I-40 Lane Reversal Traffic Analysis

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16. Abstract

A detailed traffic analysis and related research was conducted for the I-40 Lane Reversal Plan. The I-40 Lane Reversal Plan was developed jointly by the North Carolina Department of Transportation and Department of Crime Control and Public Safety to expedite the safe and efficient evacuation of the New Hanover County coastal region under hurricane threat conditions.

The objectives of this research were to generate and compare several measures of effectiveness (MOEs) from microsimulation models to investigate the effects of lane reversal on the performance of the evacuation network. The MOEs analyzed in this modeling effort were queue lengths, average link speeds and throughput at key nodes. Thus the primary research issues regarding lane reversal operations were:

- Will the lane reversal increase throughput and average link speeds while reducing queue lengths?
- Is the current storm severity threshold set for triggering the lane reversal set at an appropriate level?
- Are there bottleneck points in the network upstream of the lane reversal, on the lane reversal proper, or at the downstream termination that could lessen the benefit of contraflow operation?

The research methodology, findings, conclusions, and recommendations are presented.

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EXECUTIVE SUMMARY

A detailed traffic analysis and related research was conducted for the I-40 Lane Reversal Plan. The I-40 Lane Reversal Plan was developed jointly by the North Carolina Department of Transportation and Department of Crime Control and Public Safety to expedite the safe and efficient evacuation of the New Hanover County coastal region under hurricane threat conditions. Key project conclusions and recommendations are presented below organized by the related research issue. The executive summary also includes a list of specific recommendations for the NCDOT.

Issue –- Are there bottleneck points in the network upstream of the lane reversal, on the lane reversal proper, or on the downstream crossover that could lessen the benefit of contraflow operation

- The Phase 1 modeling of the transition to contraflow confirmed that the transition point represented a correctable bottleneck. This transition was modified to provide essentially continuously loading of four lanes through the MLK intersection.
- The Phase 2 modeling of the New Hanover County network revealed active bottlenecks on College Road at Market Street, Oleander Drive and Carolina Beach Road. However, the simulation results did not indicate that the resulting queues would seriously hamper the vehicle loading at MLK.
- The Phase 3 modeling of the full reversal network did not reveal serious queuing at the intervening interchanges. The simulation did reveal significant queuing at the downstream termination. Although queuing at the lane drops was expected, the model results indicated the potential for unacceptable queue imbalance and extreme queue lengths in the reversed lanes (9 – 10 miles from the lane drop). Further analysis revealed that keeping the queue

discharge capacity at the crossover as high as practicable is a key factor in mitigating queue imbalance.

Issue – Will the lane reversal increase throughput and average link speeds while reducing queue lengths?

- The Phase 1 and 2 modeling results indicate that the lane reversal plan as modified to allow simultaneous loading of four lanes through the MLK intersection will significantly reduce queue lengths and expedite evacuee travel to I-40 under moderate and severe evacuation traffic demand levels.
- The Phase 3 modeling further highlighted the need to ensure smooth operation of the termination crossover. If the queue discharge rate of the crossover can be kept near 1,800 vph, then the lane reversal will maintain average travel times to I-95 and significantly reduce corresponding maximum travel times. However, if the queue discharge rate is on the order of 1,500 vph as resulted from the initial model specification for the crossover (free flow speed of 15 mph), then both average travel times and maximum travel times to I-95 could be degraded for evacuees using the contraflow lanes as compared to travel times based on no contraflow under identical demand conditions.

Issue – Is the current storm severity threshold set for triggering the lane reversal set at an appropriate level?

- The lane reversal analysis indicated measurable benefits under the moderate and severe evacuation demand scenarios. These scenarios were designed to simulate conditions clearly above the threshold for considering lane reversal.
- For the minimal event scenario designed to simulate evacuation demand under a storm that just meets the threshold for consideration, the benefits of lane reversal were not clearly

indicated. However, given the risk of rapid storm strengthening off the south Atlantic coast, as well as the general uncertainty that remains in storm strength and storm track forecasting, the project team views the results to be a confirmation of the appropriateness of the established threshold.

In light of the project research findings, it is recommended that the NCDOT –

- Closely monitor the operation of the MLK transition to ensure that the deployed traffic control devices provide sufficient and clear guidance while creating minimal traffic flow impedance.
- Initiate a meeting with the State Highway Patrol to jointly developing strategies and procedures to maximize the throughput of the crossover at the downstream termination.
- Develop methods to monitor (and anticipate as much as possible) queue formation at the downstream end of lane reversal along with strategies to avoid or correct unacceptable levels of queue imbalance between the reversed flow and normal flow lanes.
- Develop joint plans with the City of Wilmington to collect extensive traffic data under evacuation conditions. Detailed recommendations for this data collection effort are presented in Chapter 6.

Evacuation experience and/or changing conditions will motivate continue reassessment and possible modification of the I-40 lane reversal plan. Chapter 6 also provides a list of future plan modifications for consideration under specific circumstances.

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CHAPTER 1. INTRODUCTION

1.1 Background and Problem Statement

The Atlantic and Gulf of Mexico coasts of the United States are the site of some of the most picturesque scenery in the world. Millions of tourists flock to these regions annually and permanent residential population growth has grown exponentially in the past quarter century. However, highway capacity has not kept pace with this population growth. In many cases, coastal communities are beginning to experience previously unseen congestion in morning and afternoon peak periods on typical weekdays or on weekends in high tourist occupancy situations.

Hurricanes are extremely dangerous, potentially fatal forces of nature that menace the Atlantic and Gulf coasts more than other regions of the United States. Major hurricanes, those registering Categories Three through Five on the Saffir-Simpson Hurricane Rating Scale (winds 111 miles per hour (mph) and stronger), produce severely damaging winds and serious storm surge-related flooding to coastal regions within a large radius of a particular storm's center. Floods are particularly damaging to low-lying areas along the coast, while winds are particularly damaging right near the coast as well as for mobile homes in the storm's path.

One of the primary goals of emergency management agencies in the event of an approaching hurricane is to ensure all vulnerable inhabitants of a jurisdiction are in a position of safety when the storm makes landfall. In order to provide for this safety, officials will send out evacuation orders in advance of a storm, sometimes two or more days before the storm makes landfall. While meteorologists' forecasting methods are improving annually, it is still not a certainty that a storm will make landfall where an evacuation has been ordered. In the case of Hurricane Floyd in 1999, evacuation orders were given from the central Atlantic coast of Florida northward to the outer banks of North Carolina. However, the storm took an unexpected turn in its final hours at sea and eventually made landfall at Cape Fear, North Carolina several days after the initial evacuations were ordered in areas left unaffected by the storm. The progressive northward evacuations resulted in an extreme period of congestion from northern Florida to southern Virginia due in part to the combination of these multiple evacuations. Several trips that normally take a few hours took up to a day in this situation. Since so many areas that were evacuated were not affected by Floyd, many of these coastal residents may be more likely not to evacuate if the order is given in the future. For this reason, emergency managers are often reluctant to issue mandatory evacuations unless the situation is especially ominous. In addition, since storms may take unexpected paths, rather than making an evacuation order days in advance of a storm's landfall, managers may be more likely to order an evacuation with less time available before landfall.

However, as mentioned previously, the highway network is sometimes inadequate for commuter traffic during typical weekday morning and evening peak periods, so in some emergency evacuations, long queues and extremely lengthened travel times may be the rule rather than the exception.

In order to facilitate evacuations so that residents are in positions of safety as quickly as possible, transportation and emergency management officials in most Atlantic and Gulf coastal states have developed lane reversal plans for major federal or Interstate highways viewed as the keys to evacuating the most inhabited coastal urban areas. Most of these plans were developed in the wake of Hurricane Floyd, since the evacuation from this storm enveloped several states and caused major traffic congestion on several U.S. and Interstate highways from Florida to Virginia. In addition, the State of Georgia executed a lane reversal from Savannah inbound to Macon on Interstate 16 in the evacuation of Hurricane Floyd, and the level of congestion found in this evacuation was not as severe as in neighboring states, especially those along the Interstate 95 corridor.

1.2 Project Scope and Research Objectives

As of the end of the 2004 hurricane season, only a handful of evacuation lane reversal plans had been triggered in the southeastern United States. These plans were as follows:

- Georgia, Interstate 16 westbound, during the evacuation for Hurricane Floyd in 1999
- South Carolina, Interstate 26 westbound, during the evacuation for Hurricane Floyd in 1999 (improvised, unplanned reversal)
- South Carolina, US Highway 501 northbound, during the evacuation for Hurricane Charley in 2004
- Louisiana, Interstate 10 westbound, during the evacuation for Hurricane Ivan in 2004
- Alabama, Interstate 59 northbound, during the evacuation for Hurricane Ivan in 2004

Although, Florida was ravaged by an unprecedented four hurricanes in 2004 (Charley, Frances, Ivan, and Jeanne), none of Florida's lane reversal plans were implemented.

Since contraflow has been executed in so few situations, and most of these evacuations occurred in late 2004, accurate performance data on the effectiveness of lane reversal on large-scale evacuations are not available to this point. Consequently, several teams of researchers in coastal regions have begun efforts to evaluate existing contraflow plans using traffic simulation models. Both macroscopic and microscopic models have been utilized in these efforts; however advancements in computer technology have led researchers to tend toward the simulation of evacuations with microscopic models.

Microscopic simulation models more rigorously analyze a network by tracking individual vehicle trajectories stochastically with varying random number seeds, resulting in greater detail and performance measures aggregated over the entire sample of drivers and vehicles. Macroscopic models analyze platoons of uniform vehicles throughout a network, which could be advantageous in oversaturated conditions.

In early 2000, the Intelligent Transportation Systems (ITS) unit of the North Carolina Department of Transportation (NCDOT) was authorized to produce a lane reversal plan for the evacuation of the City of Wilmington, the communities of Wrightsville Beach, Carolina Beach and Kure Beach, and other vulnerable areas of southeastern North Carolina via Interstate 40. In 2003, NCDOT authorized North Carolina State University and the University of North Carolina at Wilmington to conduct a two-year research project utilizing simulation modeling to analyze the effectiveness of the Interstate 40 lane reversal plan since it had not been triggered by any pending storms since its creation. The research sought to determine first whether traffic evacuating vulnerable areas can be effectively delivered to the contraflow lanes without experiencing bottlenecks upstream. This inability to efficiently fill the excess capacity in the reversed lanes was also documented in research by Theodoulou and Wolshon in the case of Interstate 10 in New Orleans, Louisiana (2004). Two microscopic simulation models were ultimately chosen for analysis: CORridor SIMulation (CORSIM) model, developed by the Federal Highway Administration (FHWA), and the German-based VISSIM model, developed by PTV-Vision, Incorporated. The Synchro/SimTraffic software package developed by Trafficware, Incorporated was also considered for use. However, initial attempts to run

SimTraffic simulation on the full New Hanover County model revealed computational time and file storage requirements that were impracticably high.

This analysis is unique because the Interstate 40 lane reversal begins along an arterial surface street, whereas other states' reversal plans are generally located solely on interstate highways. In this vein, the transition to contraflow is unique in that it occurs at a signalized intersection where turning movements can occur concurrently and feed all lanes more efficiently.

The objectives of this research were to generate and compare several measures of effectiveness (MOEs) from the simulation models to investigate the effects of lane reversal on this evacuation network. The MOEs analyzed in this modeling effort were queue lengths, average link speeds and throughput at key nodes. Thus the primary research issues regarding lane reversal operations were:

- Will the lane reversal increase throughput and average link speeds while reducing queue lengths?
- Is the current storm severity threshold set for triggering the lane reversal set at an appropriate level?
- Are there bottleneck points in the network upstream of the lane reversal, on the lane reversal proper, or at the downstream termination that could lessen the benefit of contraflow operation?

In addition to these operational research questions, the project also provided an assessment of currently available micro-simulation tools that could be considered for detailed analysis of lane reversal plans such as the I-40 plan.

CHAPTER 2. LITERATURE REVIEW AND PRELIMINARY SOFTWARE REVIEW

2.1 Review of Current Evacuation Plans and Procedures

Hurricane Georges in 1998 and Hurricane Floyd in 1999 produced two of the largest hurricane evacuation orders in U.S. history. The number of residents affected by the evacuations due to Hurricanes Georges and Floyd was higher than ever due to two primary factors: erratic storm tracks and coastal population growth.

In the cases of both Georges and Floyd, landfall occurred at a location a significant distance from that which was forecast 48 hours prior to the storm's arrival. This caused evacuation orders to progress in a manner which, especially for Floyd, caused evacuation traffic to encounter traffic from other evacuations that were previously ordered from areas no longer targeted by the storm. Floyd evacuations stretched from Florida northward to North Carolina. As a result, traffic leaving Florida and Georgia heading northward on major thoroughfares such as Interstate 95 became entangled with traffic later ordered to leave coastal areas of Charleston, South Carolina along I-26 (Dow and Cutter, 2002). Traffic continuing northbound on Interstate 95 encountered yet more conflicting evacuation traffic as the Wilmington, North Carolina, area was evacuated along Interstate 40. As a result, anecdotal accounts claim that the approximately 100-mile distance from Charleston to Columbia took upwards of 18 hours to complete during the evacuation's peak along Interstate 26, and Interstate 40 backups stretched for miles as Wilmington traffic moved inland.

These traffic backups were exacerbated by the fact that there were simply more people to evacuate in coastal areas than there had ever been. A research study estimated that property values, a primary indicator of development and growth, in coastal areas increased nearly 50 percent between 1988 and 1993 alone (Dow and Cutter, 2002). Since 1993, this growth rate is believed to have continued or even increased along the Gulf of Mexico and Atlantic coastlines. This growth has overburdened highway infrastructure to the point where, in some areas, even the summer tourist season traffic has exceeded the capacity of the existing highways. Since many of these highways are in areas that are sparsely populated in the tourism off-season, capacity increases in these areas have been overlooked in many states in order for traffic problems in other inland areas to be addressed. In hurricane evacuation scenarios the demand on these highways is exacerbated. In addition, according to Dow and Cutter (2002), 25 percent of South Carolina residents evacuating in advance of Floyd took more than one vehicle with them, and another significant number of residents attached trailers or tied belongings to their vehicles, making them "heavy vehicles" from a traffic standpoint and bogging down the performance of the evacuating traffic stream. The troubles encountered by evacuees have not gone unnoticed by state Departments of Transportation (DOTs). DOTs in every Atlantic or Gulf coastal state have enacted or evaluated plans to better evacuate its coastal residents. Wolshon et al. compiled a review of these policies and procedures in 2001.

2.2 Lane Reversal Implementation

One of the most recent developments in hurricane evacuation procedures is the use of lane reversal, or contraflow. Contraflow involves closing one or more lanes on a divided highway in the inbound direction in order to create more capacity for outbound traffic by allowing it to travel on the closed lanes. While lane reversal is a new and relatively untested system for hurricane evacuations, contraflow has been used for many years in more everyday scenarios, such as reversible High Occupancy Vehicle (HOV) facilities in urban areas, or as a means of accommodating traffic exiting from sporting events at large venues, such as North Carolina State University football and basketball games in Raleigh, NC and auto races at the Lowe's Motor Speedway in Charlotte, NC. However, these cases are familiar to the drivers using the facility and these travel ways have been designed with contraflow in mind. For the special case of hurricane evacuations, the contraflow plans have been developed for highways that were not originally designed for lane reversal to take place, and the setting of the evacuation (driver behavior, level of confusion) is much different than in the morning commute or leaving a football game. According to Wolshon et al. (2001), the costs and benefits of lane reversal for hurricane evacuations are largely unknown.

The U.S. states with borders on the Atlantic Ocean or Gulf of Mexico have produced evacuation plans showcasing a total of four different contraflow scenarios. The most common case, and the case included in the I-40 Lane Reversal, is to reverse both inbound lanes and provide four total outbound lanes. No inbound traffic is permitted on I-40 if lane reversal is enacted; all inbound traffic must follow U.S. Highway 421, a major (two-lane) thoroughfare that runs parallel to I-40 in the study area. Other contraflow configurations include: three outbound lanes for evacuation traffic and one inbound lane for emergency vehicles only; three outbound lanes for evacuation and one for all inbound traffic; and three outbound lanes plus one shoulder for evacuation and one inbound lane for all traffic (Wolshon et al. 2001). Figure 2-1 depicts these cases graphically. Previous research (FEMA, 2000) has produced the following estimates for contraflow capacity increases:

a) All four lanes outbound: 70% increase over two lanes outbound, two lanes inbound

b) Three lanes outbound, one lane inbound: 30% increase over two lanes outbound, two lanes inbound

c) Three lanes plus one shoulder outbound, one lane inbound: 40% increase over two lanes (8% increase over scenario (b))

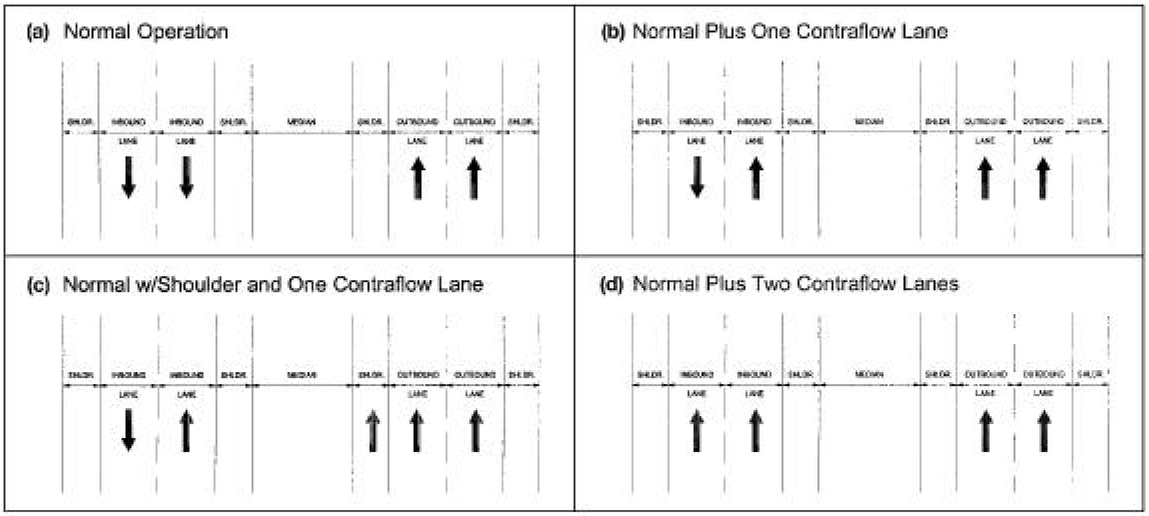


Figure 2-1. Contraflow Cases for Divided Highways (Wolshon, 2001).

