez Trace Parkway through the off-ramp, as shown in Figure 20. The average speed decreased from 59 mph for the background demand condition to 49 mph for the first evacuation condition and to 39 mph for the second evacuation condition. The average delay increased from 2.0 sec for the background demand condition to 16 sec for the first evacuation condition and to 30 sec for the second evacuation condition.

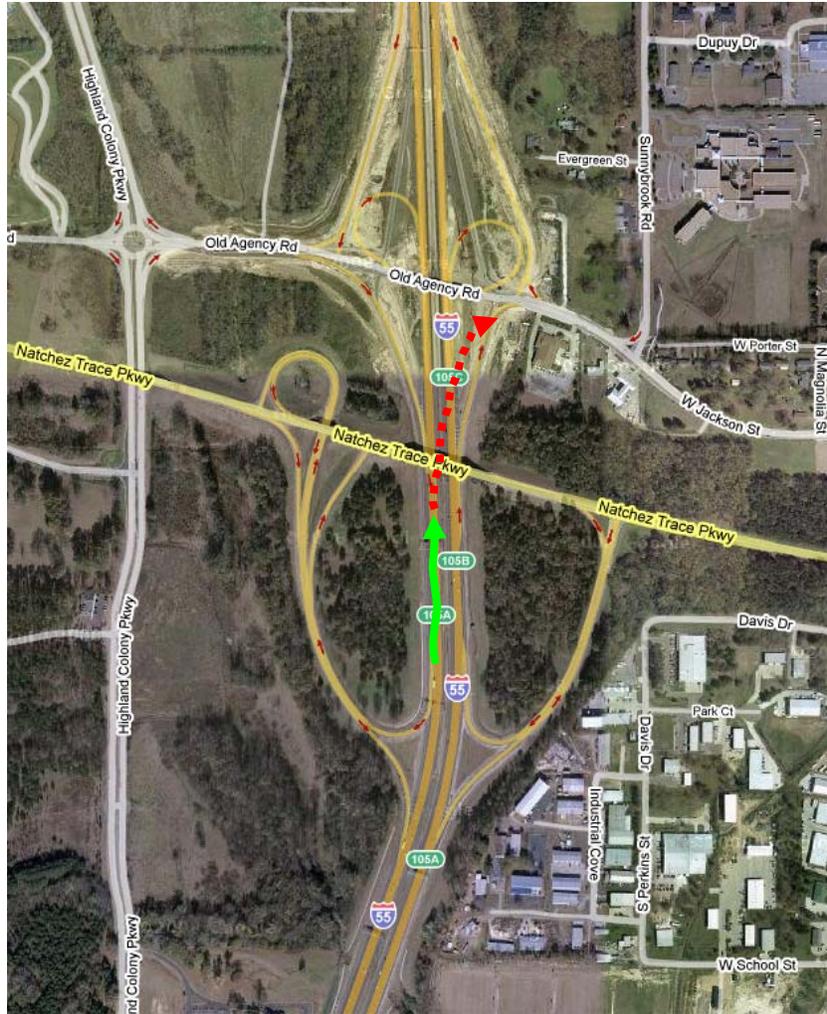


Figure 20 Natchez Trace Parkway Interchange with I-55 NB

The description about the nine most congested locations is listed in Table 11. There were 6 congested freeway segments which were located at interchanges with I-55 NB and 3 arterial roads, which were located near freeways. In addition, the most congested locations for each of the four traffic management strategies under two evacuation intensities are listed in Table 11. For the reasons mentioned earlier, the NS and IS strategies were tested only under evacuation intensity level one, while the CS and ICS strategies were tested for two intensity levels.

Table 11 Congested Locations and Effect of Traffic Management Strategies

Location ID	Locations	NS	IS	CS		ICS	
		Level 1	Level 1	Level 1	Level 2	Level 1	Level 2
F#1	West Cunningham Avenue interchange with I-55 NB	Y	Y	Y	Y	N	N
F#2	Siwell Rd interchange with I-55 NB	Y	Y	N	Y	N	N
F#3	Wynndale Rd interchange with I-55 NB	Y	Y	N	N	N	N
F#4	Natchez Trace Parkway interchange with I-55 NB	Y	Y	Y	Y	Y	Y
F#5	E McDowell Rd interchange with I-55 NB	Y	Y	N	N	N	N
F#6	Daniel Lake Blvd interchange with I-55 NB	Y	Y	N	N	N	N
A#1	US-49 NB interchange with I-20 EB	Y	N	Y	Y	Y	Y
A#2	Hwy-468 NB interchange with I-20 EB	Y	Y	Y	Y	Y	Y
A#3	Hwy-463 WB interchange with I-55 NB	Y	N	Y	Y	Y	Y
Sum of N's		0	2	4	3	5	5

In the table, the letters “Y” and “N” stand for the particular link was or was not included in the most congested link list in the simulation tests. The effect of the four traffic management strategies can be assessed from the numbers of congested links in the simulation results. At evacuation intensity level one, the ITS strategy reduced the number of congested links by 2, whereas the contraflow strategy and the contraflow plus ITS strategy reduced the most congested links by 4 and 5 respectively. At evacuation intensity level two, while the ITS only strategy could not help relieve the congestion significantly, the contraflow strategy and the contraflow plus ITS strategy helped reduce the numbers of congested links by 3 and 5 respectively.