If only one inbound lane is reversed, the probability of head-on collisions is introduced (Wolshon et al., 2001). In these cases fatalities, injuries, and incidents that could severely hinder capacity become an increased possibility.   The risks of collision and discomfort are also increased with shoulder use, due to the possibility of hindrances occurring in the shoulder that the driver would not normally have to encounter. Shoulder use is only possible on stretches of highway where the shoulder maintains a width capable of carrying a vehicle at a significant rate of speed.

Several methods have been devised to merge the traffic from all lanes back into the normal lanes. The most common procedure (and that utilized in the existing I-40 Lane Reversal) is the median crossover (Wolshon et al., 2001). The median crossover at the western terminus (end) of the North Carolina plan involves a capacity drop from two lanes to one on each side of the highway before joining the traffic back together on the outbound lanes. Wolshon et al. suggest that lane reversals that terminate in this manner must rely on a significant number of vehicles to leave the evacuation at one of the many exits along the way in order for this capacity reduction not to produce congestion. In another method common in plans that terminate where two Interstate highways intersect, the outbound lanes are directed onto the ramp to the intersecting highway and the inbound lanes are routed to the empty outbound lanes downstream of the interchange.

As of late 2004, the following states had formal lane reversal plans of some fashion (Wolshon et al., 2001, confirmed 2004):

- New Jersey
- Maryland
- Virginia
- North Carolina
- South Carolina
- Georgia
- Florida
- Alabama
- Mississippi
- Louisiana
- Texas

As observed in the case of Hurricane Isabel in September 2003 and in keeping with the plan guidelines, contraflow is expected to be used sparingly for evacuations of New Hanover County. Given the manpower and cost necessary for implementation as well as the movement restrictions and potential confusion associated with reversed lane operations, it would be prudent to reverse eastbound I-40 only when these costs are likely to be outweighed by the benefits to the evacuees. Most states only plan to implement lane reversal when major (Saffir-Simpson Categories 3, 4 or 5) storms threaten (Wolshon, 2001). North Carolina's plan has a slightly lower threshhold, with implementation possible (but not necessarily required) when a storm of strong Category 2 or higher status threatens Wilmington. The timing of lane reversal varies by state. Most states will not operate contraflow lanes in during nighttime. Therefore, contraflow must be ordered in a manner which will allow the majority of traffic to evacuate before darkness falls or (in North Carolina's case) three hours before tropical storm-force winds are expected (Wolshon et al., 2001)

This goal is a challenging one given the uncertainty of the hurricane tracks and the cost of evacuation. According to Wolshon (2002), an evacuation can cost between $200,000 and $1 million per mile of coastline. Furthermore, tourists often do not return to complete their stay even if an evacuation occurs in the middle of their vacation and may be reluctant to return in the future if they are forced to evacuate. Therefore, local emergency management decision makers hesitate to trigger a mandatory evacuation until it is clear that their local area is in the storm's path and that the storm will be of sufficient intensity to warrant evacuation. Government officials also wish to avoid the "cry wolf" scenario, where an unnecessary evacuation order leads to the unwillingness of the residents of that area to leave when a future storm threatens.

2.3 Determining Evacuation Demand

The vast majority of evacuation demand research has been performed for the U.S. Army Corps of Engineers and the Federal Emergency Management Agency (FEMA) through their hurricane evacuation analyses. These analyses are performed and updated on a regular basis for each coastal state in the southeastern United States, both along the Atlantic Ocean and Gulf of Mexico coasts. The North Carolina Hurricane Evacuation Restudy was performed by Post, Buckley, Schuh and Jernigan, Incorporated (2000). This study created a network of evacuation zones based on Geographical Information Systems (GIS) and created a matrix of evacuating vehicle demand based on Saffir-Simpson storm category and the expected related storm surge and flooding with this Category storm. However, as Hurricane Floyd demonstrated, hurricane strength is sometimes not directly related to coastal vulnerability. At landfall, Floyd had weakened to a Category 1 storm on the Saffir-Simpson scale, yet it caused what climatologists have assessed as a "500-year flood" in eastern North Carolina. Wilmot and Meduri (2005) analyzed different procedures for accurately determining hurricane evacuation demand in the New Orleans area and determined that storm category alone may not be sufficient as a means of determining evacuation demand.

> "In the past, hurricane evacuation zones have been established manually using professional judgment. The resulting zones have typically been classified into categories 1 to 5 to correspond to the category storm that would be needed to flood the zone. However, other factors such as the track, speed, and size of a storm are also important in establishing flood levels. Thus, flooding of a particular hurricane evacuation zone is best described in terms of a scenario rather than as a function of the category of a storm alone. Using a system of zones of homogeneous elevation that are overlaid on a surge map to identify those that will

be flooded in each scenario is, in our opinion, a more appropriate way to identify which evacuation zones need to be evacuated"

(Wilmot and Meduri, 2005).

Wilmot and Meduri recommend future research to develop enhanced methods for determining evacuation demand for particular areas. However, for the I-40 lane reversal analysis and research, the *Hurricane Evacuation Restudy* continues to be the best available source for evacuation demand estimates.

2.4 Contraflow Crossovers

Recent research conducted by Theodoulou and Wolshon (2004) supported an expectation that a low-speed median break crossover might actually reduce network capacity rather than providing additional throughput. In order to obtain a better estimate of the characteristics of a median break, a review of research on work zone capacity, speed, and saturation flow rates was conducted. Jiang (1999) performed speed and volume data collection at several freeway work zone locations in Indiana, using standard collection equipment as well as Global Positioning Systems (GPS). One of these locations was a median crossover. Capacity, speed and flow distributions were obtained and analyzed with the ANOVA statistical test.

The mean capacity of the median crossover zone was 1,612 passenger cars per hour, the mean speed of this zone was 25.24 mph, and the mean saturation flow rate was 1,587 passenger cars per hour. However, the "uncongested" mean speed in the zone was estimated at 57 mph, higher than the expected free-flow speed of transition to contraflow either with surface street transition (the Wilmington case) or with freeway transition (the New Orleans case). The workzone crossover research has more applicability to the I-40 terminating crossover. However, evacuation operations will also be affected by the unique characteristics of evacuation traffic streams. Therefore, while the Jiang (1999) data set provides some insight on reasonable capacity and saturation flow parameters for the I-40 transition models, the observed crossover was designed with higher speeds than will be experienced at either end of the I-40 lane reversal.

2.5 Lane Reversal Plan Modeling

Since most states have not implemented their respective lane reversal plans to this point, simulation models have been used in several cases to attempt to estimate the performance of specific lane reversal plans.

The Texas Transportation Institute (TTI), Texas Department of Transporation (TxDOT), and the City of Corpus Christi recently used the CORSIM model to optimize a lane reversal it developed. This lane reversal plan is "modeled after the reverse-flow method used in the Carolinas" (Henk, 2002). This plan reverses approximately 90 miles of Interstate 37 from Corpus Christi to San Antonio.

A lane reversal plan developed for traffic headed westbound out of New Orleans, Louisiana, on Interstate 10 was recently modeled in detail with CORSIM at the Louisiana State University by Theodoulou and Wolshon (2004). The researchers attempted to allow the number of vehicles expected to be produced in a Category 4/5 evacuation (as determined by PBS&J) to proceed through the carefully-coded contraflow model network produced with the aid of GIS in order to determine if the reversed lanes could accommodate the evacuation demand expected in a major storm (Theodoulou and Wolshon, 2004). The researchers chose a heavy vehicle composition of fifteen percent to account for travelers securing cargo to their vehicles or towing trailers with their vehicles. Free-flow speeds on the contraflow lanes and in the median crossover were coded at a value lower than that on the regular I-10 outbound lanes due to the impacts of confusion and design constraints on the median crossover. The model was run thirty times with varied random number seeds. The resulting analysis produced outputs that suggested to the researchers that the capacity of the contraflow system was not being fully utilized under the current plan. Further study showed that the opening of two on-ramps to I-10 from I-310 would allow significantly more evacuees to access the contraflow system without constraining the capacity of the four lanes. The small adjustments to the existing plan that were analyzed in the model increased the total number of vehicles processed by the contraflow network from approximately 88,000 to 114,000 over the course of a 19-hour evacuation period. This ability to better feed the network through multiple entrance points is suggested as a possible consideration in amending the New Orleans and other contraflow plans (Theodoulou and Wolshon, 2004).

Overall, the simulation model produced a 53 percent increase in capacity for the reversed system as opposed to a two lanes outbound-two lanes inbound system. However, the median crossover and its included speed reduction produced a bottleneck that extended for miles upstream of the entrance to contraflow. The researchers report that the model "suggests that the segment itself does little good if adequate capacity is not provided at the point where vehicles enter the segment" (Theodoulou and Wolshon, 2004). This concern will be analyzed in detail in this research project.

A follow-up presentation by Wolshon at the 84th Annual Meeting of the Transportation Research Board (TRB, 2005) explained that the traffic measures of effectiveness demonstrated in the models were similar to those found in the field implementation of the plan in 2004, and the bottlenecks demonstrated in the modeling procedure were in fact observed in the field.

2.6 Preliminary Simulation Software Review

Initially, efforts were made to develop evacuation traffic models on a macroscopic scale. In 1985, Hobeika et al. developed the macroscopic MASSVAC 3.0 model to simulate the evacuation of a nuclear disaster. This model was enhanced in 1998 with the addition of the user-equilibrium (UE) assignment algorithm. This algorithm was not truly a dynamic assignment but was a major step in origin-destination mapping (Hobeika, 1985). Another such model is the Hurricane and Evacuation (HURREVAC) model, first developed in 1988 (http://www.hurrevac.com). This model uses Geographic Information Systems (GIS) technology to compile demographic data and correlate this data with proximity to evacuation routes in order to better determine factors such as evacuation traffic volume on the highway network (Wolshon et al., 2001). The consultant Post, Buckley, Schuh and Jernigan (PBS&J) developed another macroscopic model, the Evacuation Travel Demand Forecasting System (2000). This model attempts to simulate and determine the impact of the inter-state evacuation traffic encountered in situations such as that produced by Hurricane Floyd.

In an effort to better analyze evacuation systems, further work was performed to investigate evacuation traffic patterns on a microscopic scale. The ability to evaluate microscopically is unique in that microscopic models track individual driver behavior whereas macroscopic models view all vehicles in the traffic stream as platoons exhibiting identical individual behavioral characteristics. Macroscopic models analyze platoons of uniform vehicles throughout a network, which could be advantageous in oversaturated conditions. However, it was decided to focus on microscopic simulation in this analysis. The Oak Ridge Evacuation Modeling System (OREMS), developed by the Oak Ridge National Laboratory (ORNL), utilized the traffic modeling capabilities of the microscopic simulation model CORridor SIMulation (CORSIM) in conjunction with unique evacuation-related performance measures (such as clearance times) in order to analyze traffic flow in a defense-related emergency (Wolshon et al., 2001). This model can be loosely translated to hurricane evacuations, but the nature of the evacuation is a bit different in the two cases: hurricane evacuations often occur a day or two before the storm occurs and in good weather conditions, whereas defense-related emergency evacuations would occur after a disaster has taken place and most likely would exhibit a more panicked group of participants. Microscopic simulation models are preferred in this type of analysis due to their ability to model individual driver behaviors, but the I-40 lane reversal encompasses approximately 90 miles so their use in modeling the entire lane reversal may be difficult. This research has examined the capabilities of several microscopic and macroscopic models in order to produce the most accurate results possible for the particular case of Interstate 40 westbound from Wilmington, NC, inland.

Alsnih and Stopher (2004) performed a canvas of the state of the art in emergency evacuation modeling in order to determine the capability of existing models to accurately depict the deficiencies of a highway network in an evacuation scenario. The researchers determined that current modeling procedures “do not incorporate all aspects of evacuation behavioral analyses, and some of the models used do not contain a dynamic traffic assignment, a critical feature that will more accurately depict evacuee behavior on the transport network.” In addition, “to develop microsimulation models that incorporate dynamic traffic assignment, more accurate relationships expressing human travel behavior are needed. To date, no microsimulation model is able to incorporate a dynamic traffic assignment while also adapting to the emergency-evacuation scenario." To this point, the VISSIM model has been used sparingly, if at all, in evacuation simulation. This German microscopic simulation model adds the capability of Dynamic Traffic Assignment (DTA) to its standard static traffic assignment algorithms. CORSIM does not contain this capability. In addition, VISSIM models traffic flow based on a series of routing decisions rather than the link-node analysis found in CORSIM. The lane reversal research project included the task of evaluating available modeling tools and selecting the appropriate tool or tools for each modeling phase. The following software packages were initially considered for the New Hanover County component of the lane reversal plan modeling:

- OREMS
- CORSIM
- Synchro/SimTraffic
- VISSIM

Existing speed limits, geometry and phasing data were obtained through field observation and identically coded into all models.

2.6.1 OREMS

The Oak Ridge Evacuation Modeling System (OREMS) was designed to analyze evacuation measures of effectiveness such as clearance time. The package is based on the CORSIM platform but with abridged traffic control modeling capabilities. For example, actuated signal control is not included in OREMS. For this reason, OREMS will not be used to model the New Hanover County network. However, traffic volumes for the Martin Luther King, Jr. (MLK) Parkway/College Road intersection approaches derived from the countywide CORSIM and VISSIM models could be loaded onto an OREMS model of the 90-mile freeway section of the lane reversal in future research.

2.6.2 CORSIM

The CORSIM model was created using the Traffic Software Integrated System (TSIS) Version 5.1 software package, developed by FHWA.

2.6.2.1 CORSIM Advantages

CORSIM is readily available and well known throughout the traffic engineering community. CORSIM models freeway and surface street links using separate algorithms. This allows roadway facilities with vastly different characteristics to be modeled with relatively little effort. CORSIM also produces a simulation run relatively quickly.

2.6.2.2 CORSIM Disadvantages

TSIS 5.1 is the final version of CORSIM that will be created by FHWA. No software updates are expected from FHWA. In addition, observation of the TRAFVU program shows the animation TRAFVU reader has a .tsd file size limit of 2 gigabytes (although the CORSIM simulation file will run to completion regardless of this TRAFVU limitation). This was not considered a fatal error for this analysis, since the .tsd files were created to completion and the only error was observed in the TRAFVU animation viewer itself.

2.6.3 Synchro/SimTraffic

The New Hanover County network was coded in the Trafficware, Incorporated, Synchro/SimTraffic package (version 6) for the purpose of simulation using SimTraffic.

2.6.3.1 Synchro/SimTraffic Advantages

As with CORSIM, the Synchro/SimTraffic package is widely used and well known. In addition, this software has a very user-friendly graphical user interface that allows new users to become proficient with less extensive effort. Finally, SimTraffic has the capability of reading of uniform traffic data format (UTDF) databases for volumes and signal timings. This feature is useful when small changes must be made to large-scale networks.

2.6.3.2 Synchro/SimTraffic Disadvantages

A primary obstacle to this research is the scalability of the SimTraffic model. The package took over 24 hours to complete a single 14-hour simulation run of the New Hanover County network and created an animation file with a size of approximately 50 gigabytes. A report on the SimTraffic measures of effectiveness could not be created due to these scalability issues. In addition to the scalability issues, in the Synchro/SimTraffic package traffic demand must be entered as link turning volumes or percentages, i.e. the software cannot accept origin-destination based demand estimates and has no dynamic traffic assignment capabilities.

2.6.4 VISSIM

The VISSIM model was created using the German-based PTV-Vision, Incorporated, VISSIM software package, version 4.0.

2.6.4.1 VISSIM Advantages

VISSIM has the ability to model origin/destination based traffic demand and assign vehicles statically or dynamically. This feature makes VISSIM very attractive for evacuation modeling and will allow analysis of the effect of lane closures due to incidents or flooding. Scalability issues such as those faced with Synchro/SimTraffic were not encountered with the VISSIM platform.

2.6.4.2 VISSIM Disadvantages

The primary disadvantage of VISSIM is that it is not currently as widely known and accepted as CORSIM or Synchro/SimTraffic, at least in the southeastern United States. Also, VISSIM's Graphical User Interface (GUI) was not as user-friendly as those of the other software tools.

In terms of model robustness and effort in coding, research performed by Bloomberg and Dale (2000) comparing VISSIM and CORSIM on a congested network in the Seattle metropolitan area drew the following conclusions:

- Relative travel times were consistent between the models and lead to the same conclusions about the design options analyzed in this study. However, there were differences in the absolute predictions of the two models for some scenarios.
- Both models are appropriate for modeling congested arterial street conditions.
- Although the parallel modeling effort added credibility to the analysis results, either model alone was adequate for the analysis. A specific model cannot be recommended based on this research – both were appropriate for this study. Each has specific strengths and limitations that should be evaluated on a case-by-case basis.
- On a selected section upstream of a signalized intersection, both models produced similar throughput.
- It is estimated that coding the network took approximately the same amount of time in CORSIM and VISSIM.

Based on this research, it was believed that the two models should produce similar results when the Interstate 40 reversal network was coded under the static assignment conditions. However, the research was performed several years ago when the latest versions of the simulation models were not in existence. In addition, the event of an emergency evacuation was not considered in this previous model comparison. Therefore, comparisons should be conducted in order to determine whether the simulation models do in fact produce similar outputs in a large-scale emergency evacuation condition.

2.7 Chapter Summary

Along the Atlantic and Gulf coasts from New Jersey to Texas, hurricane evacuation plans have become more advanced following Hurricanes Georges and Floyd in the late 1990s. The most common aspect of these evacuation plans in most states (Mississippi being a notable exception) is lane reversal, or contraflow. Among the various evacuation plans, four different contraflow scenarios are utilized: reverse both inbound lanes; reverse one inbound lane with emergency access only on the other inbound lane; reverse one inbound lane with full access on the other inbound lane; and same as previous but with shoulder use on the outbound side. Prior to the hurricane season of 2004, Georgia was the only state to execute its lane reversal plan, during Hurricane Floyd evacuations in 1999. South Carolina executed an impromptu lane reversal on Interstate 26, but that plan was superseded by an official plan following the storm. Due to the recent nature of these evacuations, sufficient data are not available at this time to analyze the performance of the plans recently field-tested.

Since there are very little data available on contraflow operations, simulation models have been viewed as the best means with which to determine whether the performance of the lane reversal will demonstrate a capacity increase over existing conditions, and whether the transition to contraflow will occur without causing an exacerbation to upstream congestion due to the possibly confusing crossover maneuver. Several models have been utilized in hurricane evacuation analysis, with CORSIM being used in evacuation models for both the Oak Ridge National Laboratory (ORNL) and for the City of New Orleans (per the Louisiana State Police evacuation plan). CORSIM analysis of the New Orleans model has shown that contraflow can provide a capacity gain; however the median crossover has been shown to cause a long upstream queue and the capacity of the highway in contraflow conditions is not met. Further analysis showed that multiple access points to the contraflow better utilizes the capacity of the system and alleviates some of the congestion upstream of the primary transition to reversed lanes. While VISSIM and CORSIM have been used in concert in order to obtain a comparison between the two models in the past, these models have not been compared in the context of their latest versions and in emergency evacuation conditions. Finally, since the transition to contraflow in this lane reversal plan is so unique, in order to better determine the transition speed to contraflow in this lane reversal network, a review of work zone crossover research was conducted but this review did not reveal a situation similar to that expected when the Interstate 40 reversal is enacted.

CHAPTER 3. METHODOLOGY

3.1 Outline of Research Methods

This research aims to analyze a case study in emergency evacuation conditions with traffic simulation modeling in order to produce measures of effectiveness that can be investigated to determine the efficiency of the implementation of lane reversal. Demand is estimated using historical studies because there is a dearth of empirical data available for emergency evacuation conditions. A simplified flow chart of this methodology is shown in Figure 3-1.

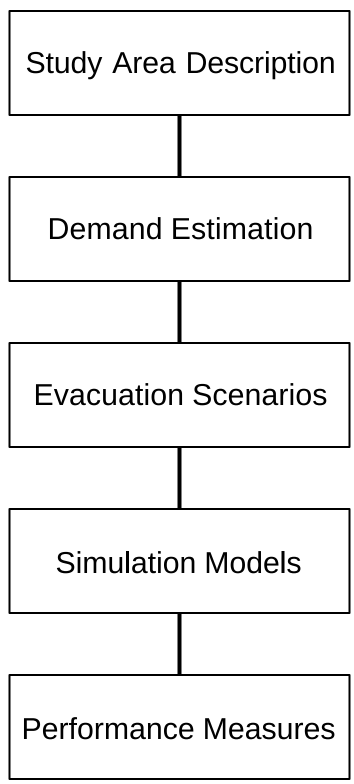


Figure 3-1. Research Methodology

3.2 Study Area Background

The simulation modeling analysis for the southern terminus of the lane reversal plan was performed in two phases. The first phase focused solely on the transition to contraflow by feeding all evacuating traffic directly to this transition and evaluating the original plan as well as alternative methods to feed the reversed lane network. Since this analysis was focused on making fast-track policy decisions, the highway network analyzed was confined to a small selection of intersections near the transition to contraflow and only one simulation model was utilized in this analysis. Figure 3-2 through Figure 3-5 depict the four alternatives originally considered for the transition to contraflow. Case (a) was considered as the "do-nothing" alternative (no lane reversal). Case (b) represents the original transition to contraflow written into the I-40 Lane Reversal Plan from 2000-2003. Case (c) shows a second transition to contraflow considered to be paired with that of case (b). However, this alternative was removed from consideration when it was learned that safety improvements to the intersection of College Road and Spring View Drive prevented a transition to contraflow from being implemented here. Case (d) shows the lane-based evacuation routing that would be established with the Martin Luther King intersection transition that was ultimately chosen by NCDOT for addition to the official lane reversal plan in 2004.