6. OBSERVATIONS AND SUMMARY

After reviewing various evacuation simulation packages that were developed using microscopic, mesoscopic, or macroscopic simulation approaches and effective traffic control strategies that were used to improve efficiency and capacity of transportation infrastructure during emergency evacuations, a mesoscopic simulation package, DYNASMART-P, was adopted in the simulation and analysis in this study. In order to build the traffic network model on DYNASMART-P for the study area, three types of data were collected. The geographic data which includes the highway network topology characteristics (i.e. nodes, links and traffic analysis zones) of the Greater Jackson area, including Hinds, Madison, and Rankin counties, was provided by MDOT. The origin-destination (OD) trip demand matrix provided by MDOT which was then processed by TransCAD is a required input data for DYNASMART-P. The peak time hourly traffic volume data which was manually collected is needed for simulation calibration.

In order to determine input parameters of hourly volume percentages for the simulation program DYNASMART-P, calibration was conducted for the network model. The Mean Absolute Percent Error (MAPE) was used as the error model for the calibration. The calibration was an iterative process of determining the optimal input parameters by minimizing the error between simulation outputs with corresponding observed traffic characteristics under specified background traffic conditions. After more than 30 simulation trials, the optimal input parameters of hourly volume percentages were determined as 6.0%, 9.3%, 5.6%, and 4.0%, satisfying all FHWA limits. The difference between the overall assignment volume for all links in the network and that given by MDOT was -3.6% (within the $\pm 5\%$ limit). The difference between the total assigned freeway volume and the observed total was -6.6% (within the $\pm 7\%$ limit). The errors on specific links between assigned hourly volumes and observed ones were all within the $\pm 20\%$ limit.

In this report, an evacuation scenario was designed to study the impacts of the evacuating traffic from southeastern Louisiana to the Greater Jackson metropolitan area of Mississippi due to an assumed approaching hurricane disaster. Critically congested freeway segments under two evacuation intensity levels were identified based on the criterion of the average queue length percentage and level of service. The causes for the congestion of roads were analyzed and explained.

The simulation results showed that:

- 1) The feasibility of applying the DTA program DYNASMART-P to simulate emergency evacuation traffic conditions and analyzing the potential impacts of the evacuation traffic on the Greater Jackson, Mississippi, metropolitan area was verified.

- 2) The whole traffic network service level under evacuation conditions would significantly decrease from the normal condition. With increased evacuation intensity, traffic performance of the urban highway network might have some resilience at low evacuation intensities and deteriorate quickly with an accelerated cascading tendency at higher evacuation intensities.

For example, the average trip travel time in the first evacuation intensity level increased from 13.7 minutes to 15.2 minutes, and the second evacuation intensity level increased the average trip travel time to 16.8 minutes. The 85 percentile speed at the background demand condition was about 62 mph, and the corresponding speeds were 58 mph and 54 mph for the two evacuation intensity levels, respectively. The 85 percentile density was 53 vehicles per hour per lane for the background demand condition and 62 veh/hr/ln and 85 veh/hr/ln for the two evacuation intensity levels, respectively. The 85 percentile queue length percentage was 50% at the background demand condition and 75% and 120% for the two evacuation conditions, respectively. The 85 percentile average trip delay was 18 sec under the background demand condition and 25 sec and 50 sec in the two evacuation situations.

3) The congested highways under the evacuation conditions identified in the study suggested that congestion usually happens in highway interchanges.

Highway interchanges may become the most possible weak points in an urban highway network undergoing evacuation. For example, in the first evacuation intensity simulation, there were seven critical congested locations in the network. All of them were located at highway interchanges and congested by conflicting traffic to or from ramps. Two of them were eliminated from the list of the most congested links when ITS strategy was used, and the contraflow strategy and the contraflow plus ITS strategy reduced the most congested links by 4 and 5, respectively. At evacuation intensity level two, the contraflow strategy and the contraflow plus ITS strategy helped reduce the numbers of congested links by 3 and 5, respectively.

4) Precaution procedures such as traffic control strategies and implementation of intelligent transportation systems devices such as dynamic message signs at these weak points are recommended at emergency evacuations.

This study used the DTA-based program DYNASMART-P to analyze the potential impacts of the evacuation traffic and evaluated the effect of various traffic management strategies including non-strategy (NS), ITS strategy (IS), contraflow strategy (CS), and ITS plus contraflow strategy (ICS) operations under four different evacuation traffic intensity levels. The simulation results suggest that the ITS strategy could add more than 20% extra capacity to the existing highway network when the real-time traveler information provided through ITS facilities such as dynamic message signs diverts evacuation traffic from congested routes to alternative routes; the contraflow strategy could increase evacuation capacity by 38% to 60% because the contraflow strategy can reverse traffic in the direction of low demand to the opposite direction of high demand; contraflow plus ITS strategy could most significantly increase the capacity of the highway system by 38% to 79% and could be the most effective strategy to mitigate congestion in an emergency evacuation of high evacuation traffic demand. Analysis of the effect of different traffic management strategies showed that the contraflow operation, ITS strategy, and contraflow plus ITS strategy could significantly increase traffic flow speed and reduce trip delay and queue length for the evacuation traffic on evacuation corridors such as freeways. On the other hand, the contraflow operation may cause significant disturbance to other traffic near the evacuation corridors in the area that receives evacuation traffic. While the traveler information of ITS strategy helps direct evacuation traffic to leave the congested freeway segments and take alternative routes, the congestion may be transferred from the evacuation corridors to local roads in the area.

Finally, the traffic management strategies used in the study were popular methods of managing traffic during evacuation operations, and because the Greater Jackson area shares a great deal with other US cities in highway network layout and traffic characteristics, the simulation results developed in this study would be applicable to other metropolitan areas as well.

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