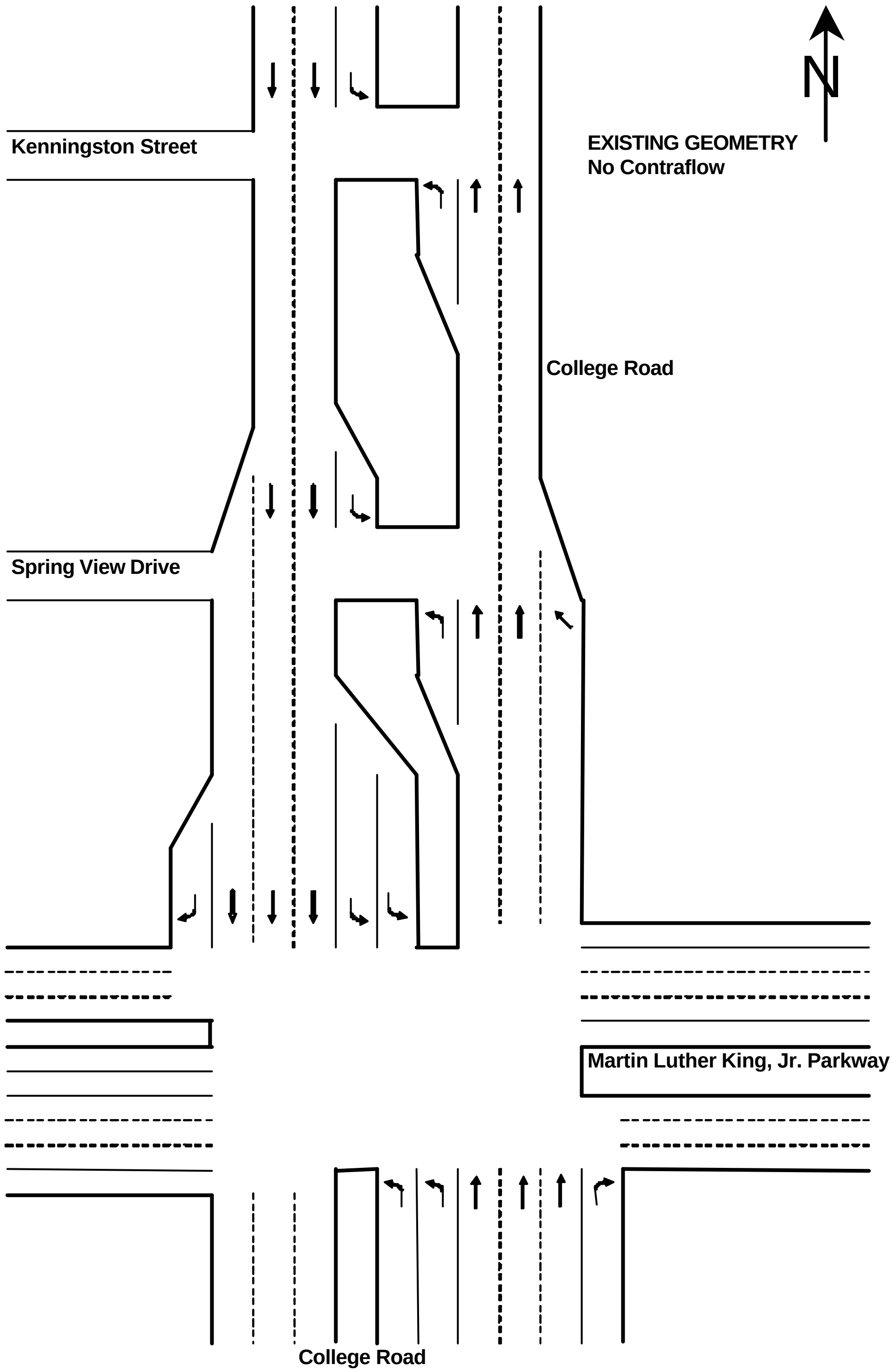


Figure 3-2. Schematic - No Implementation of Contraflow

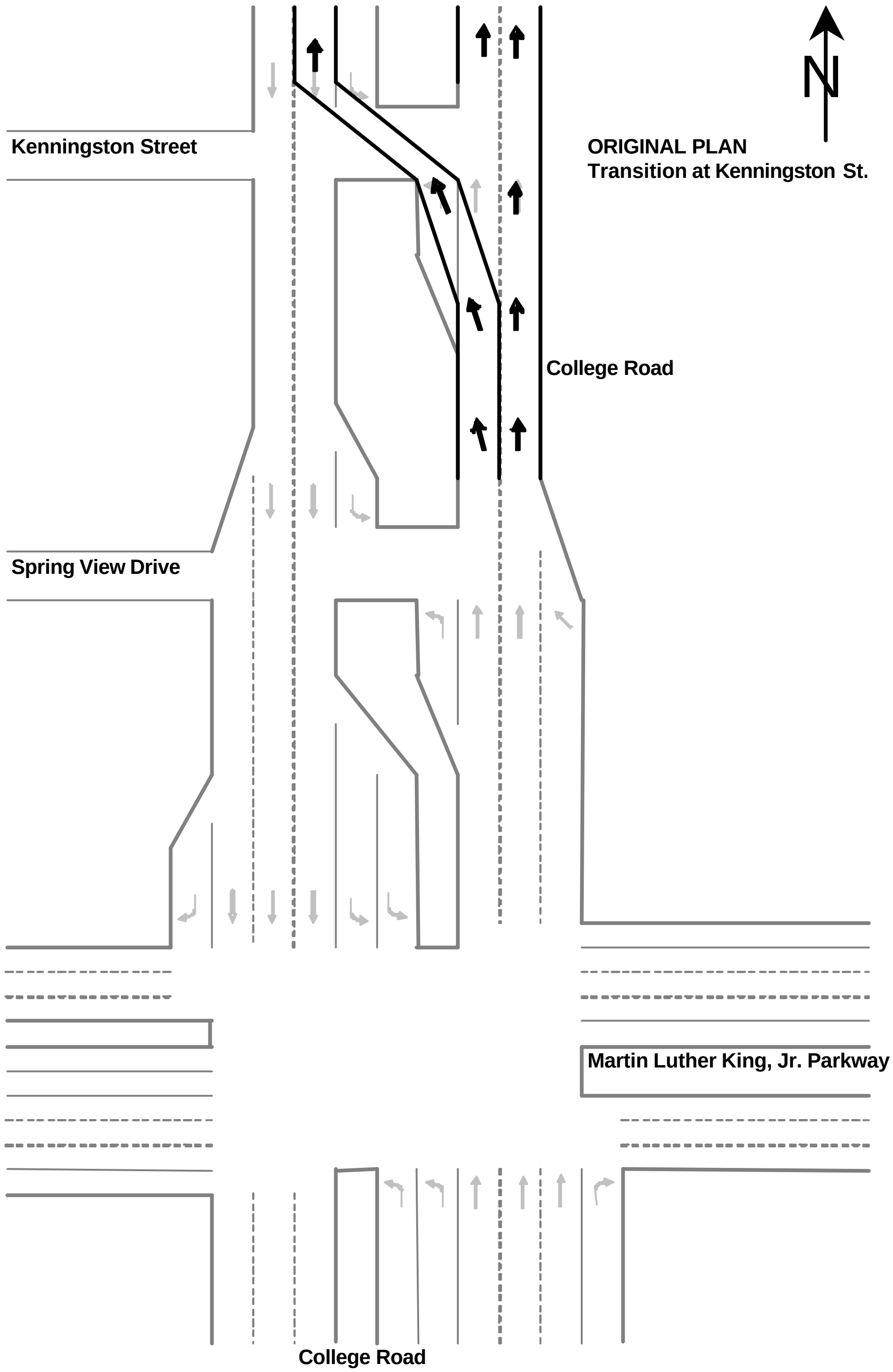


Figure 3-3. Schematic - Original (2000-2003) Transition to Contraflow

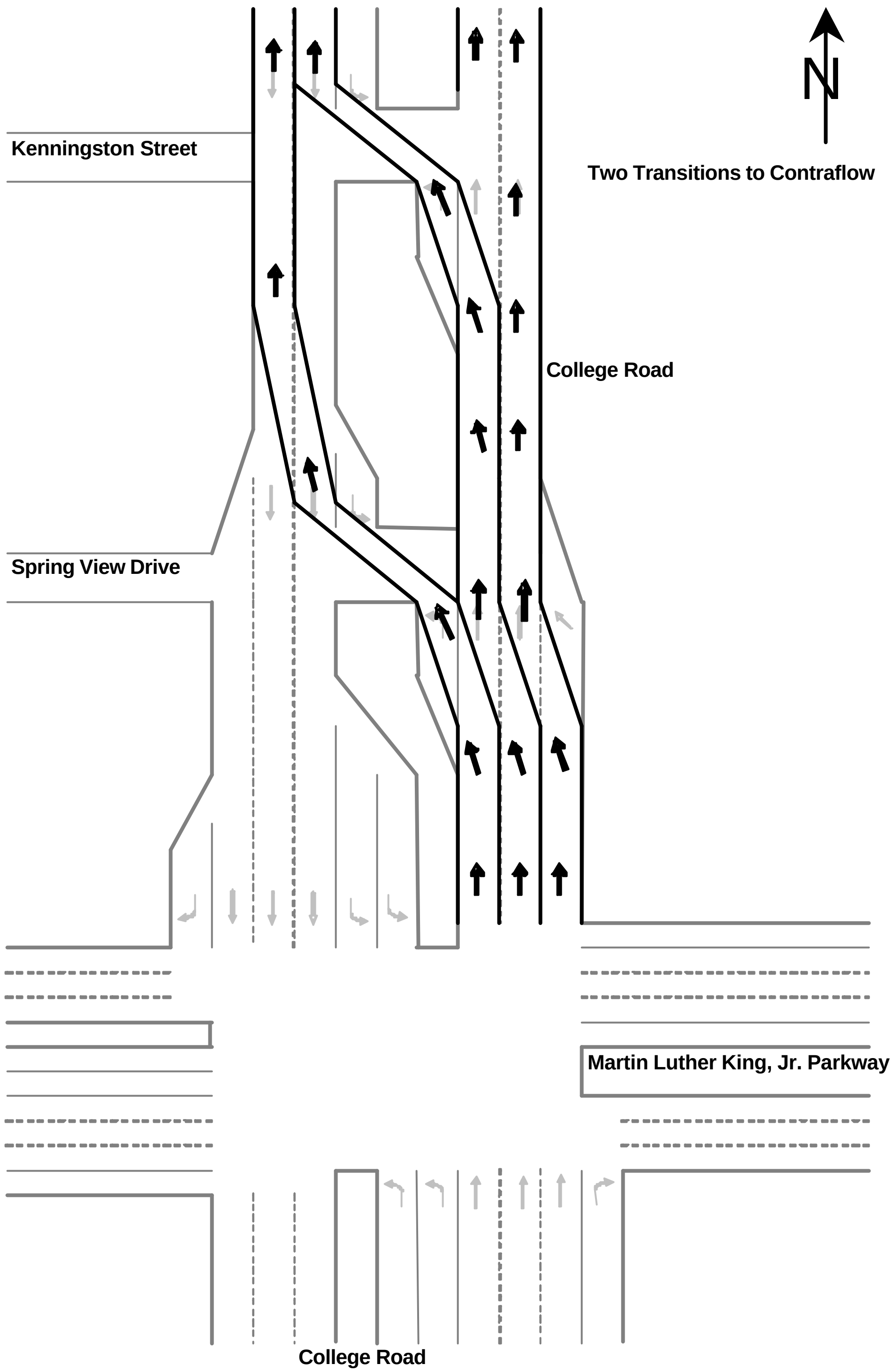


Figure 3-4. Schematic – Possible Second Transition to Contraflow

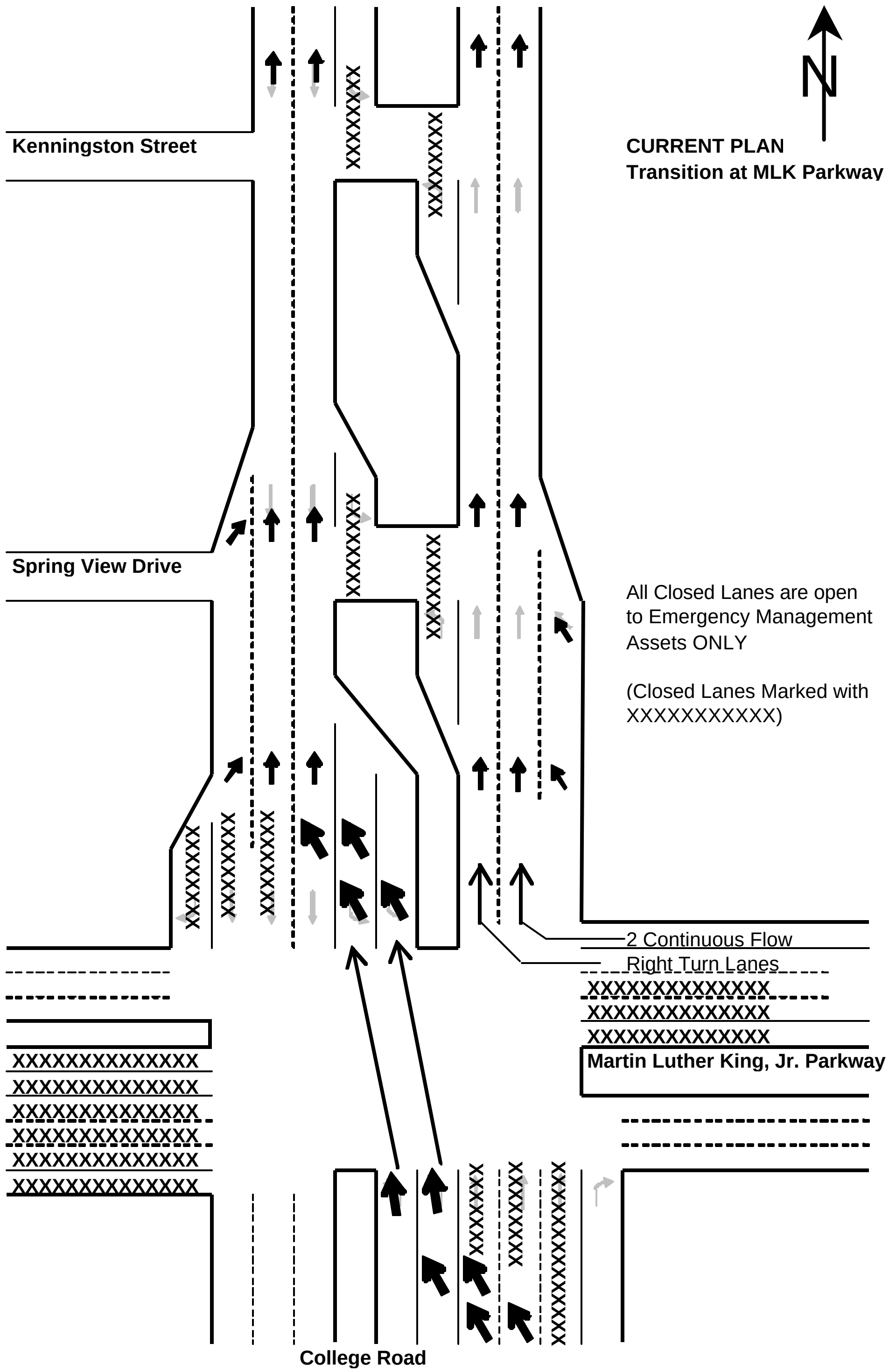


Figure 3-5. Schematic – Revised (and Current) Location of Transition to Contraflow

Figure 3-6 represents an aerial photograph of the location of the original transition to contraflow. The transition was located at a median break for the unsignalized intersection of College Road and Kenningston Street, approximately three-quarters of a mile north of the Martin Luther King, Jr. Parkway/College Road intersection. Coincidentally, the aerial photo was taken at the same time a vehicle is performing a movement that essentially mimics the crossover to contraflow. All aerial photography utilized in this analysis was provided by New Hanover County Geographic Information Systems (GIS) and is from 2002.

Approximate Scale: 1” = 120’

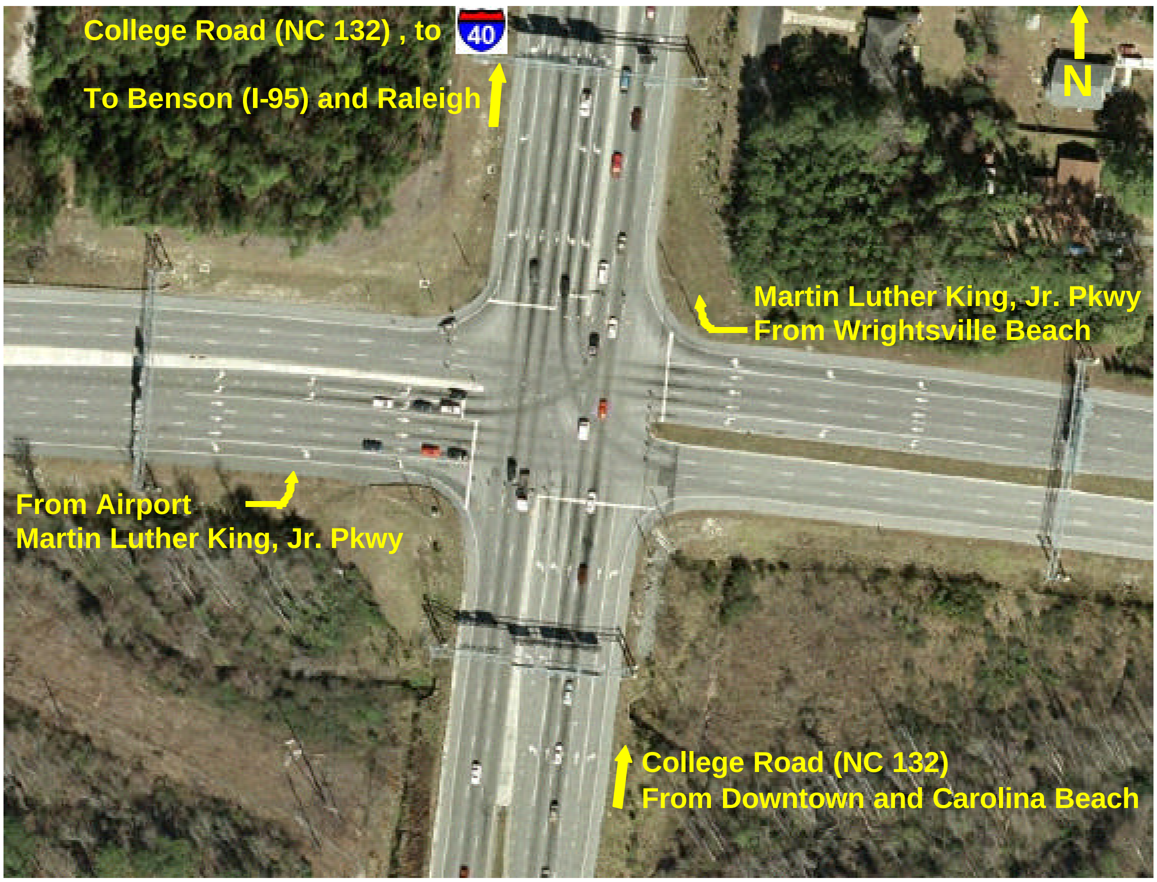
Figure 3-6. Original Plan (2000-2003) Transition to Contraflow (New Hanover County, 2002)

Figure 3-7 depicts a median break at the intersection of Spring View Drive and College Road, approximately one thousand (1000) feet north of the Martin Luther King, Jr. Parkway/College Road intersection. This location was considered as a possible second transition to contraflow in order to better utilize the existing pavement. However, consideration of this alternative was discontinued after it was learned that NCDOT planned (and eventually constructed) a "left over" system at this median break with concrete islands that would prevent a crossover at this location.

Approximate Scale: 1" = 165'

Figure 3-7. Possible Transition at Spring View Drive (New Hanover County, 2002)

The second phase of analysis was performed after the 2004 policy changes were made and the transition to contraflow was shifted approximately one mile upstream of the original transition to the signalized intersection of College Road (NC Highway 132/US 117) and Martin Luther King, Jr. Parkway. Figure 3-8 depicts an aerial photo of this intersection.



Approximate Scale: 1” = 155’

Figure 3-8. MLK Parkway/College Road Intersection (New Hanover County, 2002)

This move of the transition to contraflow was assumed to alleviate two possible bottlenecks: one at this intersection itself and one approximately 1000 feet downstream of the signalized intersection where a three outbound lanes drop to two. The preliminary analyses that led to and supported this plan change are discussed in detail in section 5.2.

Upon the completion of this preliminary modeling, the full countywide model was prepared with the transition to contraflow taking place at the College Road/MLK parkway intersection. The scope of this phase of analysis increased to encompass all major arterials in New Hanover County. The principal New Hanover County routes included in the model are as follows:

- **Interstate 40.** I-40 is a four-to six-lane freeway extending from approximately a mile north of the intersection of College Road and Martin Luther King, Jr. Parkway to the county line and beyond. There are two interchanges in New Hanover County, both of which will be closed to the contraflow lanes in the event of a lane reversal. The speed limit on I-40 is 70 miles per hour (mph) through the network.

- **College Road (NC Highway 132/US 117).** College Road is a four-to six-lane arterial facility serving as the primary north-south arterial in New Hanover County. The land use on College Road is primarily commercial, but also includes the University of North Carolina at Wilmington. The speed limit on College Road varies between 45 and 55 mph through the network.

- **Martin Luther King, Jr. Parkway.** MLK Parkway is a six-lane divided arterial with a speed limit of 55 mph. This highway is still under construction, and once completed will serve as a primary east-west arterial in New Hanover County. The Wilmington International Airport is served by MLK Parkway.

- **Market Street (US 17/74).** Market Street is a four-to six-lane arterial that serves as the primary east-west access in New Hanover County. This highway provides service to downtown Wilmington as well as the beaches of Pender County to the northeast of Wilmington and points south and west via US 17 and US 74. Land uses along Market Street vary from residential to commercial and speed limits vary from 35 to 55 mph.

- **Carolina Beach Road (US 421).** Carolina Beach Road is a four-lane arterial that serves the beaches south of Wilmington, connects with College Road, and continues north to downtown Wilmington. This arterial provides service north of Wilmington via US 421 (inbound traffic is directed to US 421 in the event of a lane reversal). The speed limit on Carolina Beach Road varies from 40 to 55 mph.

- **Oleander Drive (US 76).** Oleander Drive is a four-to six-lane east-west arterial that serves the Wrightsville Beach area as well as downtown Wilmington. This highway also provides access to points west via US 76. The speed limit on Oleander Drive varies from 35 to 55 mph.

Following the Phase 2 countywide modeling effort, the network simulation models were expanded to include the entire lane reversal plan. This final simulation and analysis phase provided assessment of the operation of the interchanges between the transition to contraflow and the contraflow termination as well as assessment of the operation of the termination point.

3.3 Evacuation Demand Estimation

Recent evacuation demand data was not readily available for this analysis. The demand estimation for this analysis was extracted from the *North Carolina Hurricane Evacuation Restudy* (hereinafter referred to as *Restudy*) and *Evacuation Travel Demand Forecasting System*, conducted by Post, Buckley, Schuh and Jernigan, Inc. (PBS&J). This was done in order to establish an accurate estimation of both evacuation demands and clearance times for all coastal areas of North Carolina in the event of storm landfall. These estimations are categorized first by region of the state (either by county or groups of counties) and then further by manually generated evacuation analysis zones. These zones are similar in nature to Transportation Analysis Zones found in other transportation demand modeling. The edition of PBS&J's *Restudy* utilized in this analysis was published in 2001.

New Hanover County was considered by itself in the *Restudy*, providing detailed data for this analysis based on only the county involved in the scope of the project. Therefore, all demand for New Hanover County was considered in this research. However, local traffic and emergency management officials suggested that a fraction of the demand expected from Brunswick and Pender counties (other coastal counties neighboring New Hanover) would also feed the New Hanover County highway network and ultimately Interstate 40. Therefore, 10% of the *Restudy* demand for Brunswick and Pender Counties was added to the New Hanover County demand values for consideration. Figure 3-9 is a graphical representation of the Evacuation Demand Zones for New Hanover County. Since evacuations vary in demand and concentrated location, the PBS&J demand models, evacuation zones and clearance times are categorized in terms of Category of storm (on the Saffir-Simpson scale), storm movement, and tourist occupancy. Table 3-1 shows the New Hanover County demand values based on High Tourist Occupancy from the *Restudy*.

Table 3-1. New Hanover County High Tourist Occupancy Volumes (vehicles)

County	Total Evacuated Population	Evacuees to Shelters	Vehicles to Shelters	Vehicles to Friends/ Relatives	Vehicles to Hotel/ Motel	Vehicles to Out of County	Total Evacuating Vehicles
New Hanover							
Category 1-3	45,230	3,965	1,762	6,630	581	11,467	20,438
Category 4-5	61,110	7,649	3,358	6,617	581	16,735	27,290

Source: PBS&J, 2001.

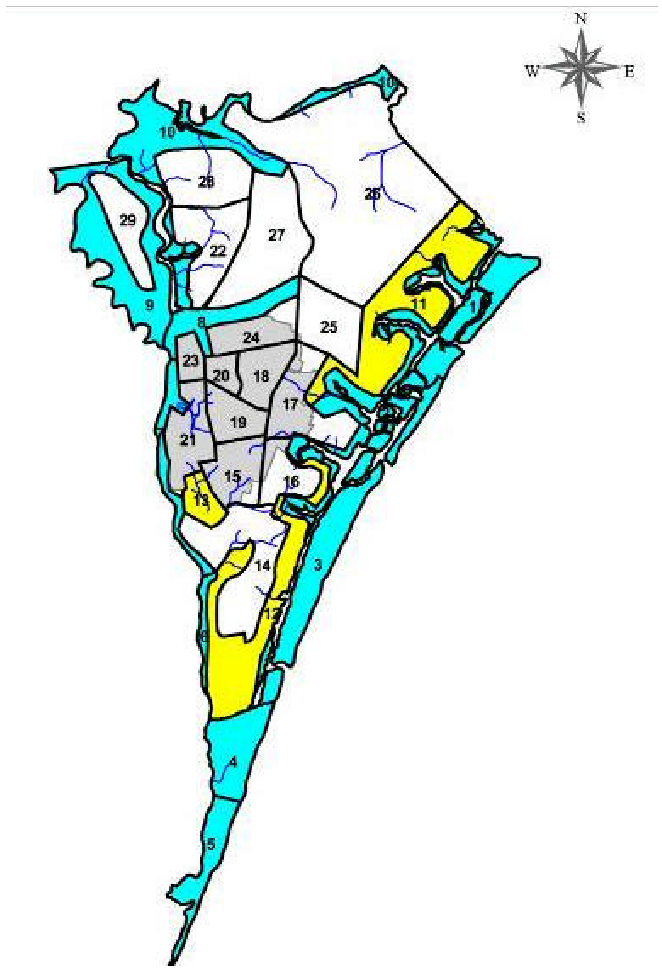


Figure 3-9. Evacuation Demand Zones for New Hanover County (PBS&J, 2001)

3.3.1 Response Time Curves

Another variable considered in the evacuation demand analysis was the behavioral reactions of evacuees. Perhaps the most important of these reactions is response time. The *Restudy* also developed "evacuation response curves" based on response time of the particular evacuation. These curves have been developed individually for all coastal areas studied in these FEMA analyses. The New Hanover County "evacuation response curves" based on evacuation response time (which is related to storm movement speed) are depicted in Figure 3-10.

Figure 3-10. Evacuation Response Curves (PBS&J, 2001)

3.3.2 Evacuation Trip Distribution

The data provided in the *Restudy* were broken down by evacuation zone and expected destination. However, detailed trip distributions were not provided. Therefore, it was necessary to manually distribute trips throughout the highway network. In order to do this, all demand for each evacuation zone that was not expected to travel "out of county" was not loaded into the network. Internal New Hanover County trips were assumed to be accounted for in background traffic additions (explained in the next section). All "out of county" trips were then distributed on a origin-destination level based on where the evacuation zone was located and where these vehicles would be expected to go based on knowledge of the highway network and the area where the zone was located. For instance, if the evacuation zone was located in the northern part of New Hanover County near Interstate 40, a vast majority of the trips were labeled to be destined to leave New

Hanover County via the interstate. If the evacuation zone was located in the western section of the county nearer downtown and US 17/74/76, a greater proportion of trips would be labeled to exit the county westbound via US 17/74/76. However, great care was taken to be conservative in terms of feeding Interstate 40. In other words, in most cases the proportion of trips destined for I-40 from most zones was somewhat overestimated in order to provide a more conservative estimate of demand destined toward the intersection of College Road and Martin Luther King, Jr. Parkway. These traffic distributions were cross-checked with origin-destination survey data conducted by the University of North Carolina at Wilmington and with the City of Wilmington Traffic Engineering Department.

Once this high level origin-destination distribution was established, routing distributions were created based again on knowledge of the highway network. Since this was a manual trip distribution and assignment, engineering judgment was used and “all-or-nothing” assignment was not implemented since this did not seem realistic. For example, if two routes from an origin to a destination seemed similarly feasible, trips were split (not necessarily equally) between the two routes rather than assigning all trips to one absolutely shortest route.

Once routing proportions were completed, raw evacuation counts were aggregated to and from each evacuation zone to generate link-node flows. This created detailed intersection turning movement evacuation counts for the entire highway network to be combined with the established background traffic. Appendix A depicts the resulting volumes of this distribution for the example of the Severe Event case.

3.3.3 Background Traffic

In order to effectively capture internal trips within New Hanover County as well as non-evacuees on the highway network, background traffic volumes were established through the utilization of available turning movement counts provided by the City of Wilmington as well as a uniform value of fifty (50) vehicles per turning movement at locations where counts were not available. In addition, for the final four hours of simulation where evacuation demand is minimal or zero, the uniform value of 50 vehicles per movement is applied to all locations. This was done both because it is expected that these hours will be very near the time when tropical-storm-force winds (39 mph or higher) are approaching the area, and in order to give an accurate estimation of the time evacuation queues will clear. This background traffic was combined with the evacuating traffic to produce turning movement counts at all study area intersections and interchanges in New Hanover County.

3.4 Evacuation Demand Scenarios

Based on the estimated demand data, three unique evacuation demand scenarios were analyzed. These scenarios are as follows:

Severe Event Demand Case:
Storm Strength: Category 4 or stronger (winds of 131 mph or higher)
Evacuation Demand: Largest potential evacuation population
Response Time: Fast (storm forward speed of 15 to 35 mph)

Moderate Event Demand Case:
Storm Strength: Category 2 or 3 (winds between 100 mph and 130 mph)
Evacuation Demand: Average evacuation population
Response Time: Fast (storm forward speed of 15 to 35 mph)

Minimal Event Demand Case:
Storm Strength: Category 2 at the plan threshold (winds approximately 103 mph)
Evacuation Demand: Average evacuation population
Response Time: Slow (storm forward speed of 0 to 15 mph)

Table 3-2 shows an example of the anticipated clearance times for New Hanover County from the *North Carolina Hurricane Evacuation Restudy*. "Clearance times" in Table 3-2 refer to the time required to clear all evacuating traffic to I-95.

Table 3-2. New Hanover County Clearance Times (hours)

	Low Seasonal Occupancy	High Seasonal Occupancy
Category 1-2		
Fast Response	5 1/2	7
Medium Response	6 1/2	8 1/4
Slow Response	9 1/2	10 1/4
Category 3-5		
Fast Response	6 1/2	7 3/4
Medium Response	7 1/4	9 1/4
Slow Response	9 1/2	11 1/4

Source: PBS&J, 2001.

All scenarios were analyzed in each model for both the "no contraflow" and "MLK contraflow" alternatives. Therefore, multiple simulation runs were performed in both CORSIM and VISSIM for the following scenarios:

- No Contraflow, Severe Event Case
- With Contraflow, Severe Event Case
- No Contraflow, Moderate Event Case
- With Contraflow, Moderate Event Case
- No Contraflow, Minimal Event Case
- With Contraflow, Minimal Event Case

The following measures of effectiveness were output in both models:

- Maximum Queue Length at Key Nodes
- Throughput on Key Links
- Average Speeds on Key Links

The official storm criteria (from the NCDOT I-40 Lane Reversal Plan) for implementation of contraflow are as follows:

Strength/intensity of the hurricane: At a minimum the threat should be in the upper range of wind velocity (sustained winds of 103 mph or greater) of a Category II hurricane.

Track/movement: The potential landfall of the hurricane should be within a window that extends from 50 miles north to 100 south miles of Wilmington.

Tourist population: Medium to maximum tourist population (height of tourist season). Reversal may not be necessary for smaller tourist populations.

Traffic volume: Medium to maximum volume is anticipated (based upon combined population of residents and tourist).

Expected onset of tropical storm force winds (sustained speeds of 39mph – 73 mph): Estimated as a function of time calculated from the forward speed of the storm.

Expected start of the evacuation and required clearance time: The average clearance time for Wilmington is 8 hours.

Time of day: Counties are advised to conduct evacuations during daylight hours to ensure evacuations are complete before the arrival of tropical storm force winds. Lane reversal should only be implemented during daylight hours and during mandatory evacuations.

3.5 Simulation Model Parameters and Calibration

As mentioned previously, evacuation lane reversal plans have been enacted in very few cases. Several of these were executed in just the past several months. Therefore, data are not readily available to analyze from previous evacuation lane reversal efforts. For this reason, several behavioral parameters such as saturation headways, driver reaction times, vehicle types, free flow speeds, and acceleration/deceleration data are not easy to calibrate for any simulation model in this context. In addition, this research placed an emphasis on a comparison of two prominent microscopic simulation models. Therefore, editing of default simulation parameters may produce biases that could be detrimental to a comparison of simulation models in identical evacuation conditions. However, several edits to default parameters were considered. A literature review of work zone crossovers was conducted in order to attempt to obtain an accurate saturation flow in work zone crossover situations. The thinking behind this review was to compare work zone crossovers to the transition to contraflow. However, once the transition was moved to its current location at the intersection of Martin Luther King, Jr. Parkway and College Road, similarities between the transition and work zone crossovers were effectively eliminated. Since the contraflow will begin at a signalized intersection, some semblance of normal saturation flow at typical signalized intersections is assumed at the transition. Driver behaviors should differ from a typical time, but it is also expected that the lane reversal plan's logistics and Intelligent Transportation Systems (ITS) deployments account for more than adequate driver information before vehicles reach the crossover point.

3.5.1 Parameter Comparison between Models

As previously noted, the default simulation parameters were retained in each model in order to provide a side-by-side comparison of the two simulation models. Table 3-3 details some of the key parameters inherent to the two simulation models.

Table 3-3. Comparison of Key Default Simulation Parameters

Simulation Parameter	CORSIM Value	VISSIM Value
Free Flow Speed	Distribution based on Driver Type: 75% to 127% of Posted Speed Limit on each link	Distribution based on Driver Type: 90% to 110% of Posted Speed Limit on each link
Saturation Flow/Headways	Distribution based on mean 2000 vphpl Saturation Flow (1.8 sec. Discharge Headways)	HCM Value of 1900 vphpl Saturation Flow (1.89 sec. Discharge headways)
Headway Distribution	Uniform	Erlang
Percent Heavy Vehicles	User Defined - 15%	User Defined - 15%
Signal Type	Actuated Control - internal algorithms	Actuated Control - NEMA software algorithm
Lane Widths	12 feet	12 feet
Perception Reaction Time	Distribution based on Driver Type: mean 2.0 Seconds	Distribution based on Driver Type: mean 1.59 Seconds
Definition of "In Queue"	Acceleration Less than 2 ft/sec^2, Speed Less than 9 ft/sec	From the time Speed falls below 4.5 ft/sec until the time Speed rises above 9 ft/sec

Model coding in CORSIM was completed using the Synchro translation algorithm, the TSIS TRAFED network editor, and manual editing of the record cards. The VISSIM model utilized the Synchro model and VISSIM's import algorithm. Measures of effectiveness were recorded and averaged over the ten runs. Ten unique model runs were completed for each of two alternatives: 1) no contraflow and 2) contraflow beginning at the Martin Luther King, Jr. Parkway/College Road intersection. A 15 percent heavy vehicle proportion was assumed because this percentage was used in previous contraflow research such as Theodoulou's thesis from the Louisiana State University (2003) related to contraflow out of New Orleans. Commercial vehicle rates are not expected to fill the fifteen percent proportion, but many drivers have been known to haul many personal belongings along with their vehicles through the use of trailers, or tied down to the vehicle itself. This procedure also allows for the models to be run with default parameters for a more direct comparison of MOEs between them. Demand inputs (detailed in the next chapter) were identical based on link and node flows and turning movements. Origin-destination values and trip distribution was done completely by hand so that turning movements at all nodes would be identical among models.

3.5.2 Sample Size

When microscopic traffic simulation is performed, the question of the number of simulation runs to perform becomes a significant point of discussion. It is often mentioned in the statistical community that a minimum thirty runs of a single particular simulation are necessary in order to produce robust results. However, the scope of this research was quite extensive, both in terms of the number of scenarios analyzed and the size of the network being modeled itself. Therefore, for the sake of computing resources, time, and labor efficiency, it was decided that ten simulation runs of each case modeled for both the No Contraflow and with Contraflow scenarios would be performed in both CORSIM and VISSIM. If a more detailed investigation of the necessary sample size was performed (assuming a normal distribution of output performance measures), it would follow the equation –

$$N_r = \frac{z^2 s^2}{d^2}$$

where N_r = the required number of runs;
z = the desired z-score (2 standard deviations = 1.96);
s^2 = sample variance; and
d^2 = the square of the tolerance desired.

The standard iterative procedure for this process is to perform an initial number of runs (in this case, ten could be used as a starting point since this is how many runs were performed) with its variability and the selected tolerance to estimate N_r for the sample.

Once N_r runs have been performed, that new value and the new variability are again put into the equation to produce a new N_r. Once the N_r output from iteration is less than the number of runs performed, the sample size is considered statistically sufficient for the tolerance chosen. Conversely, with a fixed number of runs and a calculated variability over those runs, the tolerance for a sample can be determined. Since the scope of this analysis contained several MOEs on several links in several cases, and each of these would produce its own sample size calculation, one example of this analysis is provided to give an idea of how the process would take place if all MOEs for all links were to be investigated. The example tolerance calculation provided is for the queue length in CORSIM for the No Contraflow, Severe Event Case (Section 5.3.1.1). The number of runs is 10 and the standard deviation is 29.9 ft. Therefore, the tolerance for this sample is –

$$d^2 = \frac{(1.96)^2 (29.9)^2}{10} = 343.4\, ft^2$$

d = +/- 18.5 feet

Therefore, in only 10 runs, a margin of error (tolerance) of 18.5 feet in the queue length has been attained, assuming the queues are normally distributed. For the example above, if a tolerance of +/- 20 feet (approximately 1 vehicle) was desired, the required sample size would be

$$N_r = \frac{(1.96)^2 (29.9)^2}{(20)^2} = 8.6 \text{ runs}$$

Since 10 runs were performed, the sample is considered statistically sufficient for this performance measure (assuming a normal distribution).

3.5.3 Effectiveness of Dynamic Traffic Assignment in VISSIM

The original modeling efforts for the New Hanover County phase of analysis included another consideration of VISSIM using its Dynamic Traffic Assignment (DTA) algorithms. DTA is very desirable in emergency evacuation analysis since incidents and subsequent re-routing of evacuation trips is at times more common in evacuation conditions than in typical traffic conditions. However, in the New Hanover County analysis, scalability issues again became an issue when DTA was considered. Detailed origin-destination volumes were created from the high-level analysis performed in determining evacuation demand (see Chapter 4 for more information). These volumes were input into the New Hanover County VISSIM model and routing decisions were left up to the simulation to create. Default parameters were again retained in this analysis.

After fifteen runs of the Severe Event Case in both the No Contraflow and With Contraflow scenarios, convergence of the routing decisions along the highway network had not occurred in the DTA-enabled VISSIM models. Observation of the vehicles during the simulation showed the majority of evacuees choosing only one or two of the paths available for their route while several additional paths remained lightly traveled. The results indicated that, given the level of model calibration doable under the project scope, the DTA algorithm in VISSIM had difficulty converging to an equilibrium trip assignment for the complex New Hanover County network under the heavily congested evacuation conditions.

3.6 Performance Measures

The Measures of Effectiveness analyzed in this modeling effort were queue lengths, average link speeds and throughput at key nodes. Queue lengths and throughput allow for an investigation of the ability of the lane reversal to move more vehicles through New Hanover County more efficiently, and provide the ability to pinpoint key nodes where bottlenecks may occur. Average link speeds allow for an estimate of the travel times through the county throughout the simulation. These travel times through the county can be extrapolated to reflect clearance times through further analysis.

3.7 Summary

Traffic simulation modeling was performed on a study area that encompassed all of New Hanover County, North Carolina. Major arterials in the county were modeled in addition to College Road (NC Highway 132/US Highway 117) and Interstate 40. Several simulation models were pegged as candidates for this analysis, but due to scalability and model limitations, all but CORSIM and VISSIM were eliminated from this analysis. Ten simulation runs were performed in each model for each demand scenario in the "no contraflow" and "MLK contraflow" cases. Measures of effectiveness from the two models were compared with each other to produce a detailed comparison of the two simulation models in emergency evacuation conditions. Data are not readily available to analyze from previous evacuation lane reversal efforts. For this reason, several behavioral parameters such as saturation headways, driver reaction times, vehicle types, free flow speeds, and acceleration/deceleration data are not easy to calibrate for any simulation model in this context. In addition, this research placed an emphasis on a comparison of two prominent microscopic simulation models.

Therefore, editing of default simulation parameters could produce biases that would be detrimental to this rigorous comparison of simulation models in identical evacuation conditions. All traffic volumes were entered on a link-node basis identically in each simulation model. Signal timings for the network were created with assistance from the City of Wilmington Traffic Engineering department. The city Traffic Engineer guided the analysis by confirming that along the College Road arterial, green time would be maximized during the evacuation to provide maximum progression to the north-south evacuees on College Road at the expense of the intersecting streets. This guidance was followed throughout the modeling process. A fifteen percent heavy vehicle proportion was assumed for the analysis based on previous research as well as expectations of drivers adding weight to their vehicles and being a bit distracted, resulting in lowered reaction times and acceleration/deceleration. The measures of effectiveness analyzed in this modeling effort were queue lengths, average link speeds and throughput at key nodes. Figure 3-11 and Figure 3-12 graphically represent screenshots of the CORSIM and VISSIM link-node diagrams, respectively.

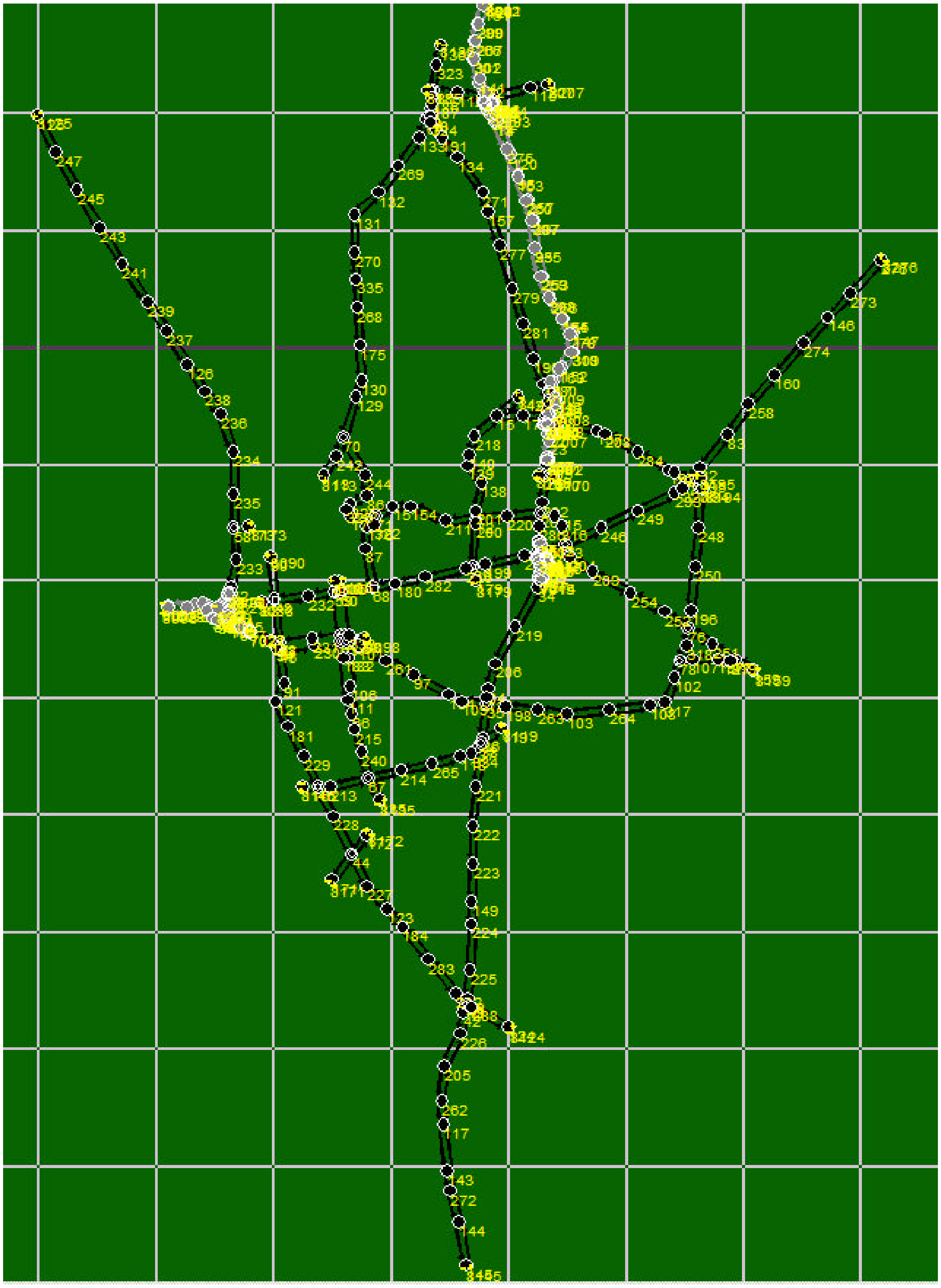


Figure 3-11. Link-Node Diagram of CORSIM New Hanover County Network

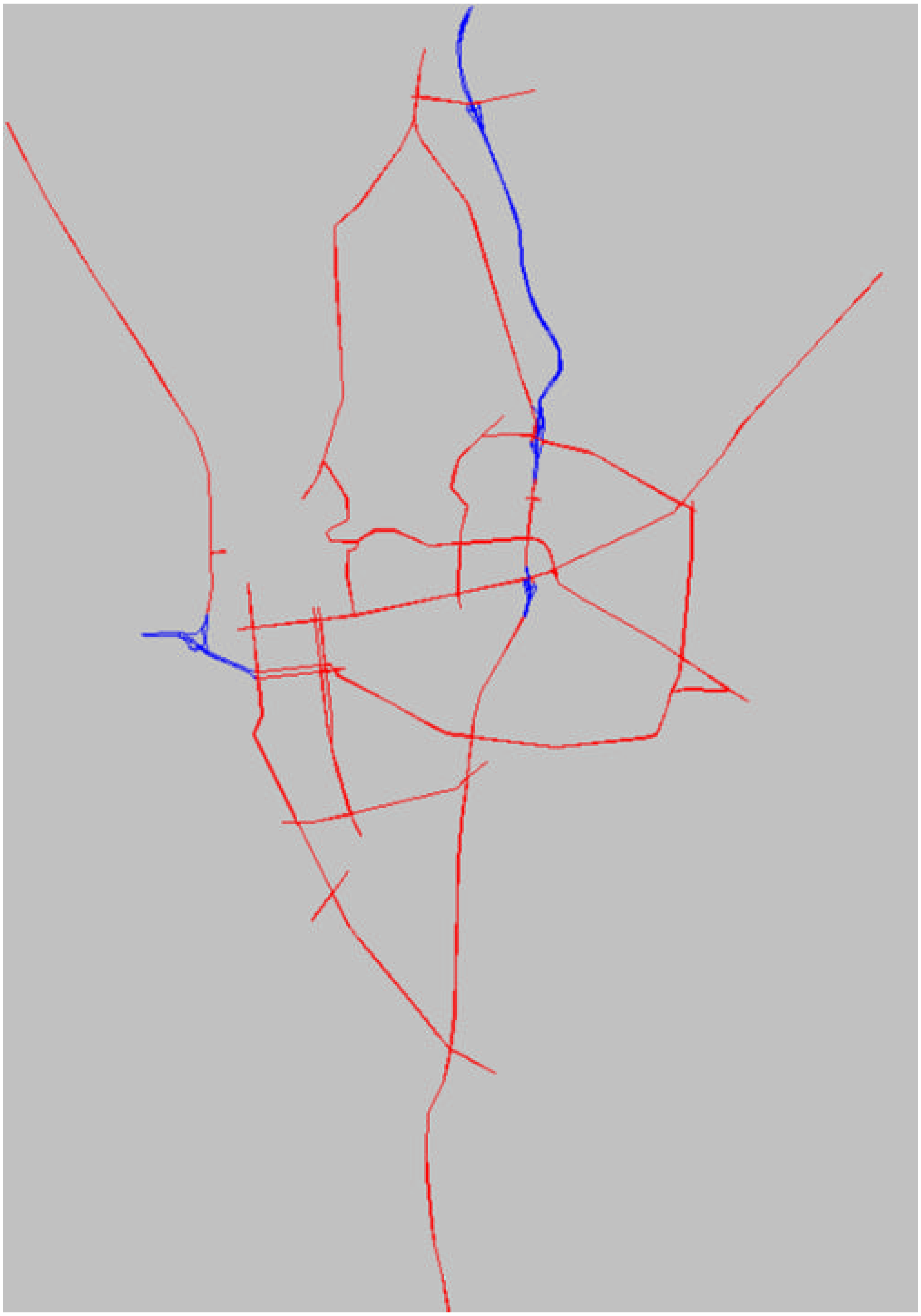


Figure 3-12. Link-Node Diagram of VISSIM New Hanover County Network

CHAPTER 4. SURVEY AND FOCUS GROUP FINDINGS

4.1 Introduction

To complement the evacuation demand data from the *Restudy*, team member Dr. Stephen Meinhold relied on both his own extensive experience in studying the evacuation behavior of residents of Southeastern North Carolina as well as a scientific survey conducted as a part of this project. The focus of the scientific survey was on anticipated evacuation behavior. In particular the research team was interested in the anticipated evacuation route, their geographic location of residence, and final destination. The survey data were used to assist in the creation of the origin/destination tables. The survey methodology and relevant data are summarized below.

4.2 Methodology and Results

The survey was conducted during November 5-19, 2003. Households were selected using random digit dialing and the interview respondent was chosen using the next birthday method. A total of 823 households were interviewed, giving the survey a margin of error of ± 3.5% Respondents had to be at least 18 years of age to participate in the survey. In the tables that follow the total number of respondents may not add up to 823 because of missing and or non applicable data.

4.2.1 Evacuation Destination (County)

Question: *Would you stay in New Hanover County or go somewhere else?*

Table 4-1. Evacuate the County?

Answer	Frequency	Percent
Evacuate to Another County	566	78
Stay in New Hanover County	159	22
Total	725	100

4.2.2 Evacuation Destination (Place)

Question: *If you were to decide to leave your home for a hurricane would you most likely go to a public shelter, a friend or relative's house, a motel, or somewhere else?*

Table 4-2. Evacuation Destination?

Answer	Frequency	Percent
Friends/Relatives	429	58
Hotel	136	18
Public Shelter	37	5
Other/Don't Know	141	19
Total	743	100

4.2.3 Evacuation Destination (Route)

Question: *What is the main highway you would plan to use to reach your destination?*

Table 4-3. Evacuation Route?

Answer	Frequency	Percent
Interstate 40 West	312	58
Highway 74-76 West	137	26
Highway 421 North	27	5
Highway 17 North	21	4
Some Other Route	38	7
Total	535	100

Based on an additional analysis of the planned evacuation route and evacuation destination by county, we concluded that approximately 94% of vehicles that use I-40 to evacuate will travel at least as far as I-95. In other words, nearly all of the vehicles that use the reversed eastbound lanes of I-40 to evacuate will use the median crossover to return to the normal westbound travel lanes before exiting onto I-95 or continuing westbound on I-40.

In addition to examining the planned route and eventual destination of evacuees we located households by zip code in the evacuating areas to determine whether such patterns might contribute in negative ways to the loading pattern for I-40. After careful analysis the research team concluded that household evacuation behavior by zip code was sufficiently constant to present few problems not associated with the normal layout of local roads.

4.2.4 Evacuation Decision Making (Hypothetical Situations)

The timing of the survey (immediately following Hurricane Isabel) allowed us to present respondents with some hypothetical scenarios asking whether they would have evacuated had Isabel been a stronger hurricane. The results are presented below but should be interpreted with caution as the respondents were reacting to a hypothetical situation, not a real one. However, the data are consistent with other surveys conducted by Dr. Stephen Meinhold regarding the actual and anticipated evacuation behavior of Southeastern North Carolina residents.

Question: *The next few questions ask you to react to different scenarios that could have occurred with Hurricane Isabel…What if Isabel were to look like it was going to be a Category 1 hurricane and hit this area more directly would you have left your home to go someplace safer?*

Table 4-4. Evacuation at Successive Storm Strengths

Would Evacuate at Storm Level	Frequency (Cumulative)	Percent (Cumulative)
Category 5	644	84
Category 4	516	67
Category 3	256	33
Category 2	116	15
Category 1	86	11

4.2.5 Knowledge of Lane Reversal Plan

At the conclusion of the first year of the lane reversal plan most of the respondents had heard about the plan and planned to use the recommended evacuation route. The wide dissemination of information about the plan by the Department of Transportation has resulted in a high level of awareness.

Question: *Are you aware that if needed there is a plan to reverse the eastbound lanes of I-40 if a hurricane evacuation of our area is required?*

Table 4-5. Awareness of the Lane Reversal Plan

Response	Frequency	Percent
Heard about I-40 Plan	730	85
Would use recommended evacuation route	732	85

The survey results summarized in this chapter were used to inform the estimates of evacuation traffic demand and destination for the simulation modeling.

CHAPTER 5. TRAFFIC ANALYSIS RESULTS AND FINDINGS

5.1 Outline of Analysis Procedures

In this chapter, the detailed results of each set of simulation runs will be shown. In addition, a discussion of each result with statistical analysis follows the output tables in each section. Section 5.2 details the simulation modeling focused on the transition to contraflow in northern New Hanover County. The result of this preliminary, focused modeling was the shift in the transition from the Kenningston Street median crossover to the College Road/Martin Luther King, Jr. intersection in the NCDOT Lane Reversal Plan beginning in 2004. The second major section of this chapter, section 5.3, is devoted to the full New Hanover County analysis with this new transition in place. The final modeling phase involved modeling the full lane reversal plan. This phase is presented in section 5.4.

Six different models scenarios were prepared in both CORSIM and VISSIM, based on the following conditions:

- No Contraflow, Severe Event Case
- With Contraflow, Severe Event Case
- No Contraflow, Moderate Event Case
- With Contraflow, Moderate Event Case
- No Contraflow, Minimal Event Case
- With Contraflow, Minimal Event Case

First, the results of one simulation model in both the No Contraflow and Contraflow cases are summarized in the following sections:

- Section 5.3.1.1– CORSIM Severe Event Case No Contraflow vs. Contraflow
- Section 5.3.1.2– VISSIM Severe Event Case No Contraflow vs. Contraflow
- Section 5.3.2.1– CORSIM Moderate Event Case No Contraflow vs. Contraflow
- Section 5.3.2.2– VISSIM Moderate Event Case No Contraflow vs. Contraflow
- Section 5.3.3.1– CORSIM Minimal Event Case No Contraflow vs. Contraflow
- Section 5.3.3.2– VISSIM Minimal Event Case No Contraflow vs. Contraflow

Next, the simulation models were investigated based on side-by-side comparisons in all storm cases and both with and without contraflow, in the following sections:

- Section 5.3.4.1– No Contraflow Severe Event Case CORSIM vs. VISSIM
- Section 5.3.4.2– With Contraflow Severe Event Case CORSIM vs. VISSIM
- Section 5.3.5.1– Moderate Event Case CORSIM vs. VISSIM
- Section 5.3.5.2– Minimal Event Case CORSIM vs. VISSIM

5.2 Phase 1 (Detailed Contraflow Transition Investigation)

This analysis focused solely on traffic entering the transition to contraflow in both the original (2000-2003) and alternative configurations to the Lane Reversal Plan (see Figure 3-2 and Figure 3-5 for a schematic representation of these alternatives). CORSIM simulation was utilized in this analysis and eleven runs were performed for the "no contraflow, "original plan contraflow", and "Martin Luther King, Jr. Parkway contraflow" for the Severe Event case. One original run was performed once the models were calibrated, and then ten additional runs were performed once the decision on the number of runs was made. Rather than eliminating the original run, it was retained since it was considered more likely to be beneficial than detrimental to the robustness of the multiple-run average for this round of modeling. The maximum queue was the MOE in this analysis, as the primary goal was to determine whether an alternative location of the transition to contraflow would enhance the efficiency of the Plan. These model results are shown in Table 5-1.

Table 5-1. Phase I Modeling – Maximum Queue Length among All Lanes

NB College Road Queues (feet)			
Run	No CF	Current CF	MLK
1	9513	14263	650
2	9963	14363	750
3	10563	13738	1215
4	9238	14313	1065
5	11063	13638	1315
6	10688	14263	1015
7	9013	14238	1215
8	12288	14388	700
9	11163	14363	990
10	9663	14463	1215
11	10288	12688	1465
Average	**10313**	**14065**	**1054**

WB MLK Queues (feet)			
Run	No CF	Current CF	MLK
1	8312	8225	175
2	8287	8100	325
3	8562	7875	275
4	8562	8025	525
5	8162	8150	200
6	8437	8075	250
7	8337	8000	175
8	8612	8275	175
9	8237	8075	225
10	8312	8275	225
11	8462	7875	200
Average	**8389**	**8086**	**250**

The raw numbers in this analysis were not the focus of the investigation as the highway network only included the intersection of College Road and Martin Luther King, Jr. Parkway and omitted other signalized intersections along College Road that would meter traffic progressing to this location. However, the ratios of queues among the alternatives were the results sought in order to determine whether a different transition location would be more efficient, since it was expected this metering at other intersections would be uniform across all alternatives. The analysis showed considerable improvement in the loading of the contraflow lanes by moving the transition to contraflow to the College Road/Martin Luther King, Jr. Parkway. In fact, the results showed that the original contraflow plan could in fact make northbound queues worse than if contraflow was not implemented at all. The primary reason for this is that there were no additional receiving lanes north of MLK Parkway provided by the original lane reversal plan (two lanes both with and without contraflow) and one of the two exiting lanes was forced through a low speed crossover using the median break at Kenningston Street under contraflow operations. Furthermore, the original plan restricted commercial vehicle operation to the normal lanes. This restriction resulted in lane changing by the simulated commercial vehicles just downstream of the College Road/MLK Parkway intersection, in turn creating additional turbulence and congestion.

This commercial vehicle restriction was lifted as a part of the "MLK contraflow" configuration. ITS technologies will be implemented upstream of the transition to recommend that commercial vehicles be routed to the normal flow lanes via Martin Luther King, Jr. Parkway whenever possible. The two primary factors behind the vast improvements found when the transition was shifted to the College Road/MLK Parkway intersection were the fact that this intersection is a bottleneck in and of itself so shifting the transition (which will cause its own bottleneck) to this intersection essentially merges two bottlenecks into one, and also the fact that as previous research (Cova and Johnson, 2003) supports, lane-based routing at key nodes increases the efficiency of an evacuation (see Chapter 2 for a more detailed description of Cova and Johnson's research).

As a result of this Phase 1 focused modeling, the Lane Reversal Plan was revised in 2004 to move the transition to contraflow to the College Road/Martin Luther King, Jr. Parkway intersection. All subsequent New Hanover County analysis therefore was performed with contraflow beginning at this intersection.

5.3 Phase 2 (New Hanover County) Simulation Runs and Measures of Effectiveness

These results focus primarily on the College Road corridor and the College Road/Martin Luther King, Jr. Parkway intersection. Figure 5-1 depicts the key nodes of the analysis that appear in the following results.

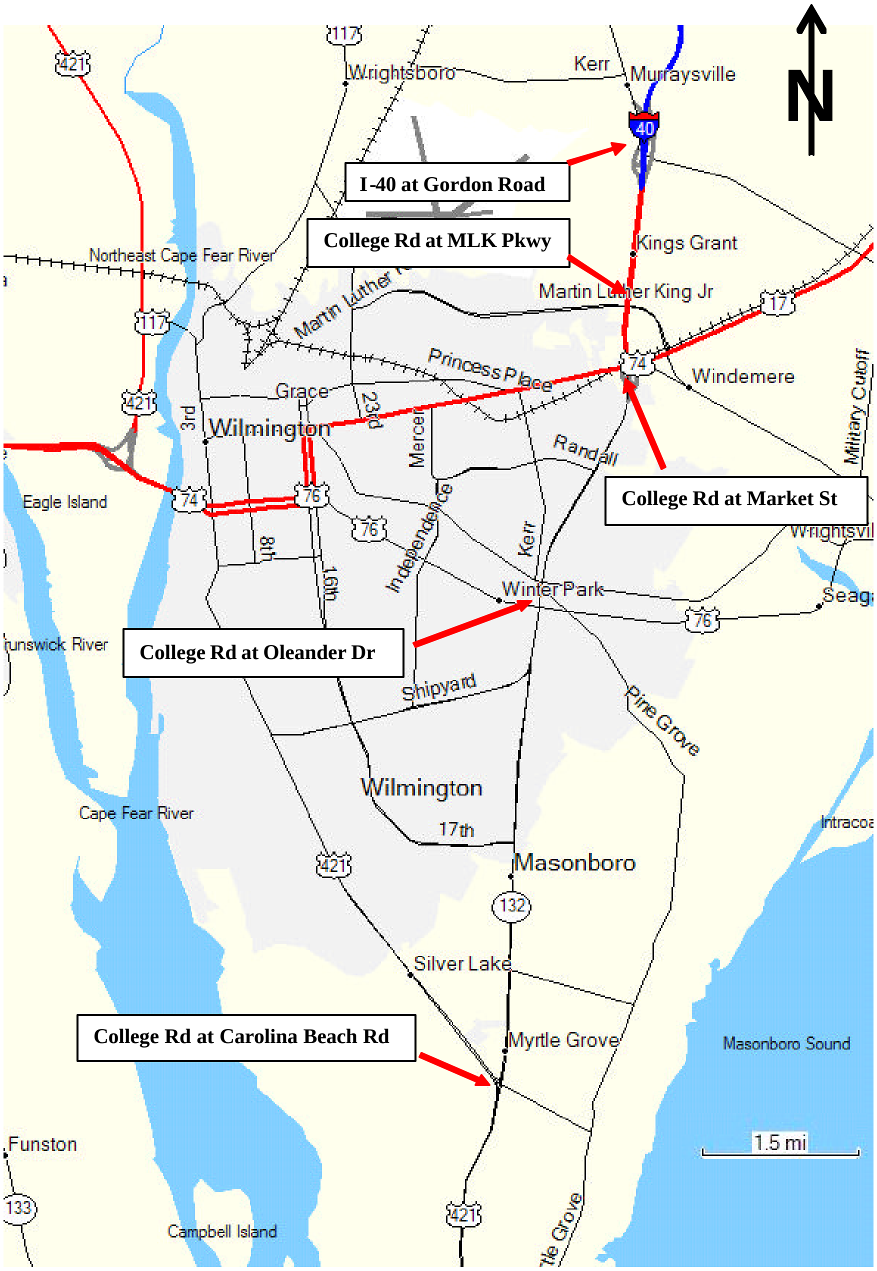


Figure 5-1. Key Nodes in New Hanover County Network (Navteq/Garmin, 2005)

Some limitations were encountered in the modeling procedures such that the node output results for certain MOEs differed slightly between models. These limitations were as follows:

- CORSIM does not report queues on freeway links, therefore Maximum Queue lengths could not be reported on the Interstate 40 sections (at the Holly Shelter Road on ramp and at the Gordon Road on ramp). The maximum queue for the Severe Event case, no contraflow scenario was reported because the queue stretched to the NETSIM links and therefore could be extrapolated.

  Note – Section 5.4 discusses a special procedure that was developed to assess freeway queues in the Phase 3 modeling. However, because the primary focus of Phase 2 was bottlenecks upstream of the MLK intersection, a similar estimating procedure was not used.

- VISSIM appeared to incorrectly report average speeds for Interstate 40 at the Holly Shelter Road link. Therefore, these results were discarded. It is unknown why this anomaly took place and attempts to correct it were unsuccessful.

5.3.1 Severe Event Case No Contraflow versus Contraflow Results

5.3.1.1 CORSIM

The 10-run averages and standard deviations for the CORSIM analysis MOEs at key links/nodes are shown in Table 5-2 through Table 5-5.

Table 5-2. CORSIM Average and Standard Deviation of Maximum Queue Lengths (ft)

Queue Location	No Contraflow 10-run CORSIM Average (s.d.)		With Contraflow 10-run CORSIM Average (s.d.)	
NB College Road at Martin Luther King, Jr. Parkway	4066	(29.9)	479	(32.4)
WB Through Martin Luther King, Jr. Parkway at College Road	328	(77.0)	180	(5.2)
WB Right Martin Luther King, Jr. Parkway at College Road	926	(30.3)	87	(5.1)
NB College Road at Market Street on Ramp	2562	(90.1)	1881	(13.2)
NB College Road at Oleander Drive	2277	(25.9)	2049	(24.8)
NB College Road at Carolina Beach Road	1213	(73.9)	1040	(75.1)
Interstate 40 WB at Gordon Road on Ramp	7510	**	*	**

* Denotes Queue does not stretch beyond limits of FRESIM links -- Queue is shorter than 6693 feet

** Denotes Standard Deviation cannot be obtained since queue contains FRESIM links

Table 5-3. CORSIM 10-run Average Throughputs (Vehicles)

Location	No Contraflow CORSIM Average Throughput Hrs 1-5	With Contraflow CORSIM Average Throughput Hrs 1-5	No Contraflow CORSIM Average Throughput Hrs 6-10	With Contraflow CORSIM Average Throughput Hrs 6-10	No Contraflow CORSIM Average Throughput Hrs 11-14	With Contraflow CORSIM Average Throughput Hrs 11-14
Interstate 40 Leaving New Hanover County	9514	10416	17646	19756	664	1622
NB Through College Road at Market Street Overpass	6894	6735	11822	11683	578	951
NB Through College Road at Market Street On Ramp	6184	6066	10506	10414	273	416
NB Through College Road at Oleander Drive	6456	6417	10158	10158	202	372
NB Through College Road at Carolina Beach Road	6940	6417	10261	10158	114	372
WB Right Martin Luther King, Jr. Parkway at College Road	1031	1054	2774	2799	178	419

Table 5-4. CORSIM 10-run Average Cumulative Throughput and Standard Deviation

Location	No Contraflow 10-run Average Total CORSIM Throughput (Standard Deviation) (Vehicles)		MLK Contraflow 10-run Average Total CORSIM Throughput (Standard Deviation) (Vehicles)	
Interstate 40 WB Leaving New Hanover County	27824	(114.5)	31794	(111.6)
NB Through College Road at Market Street Overpass	19295	(109.7)	19370	(74.4)
NB Through College Road at Market Street On Ramp	16963	(92.0)	16896	(57.5)
NB Through College Road at Oleander Drive	16817	(67.2)	16947	(66.1)
NB Through College Road at Carolina Beach Road	17315	(31.2)	16947	(47.0)
WB Right Martin Luther King, Jr. Parkway at College Road	3983	(56.1)	4273	(60.9)

Table 5-5. CORSIM 10-run Average Speeds and Overall Standard Deviation

Location	No CF Avg. Speed Hrs 1-5 (mph)	With CF Avg. Speed Hrs 1-5 (mph)	No CF Avg. Speed Hrs 6-10 (mph)	With CF Avg. Speed Hrs 6-10 (mph)	No CF Avg. Speed Hr 11-14 (mph)	With CF Avg. Speed Hr 11-14 (mph)	No Contraflow Standard Deviation (mph)	With Contraflow Standard Deviation (mph)
Interstate 40 WB at Holly Shelter Road On Ramp	64.7	69.2	37.5	67.5	61.3	69.6	1.7	0.1
Interstate 40 WB at Gordon Road On Ramp	63.3	66.5	20.4	65.9	49.2	66.6	0.8	0.1
NB Through College Rd at MLK Parkway	25.3	41.1	11.2	32.7	23.5	40.8	0.6	0.7
NB Through College Rd at Market St Overpass	50.9	51.0	26.8	48.7	47.1	49.5	3.0	0.1
NB Through College Rd at Market St Ramp	41.4	41.8	19.2	34.9	37.4	43.4	3.5	0.3
NB Through College Rd at Oleander Dr	26.3	28.2	21.4	23.1	30.8	31.6	0.7	0.4
NB Through College Rd at Carolina Beach Rd	25.2	27.0	15.4	16.3	24.8	24.4	0.7	0.7
NB Through College Road Entering network	50.0	49.9	47.1	47.1	53.1	50.8	0.1	0.1
WB Right MLK Parkway at College Rd	23.7	15.3	8.1	21.5	16.7	17.1	0.6	0.4

5.3.1.2 VISSIM

The 10-run averages and standard deviations for the VISSIM analysis MOEs at key links/nodes are shown in Table 5-6 through Table 5-9.

Table 5-6. VISSIM Average and Standard Deviation of Maximum Queue Lengths (ft)

Queue Location	No Contraflow 10-run VISSIM Average (s.d.)		MLK Contraflow 10-run VISSIM Average (s.d.)	
NB College Road at Martin Luther King, Jr. Parkway	6269	(446.9)	778	(107.9)
WB Through Martin Luther King, Jr. Parkway at College Road	91	(26.8)	0	(0)
WB Right Martin Luther King, Jr. Parkway at College Road	1192	(139.0)	199	(56.0)
NB College Road at Market Street on Ramp	13548	(1.8)	3243	(525.9)
NB College Road at Oleander Drive	25755	(41.7)	8775	(691.7)
NB College Road at Carolina Beach Road	22727	(1.3)	1464	(285.1)
Interstate 40 WB at Gordon Road on Ramp	7550	(594.2)	889	(230.5)

Table 5-7. VISSIM 10-run Average Throughputs (Vehicles)

Location	No Contraflow VISSIM Average Throughput Hrs 1-5	With Contraflow VISSIM Average Throughput Hrs 1-5	No Contraflow VISSIM Average Throughput Hrs 6-10	With Contraflow VISSIM Average Throughput Hrs 6-10	No Contraflow VISSIM Average Throughput Hrs 11-14	With Contraflow VISSIM Average Throughput Hrs 11-14
Interstate 40 Leaving New Hanover County	7733	9072	12125	17622	1780	1343
NB Through College Road at Market Street Overpass	6186	6404	6322	11338	1488	913
NB Through College Road at Market Street On Ramp	5531	5727	5062	9956	1033	502
NB Through College Road at Oleander Drive	6832	6714	5843	10376	2784	319
NB Through College Road at Carolina Beach Road	7905	7258	6851	10548	1246	283

Table 5-8. VISSIM 10-run Average Cumulative Throughput and Standard Deviation

Location	No Contraflow 10-run Average Total VISSIM Throughput (Standard Deviation) (Vehicles)		MLK Contraflow 10-run Average Total VISSIM Throughput (Standard Deviation) (Vehicles)	
Interstate 40 WB Leaving New Hanover County	21638	(30.0)	28037	(45.6)
NB Through College Road at Market Street Overpass	13996	(38.7)	18655	(35.2)
NB Through College Road at Market Street On Ramp	11625	(34.4)	16185	(33.8)
NB Through College Road at Oleander Drive	15459	(52.4)	17409	(34.9)
NB Through College Road at Carolina Beach Road	16001	(50.6)	18089	(21.3)

Table 5-9. VISSIM 10-run Average Speeds and Overall Standard Deviation

Location	No CF Avg. Speed Hrs 1-5 (mph)	With CF Avg. Speed Hrs 1-5 (mph)	No CF Avg. Speed Hrs 6-10 (mph)	With CF Avg. Speed Hrs 6-10 (mph)	No CF Avg. Speed Hr 11-14 (mph)	With CF Avg. Speed Hr 11-14 (mph)	No Contraflow Standard Deviation (mph)	With Contraflow Standard Deviation (mph)
NB Through College Road at MLK Parkway	18.9	17.6	12.8	14.2	35.3	36.0	1.1	1.2
NB Through College Rd at Market St Overpass	20.1	19.9	10.3	15.5	33.1	33.7	1.0	1.0
NB Through College Rd at Market St Ramp	22.0	21.2	8.8	14.4	39.5	41.4	1.3	1.3
NB Through College Rd at Oleander Dr	17.3	16.0	11.3	14.6	13.1	25.3	0.8	1.4
NB Through College Rd at Carolina Beach Rd	35.9	34.4	14.8	19.0	20.6	38.7	1.7	1.0
NB Through College Rd Entering network	41.7	41.7	18.0	25.5	34.6	43.1	0.4	0.4

5.3.1.3 Discussion

The 10-run averages for both CORSIM and VISSIM show a considerable increase in throughput and average speeds and a considerable decrease in maximum queue lengths when the lane reversal is implemented for the Severe Event Case. The benefits of this implementation are more considerable in VISSIM due to the fact that the queues in the no contraflow case are much more extreme. These queues in fact essentially stretch from intersection to intersection, creating a long queue of several miles from the I-40/Gordon Road interchange all the way back to upstream of the intersection of College Road with Carolina Beach Road. This queue begins at the merge of the Gordon Road on ramp with Interstate 40, downstream of any signalized intersections. The clearing of these extensive queues in the final hours (hours 11-14) is the reason that the With Contraflow throughput values are significantly lower than the No Contraflow throughputs for this last time period in the VISSIM simulations.

Statistical *t*-tests were performed on several of these performance measures in order to determine the significance of these differences at the 95% confidence interval (5%

Type I error rate). Table 5-10 represents these statistical tests. All differences investigated were shown to be significant at the 95% confidence level. Appendix B contains detailed *t*-test calculations.

Table 5-10. Statistical *t*-tests of Selected Severe Event Case MOEs

Performance Measure	Measured Difference (Contraflow Value Minus No Contraflow Value)	Does t-test (95% Confidence) reject the Null Hypothesis?
CORSIM Throughput on I-40	3970 veh	YES
VISSIM Throughput on I-40	6399 veh	YES
CORSIM Queues - NB College at MLK Pkwy	-3587 ft	YES
VISSIM Queues - NB College at MLK Pkwy	-5490 ft	YES
CORSIM Queues - WB MLK Parkway at College	-839 ft	YES
VISSIM Queues - WB MLK Parkway at College	-993 ft	YES
CORSIM Queues - NB College at Oleander Dr	-227 ft	YES
VISSIM Queues - NB College at Oleander Dr	-16980 ft	YES

5.3.2 Moderate Event Case No Contraflow versus Contraflow Results

5.3.2.1 CORSIM

The 10-run averages and standard deviations for the CORSIM analysis MOEs at key links/nodes are shown in Table 5-11 through Table 5-14.

Table 5-11. CORSIM Average and Standard Deviation of Maximum Queue Lengths (ft)

Queue Location	No Contraflow 10-run CORSIM Average (s.d.)		With Contraflow 10-run CORSIM Average (s.d.)	
NB College Road at Martin Luther King, Jr. Parkway	706	(68.6)	404	(34.0)
WB Through Martin Luther King, Jr. Parkway at College Road	101	(7.3)	148	(4.7)
WB Right Martin Luther King, Jr. Parkway at College Road	364	(10.9)	85	(6.3)
NB College Road at Market Street on Ramp	1790	(5.5)	1804	(10.8)
NB College Road at Oleander Drive	1867	(27.0)	1782	(15.9)
NB College Road at Carolina Beach Road	595	(19.6)	578	(26.4)
Interstate 40 WB at Gordon Road on Ramp	6903	**	*	**

* Denotes Queue does not stretch beyond limits of FRESIM links -- Queue is shorter than 6693 feet
** Denotes Standard Deviation cannot be obtained since queue contains FRESIM links

Table 5-12. CORSIM 10-run Average Throughputs (Vehicles)

Location	No Contraflow CORSIM Average Throughput Hrs 1-5	With Contraflow CORSIM Average Throughput Hrs 1-5	No Contraflow CORSIM Average Throughput Hrs 6-10	With Contraflow CORSIM Average Throughput Hrs 6-10	No Contraflow CORSIM Average Throughput Hrs 11-14	With Contraflow CORSIM Average Throughput Hrs 11-14
Interstate 40 Leaving New Hanover County	8823	9694	14501	16122	613	724
NB Through College Road at Market Street Overpass	6497	6414	9838	9802	551	505
NB Through College Road at Market Street On Ramp	5815	5769	8747	8741	248	244
NB Through College Road at Oleander Drive	6149	6112	8726	8713	189	191
NB Through College Road at Carolina Beach Road	6637	6112	8900	8713	110	191
WB Right Martin Luther King, Jr. Parkway at College Road	1071	1039	2300	2238	175	157

Table 5-13. CORSIM 10-run Average Cumulative Throughput and Standard Deviation

Location	No Contraflow 10-run Average Total CORSIM Throughput (Standard Deviation) (Vehicles)		MLK Contraflow 10-run Average Total CORSIM Throughput (Standard Deviation) (Vehicles)	
Interstate 40 WB Leaving New Hanover County	23937	(146.1)	26541	(89.3)
NB Through College Road at Market Street Overpass	16886	(129.5)	16721	(105.7)
NB Through College Road at Market Street On Ramp	14810	(90.3)	14754	(90.5)
NB Through College Road at Oleander Drive	15064	(67.7)	15016	(64.2)
NB Through College Road at Carolina Beach Road	15647	(32.8)	15016	(24.6)
WB Right Martin Luther King, Jr. Parkway at College Road	3546	(62.0)	3434	(47.2)

Table 5-14. CORSIM 10-run Average Speeds and Overall Standard Deviation

Location	No CF Avg. Speed Hrs 1-5 (mph)	With CF Avg. Speed Hrs 1-5 (mph)	No CF Avg. Speed Hrs 6-10 (mph)	With CF Avg. Speed Hrs 6-10 (mph)	No CF Avg. Speed Hr 11-14 (mph)	With CF Avg. Speed Hr 11-14 (mph)	No Contraflow Standard Deviation (mph)	With Contraflow Standard Deviation (mph)
Interstate 40 WB at Holly Shelter Road On Ramp	65.0	69.4	59.2	68.3	62.3	69.2	0.4	0.1
Interstate 40 WB at Gordon Road On Ramp	63.5	66.6	61.5	66.1	62.6	66.5	0.5	0.1
NB Through College Rd at MLK Parkway	24.8	42.0	20.0	37.2	25.5	40.4	0.3	0.5
NB Through College Rd at Market St Overpass	51.0	51.1	49.7	49.7	49.8	49.9	0.1	0.1
NB Through College Rd at Market St Ramp	41.8	42.1	37.3	38.0	41.9	42.1	0.3	0.2
NB Through College Rd at Oleander Dr	26.9	28.3	23.8	24.9	28.5	29.6	0.4	0.2
NB Through College Rd at Carolina Beach Rd	26.5	27.7	19.9	21.7	22.4	24.0	0.4	0.5
NB Through College Road Entering network	50.3	50.2	48.3	48.3	49.3	49.2	0.1	0.2
WB Right MLK Parkway at College Rd	24.5	14.6	15.4	19.2	18.0	16.8	0.3	0.4

5.3.2.2 VISSIM

The 10-run averages and standard deviations for the VISSIM analysis MOEs at key links/nodes are shown in Table 5-15 through Table 5-18.

Table 5-15. VISSIM Average and Standard Deviation of Maximum Queue Lengths (ft)

Queue Location	No Contraflow 10-run VISSIM Average (s.d.)		MLK Contraflow 10-run VISSIM Average (s.d.)	
NB College Road at Martin Luther King, Jr. Parkway	4170	(79.9)	650	(79.1)
WB Through Martin Luther King, Jr. Parkway at College Road	96	(15.1)	0	(0)
WB Right Martin Luther King, Jr. Parkway at College Road	921	(102.7)	142	(35.8)
NB College Road at Market Street on Ramp	13543	(7.5)	2406	(408.4)
NB College Road at Oleander Drive	25526	(535.7)	2714	(674.1)
NB College Road at Carolina Beach Road	18644	(5737.3)	757	(90.8)
Interstate 40 WB at Gordon Road on Ramp	7204	(106.2)	521	(82.8)

Table 5-16. VISSIM 10-run Average Throughputs (Vehicles)

Location	No Contraflow VISSIM Average Throughput Hrs 1-5	With Contraflow VISSIM Average Throughput Hrs 1-5	No Contraflow VISSIM Average Throughput Hrs 6-10	With Contraflow VISSIM Average Throughput Hrs 6-10	No Contraflow VISSIM Average Throughput Hrs 11-14	With Contraflow VISSIM Average Throughput Hrs 11-14
Interstate 40 Leaving New Hanover County	7127	8759	11936	15546	1543	1103
NB Through College Road at Market Street Overpass	5912	6119	7595	10136	1147	718
NB Through College Road at Market Street On Ramp	5299	5500	6509	9010	735	385
NB Through College Road at Oleander Drive	6596	6449	7855	9489	1946	252
NB Through College Road at Carolina Beach Road	7538	6929	8876	9367	631	249

Table 5-17. VISSIM 10-run Average Cumulative Throughput and Standard Deviation

Location	No Contraflow 10-run Average Total VISSIM Throughput (Standard Deviation) (Vehicles)	MLK Contraflow 10-run Average Total VISSIM Throughput (Standard Deviation) (Vehicles)
Interstate 40 WB Leaving New Hanover County	20607 (28.6)	25408 (42.5)
NB Through College Road at Market Street Overpass	14654 (38.8)	16973 (38.2)
NB Through College Road at Market Street On Ramp	12543 (38.3)	14895 (33.7)
NB Through College Road at Oleander Drive	16397 (66.4)	16189 (30.7)
NB Through College Road at Carolina Beach Road	17045 (41.8)	16545 (20.3)

Table 5-18. VISSIM 10-run Average Speeds and Overall Standard Deviation

Location	No CF Avg. Speed Hrs 1-5 (mph)	With CF Avg. Speed Hrs 1-5 (mph)	No CF Avg. Speed Hrs 6-10 (mph)	With CF Avg. Speed Hrs 6-10 (mph)	No CF Avg. Speed Hr 11-14 (mph)	With CF Avg. Speed Hr 11-14 (mph)	No Contraflow Standard Deviation (mph)	With Contraflow Standard Deviation (mph)
NB Through College Road at MLK Parkway	18.9	17.9	14.2	14.4	36.1	37.5	1.2	1.2
NB Through College Rd at Market St Overpass	20.7	20.4	12.2	15.9	32.2	33.8	1.1	1.0
NB Through College Rd at Market St Ramp	23.0	21.6	11.6	15.6	39.7	42.2	1.4	1.5
NB Through College Rd at Oleander Dr	17.3	16.1	13.6	14.9	18.3	28.9	0.9	1.1
NB Through College Rd at Carolina Beach Rd	37.3	34.7	18.3	28.4	35.6	38.8	0.7	1.4
NB Through College Rd Entering network	41.8	41.8	22.9	41.5	35.9	43.1	1.5	0.1

5.3.2.3 Discussion

The differences portrayed by the simulation models were again quite considerable in the Moderate Event case when comparing the implementation of contraflow to the do-nothing alternative. However, it should be noted that the differences, especially in the CORSIM model runs, were not as substantial as those found in the Severe Event case. Again, VISSIM produced extreme queuing in the no contraflow scenario, with a long queue of several miles again forming (although just a bit shorter than that from the Severe Event case).

Similar statistical *t*-tests to those in the Severe Event Case were performed on the same selection of performance measures in this storm case. Table 5-19 shows that, again, all differences investigated were determined to be significant at the 95% confidence level.

Table 5-19. Statistical *t*-tests of Selected Moderate Event Case MOEs

Performance Measure	Measured Difference (Contraflow Value Minus No Contraflow Value)	Does t-test (95% Confidence) reject the Null Hypothesis?
CORSIM Throughput on I-40	2604 veh	YES
VISSIM Throughput on I-40	4802 veh	YES
CORSIM Queues - NB College at MLK Pkwy	-303 ft	YES
VISSIM Queues - NB College at MLK Pkwy	-3520 ft	YES
CORSIM Queues - WB MLK Parkway at College	-279 ft	YES
VISSIM Queues - WB MLK Parkway at College	-780 ft	YES
CORSIM Queues - NB College at Oleander Dr	-85 ft	YES
VISSIM Queues - NB College at Oleander Dr	-22812 ft	YES

5.3.3 Minimal Event Case No Contraflow versus Contraflow Results

5.3.3.1 CORSIM

The 10-run averages and standard deviations for the CORSIM analysis MOEs at key links/nodes are shown in Table 5-20 through Table 5-23.

Table 5-20. CORSIM Average and Standard Deviation of Maximum Queue Lengths (ft)

Queue Location	No Contraflow 10-run CORSIM Average (s.d.)		With Contraflow 10-run CORSIM Average (s.d.)	
NB College Road at Martin Luther King, Jr. Parkway	498	(69.2)	328	(31.8)
WB Through Martin Luther King, Jr. Parkway at College Road	79	(0)	125	(3.2)
WB Right Martin Luther King, Jr. Parkway at College Road	136	(5.4)	55	(3.5)
NB College Road at Market Street on Ramp	1771	(2.5)	1779	(2.2)
NB College Road at Oleander Drive	1387	(18.0)	1339	(16.9)
NB College Road at Carolina Beach Road	404	(11.1)	396	(9.1)
Interstate 40 WB at Gordon Road on Ramp	34	(9.9)	0	(0)

Table 5-21. CORSIM 10-run Average Throughputs (Vehicles)

Location	No Contraflow CORSIM Average Throughput Hrs 1-5	With Contraflow CORSIM Average Throughput Hrs 1-5	No Contraflow CORSIM Average Throughput Hrs 6-10	With Contraflow CORSIM Average Throughput Hrs 6-10	No Contraflow CORSIM Average Throughput Hrs 11-14	With Contraflow CORSIM Average Throughput Hrs 11-14
Interstate 40 Leaving New Hanover County	8287	8877	10020	10725	3929	4423
NB Through College Road at Market Street Overpass	6126	6008	7122	7006	2368	2291
NB Through College Road at Market Street On Ramp	5508	5420	6365	6277	1827	1809
NB Through College Road at Oleander Drive	5836	5803	6547	6509	1474	1479
NB Through College Road at Carolina Beach Road	6305	5803	6922	6509	1321	1479
WB Right Martin Luther King, Jr. Parkway at College Road	812	786	1142	1107	1012	991

Table 5-22. CORSIM 10-run Average Cumulative Throughput and Standard Deviation

Location	No Contraflow 10-run Average Total CORSIM Throughput (Standard Deviation) (Vehicles)		MLK Contraflow 10-run Average Total CORSIM Throughput (Standard Deviation) (Vehicles)	
Interstate 40 WB Leaving New Hanover County	22235	(128.3)	24025	(97.5)
NB Through College Road at Market Street Overpass	15615	(113.9)	15305	(102.7)
NB Through College Road at Market Street On Ramp	13700	(73.9)	13505	(88.5)
NB Through College Road at Oleander Drive	13856	(73.3)	13791	(69.7)
NB Through College Road at Carolina Beach Road	14547	(23.1)	13791	(26.5)
WB Right Martin Luther King, Jr. Parkway at College Road	2966	(51.5)	2884	(61.0)

Table 5-23. CORSIM 10-run Average Speeds

Location	No CF Avg. Speed Hrs 1-5 (mph)	With CF Avg. Speed Hrs 1-5 (mph)	No CF Avg. Speed Hrs 6-10 (mph)	With CF Avg. Speed Hrs 6-10 (mph)	No CF Avg. Speed Hr 11-14 (mph)	With CF Avg. Speed Hr 11-14 (mph)	No Contraflow Standard Deviation (mph)	With Contraflow Standard Deviation (mph)
Interstate 40 WB at Holly Shelter Road On Ramp	65.4	69.4	64.5	69.1	68.7	69.6	0.1	0.1
Interstate 40 WB at Gordon Road On Ramp	63.6	66.6	63.0	66.4	70.0	66.4	0.1	0.1
NB Through College Rd at MLK Parkway	25.8	42.0	24.7	41.3	34.7	44.8	0.3	0.4
NB Through College Rd at Market St Overpass	51.2	51.2	50.8	50.9	51.6	51.3	0.1	0.1
NB Through College Rd at Market St Ramp	42.3	42.4	41.4	41.6	52.8	43.8	0.2	0.1
NB Through College Rd at Oleander Dr	26.9	28.2	26.0	27.5	39.0	33.8	0.4	0.2
NB Through College Rd at Carolina Beach Rd	26.8	27.8	25.1	26.1	27.4	29.6	0.3	0.3
NB Through College Road Entering network	50.6	50.5	50.1	49.9	51.9	53.4	0.1	0.2
WB Right MLK Parkway at College Rd	25.0	13.6	24.0	15.4	25.0	18.1	0.4	0.3

5.3.3.2 VISSIM

The 10-run averages and standard deviations for the VISSIM analysis MOEs at key links/nodes are shown in Table 5-24 through Table 5-27.

Table 5-24. VISSIM Average and Standard Deviation of Maximum Queue Lengths (ft)

Queue Location	No Contraflow 10-run VISSIM Average (s.d.)		MLK Contraflow 10-run VISSIM Average (s.d.)	
NB College Road at Martin Luther King, Jr. Parkway	3244	(504.1)	599	(108.8)
WB Through Martin Luther King, Jr. Parkway at College Road	79	(25.8)	0	(0)
WB Right Martin Luther King, Jr. Parkway at College Road	481	(84.5)	80	(33.2)
NB College Road at Market Street on Ramp	935	(178.8)	1207	(251.6)
NB College Road at Oleander Drive	2362	(348.8)	838	(177.9)
NB College Road at Carolina Beach Road	872	(516.4)	419	(72.2)
Interstate 40 WB at Gordon Road on Ramp	2250	(492.5)	232	(63.4)

Table 5-25. VISSIM 10-run Average Throughputs (Vehicles)

Location	No Contraflow VISSIM Average Throughput Hrs 1-5	With Contraflow VISSIM Average Throughput Hrs 1-5	No Contraflow VISSIM Average Throughput Hrs 6-10	With Contraflow VISSIM Average Throughput Hrs 6-10	No Contraflow VISSIM Average Throughput Hrs 11-14	With Contraflow VISSIM Average Throughput Hrs 11-14
Interstate 40 Leaving New Hanover County	6945	8471	10137	11362	5446	4690
NB Through College Road at Market Street Overpass	5640	5890	7293	7611	3112	2627
NB Through College Road at Market Street On Ramp	5114	5312	6562	6819	2540	2101
NB Through College Road at Oleander Drive	6367	6267	7700	7575	2228	1645
NB Through College Road at Carolina Beach Road	7188	6658	8281	7581	2121	1628

Table 5-26. VISSIM 10-run Average Cumulative Throughput and Standard Deviation

Location	No Contraflow 10-run Average Total VISSIM Throughput (Standard Deviation) (Vehicles)		MLK Contraflow 10-run Average Total VISSIM Throughput (Standard Deviation) (Vehicles)	
Interstate 40 WB Leaving New Hanover County	22527	(52.3)	24523	(57.3)
NB Through College Road at Market Street Overpass	16045	(41.8)	16127	(43.2)
NB Through College Road at Market Street On Ramp	14215	(40.6)	14231	(42.6)
NB Through College Road at Oleander Drive	16295	(48.9)	15487	(40.4)
NB Through College Road at Carolina Beach Road	17590	(29.5)	15867	(21.5)

Table 5-27. VISSIM 10-run Average Speeds

Location	No CF Avg. Speed Hrs 1-5 (mph)	With CF Avg. Speed Hrs 1-5 (mph)	No CF Avg. Speed Hrs 6-10 (mph)	With CF Avg. Speed Hrs 6-10 (mph)	No CF Avg. Speed Hr 11-14 (mph)	With CF Avg. Speed Hr 11-14 (mph)	No Contraflow Standard Deviation (mph)	With Contraflow Standard Deviation (mph)
NB Through College Road at MLK Parkway	19.5	18.0	16.3	15.2	24.6	24.0	1.4	1.4
NB Through College Rd at Market St Overpass	21.0	20.4	17.6	17.7	28.8	28.5	1.6	1.4
NB Through College Rd at Market St Ramp	23.2	22.0	19.6	18.5	33.5	32.8	1.9	1.8
NB Through College Rd at Oleander Dr	17.5	16.1	16.7	15.6	22.6	21.0	1.3	1.1
NB Through College Rd at Carolina Beach Rd	37.7	35.1	35.8	34.1	41.3	38.4	1.1	0.8
NB Through College Rd Entering network	41.8	41.9	41.6	41.7	42.7	42.7	0.2	0.1

5.3.3.3 Discussion

In the Minimal Event case, the differences between the performance measures in both models when comparing the implementation of contraflow to a do-nothing alternative are statistically significant at the 95% confidence level (see Table 5-28), but when investigated empirically, are not nearly as considerable as those found in the Severe and Moderate Event cases. In fact, these differences are small enough that the benefit of implementing the Plan – and the cost, resources and effort that go along with it in this storm scenario – is not as concrete. The ability to get evacuees to safety does not seem to be hindered nearly as much with the Minimal Event case evacuation demand than it does in the Severe and Moderate Event cases.

Table 5-28. Statistical *t*-tests of Selected Minimal Event Case MOEs

Performance Measure	Measured Difference (Contraflow Value Minus No Contraflow Value)	Does t-test (95% Confidence) reject the Null Hypothesis?
CORSIM Throughput on I-40	1790 veh	YES
VISSIM Throughput on I-40	1996 veh	YES
CORSIM Queues - NB College at MLK Pkwy	-170 ft	YES
VISSIM Queues - NB College at MLK Pkwy	-2645 ft	YES
CORSIM Queues - WB MLK Parkway at College	-81 ft	YES
VISSIM Queues - WB MLK Parkway at College	-401 ft	YES
CORSIM Queues - NB College at Oleander Dr	-47 ft	YES
VISSIM Queues - NB College at Oleander Dr	-1523 ft	YES

5.3.4 Severe Event Case Model Comparison

5.3.4.1 No Contraflow

The CORSIM and VISSIM runs for the no contraflow case were compared side-by-side for the MOEs at key links/nodes in a similar format to that of the one-model analysis. Comparisons are shown in Table 5-29 through Table 5-32.

Table 5-29. No Contraflow Maximum Queue Length Model Comparison (ft)

Queue Location	No Contraflow 10-run CORSIM Average (s.d.)		No Contraflow 10-run VISSIM Average (s.d.)	
NB College Road at Martin Luther King, Jr. Parkway	4066	(29.9)	6269	(446.9)
WB Through Martin Luther King, Jr. Parkway at College Road	328	(77.0)	91	(26.8)
WB Right Martin Luther King, Jr. Parkway at College Road	926	(30.3)	1192	(139.0)
NB College Road at Market Street on Ramp	2562	(90.1)	13548	(1.8)
NB College Road at Oleander Drive	2277	(25.9)	25755	(41.7)
NB College Road at Carolina Beach Road	1213	(73.9)	22727	(1.3)
Interstate 40 WB at Gordon Road on Ramp	7510	**	7550	(594.2)

** Denotes Standard Deviation cannot be obtained since queue contains FRESIM links

Table 5-30. No Contraflow Average Throughput Model Comparison (Vehicles)

Location	No Contraflow CORSIM Average Throughput Hrs 1-5	No Contraflow VISSIM Average Throughput Hrs 1-5	No Contraflow CORSIM Average Throughput Hrs 6-10	No Contraflow VISSIM Average Throughput Hrs 6-10	No Contraflow CORSIM Average Throughput Hrs 11-14	No Contraflow VISSIM Average Throughput Hrs 11-14
Interstate 40 Leaving New Hanover County	9514	7733	17646	12125	664	1780
NB Through College Road at Market Street Overpass	6894	6186	11822	6322	578	1488
NB Through College Road at Market Street On Ramp	6184	5531	10506	5062	273	1033
NB Through College Road at Oleander Drive	6456	6832	10158	5843	202	2784
NB Through College Road at Carolina Beach Road	6940	7905	10261	6851	114	1246

Table 5-31. No Contraflow Average Cumulative Throughput Model Comparison

Location	No Contraflow 10-run Average Total CORSIM Throughput (Standard Deviation) (Vehicles)		No Contraflow 10-run Average Total VISSIM Throughput (Standard Deviation) (Vehicles)	
Interstate 40 WB Leaving New Hanover County	27824	(114.5)	21638	(30.0)
NB Through College Road at Market Street Overpass	19295	(109.7)	13996	(38.7)
NB Through College Road at Market Street On Ramp	16963	(92.0)	11625	(34.4)
NB Through College Road at Oleander Drive	16817	(67.2)	15459	(52.4)
NB Through College Road at Carolina Beach Road	17315	(31.2)	16001	(50.6)

Table 5-32. No Contraflow Average Speed Model Comparison (mph)

Location	No CF CORSIM Average Speeds Hrs 1-5	No CF VISSIM Average Speeds Hrs 1-5	No CF CORSIM Average Speeds Hrs 6-10	No CF VISSIM Average Speeds Hrs 6-10	No CF CORSIM Average Speeds Hrs 11-14	No CF VISSIM Average Speeds Hrs 11-14	CORSIM Standard Deviation (mph)	VISSIM Standard Deviation (mph)
NB Through College Rd at MLK Parkway	25.3	18.9	11.2	12.8	21.0	30.8	0.6	1.1
NB Through College Rd at Market St Overpass	50.9	20.1	26.8	10.3	43.0	28.6	3.0	1.0
NB Through College Rd at Market St Ramp	41.4	22.0	19.2	8.8	33.8	33.4	3.5	1.3
NB Through College Rd at Oleander Dr	26.3	17.3	21.4	11.3	28.9	12.8	0.7	0.8
NB Through College Rd at Carolina Beach Rd	25.2	35.9	15.4	14.8	22.9	19.5	0.7	1.7
NB Through College Road Entering network	50.0	41.7	47.1	18.0	51.9	31.3	0.1	0.4

5.3.4.2 With Contraflow

The CORSIM and VISSIM runs for the with contraflow case were compared side-by-side for the MOEs at key links/nodes in a similar format to that of the one-model analysis. Comparisons are shown in Table 5-33 through Table 5-36.

Table 5-33. With Contraflow Maximum Queue Length Model Comparison (ft)

Queue Location	MLK Contraflow 10-run CORSIM Average (s.d.)		MLK Contraflow 10-run VISSIM Average (s.d.)	
NB College Road at Martin Luther King, Jr. Parkway	479	(32.4)	778	(107.9)
WB Through Martin Luther King, Jr. Parkway at College Road	180	(5.2)	0	(0)
WB Right Martin Luther King, Jr. Parkway at College Road	87	(5.1)	199	(56.0)
NB College Road at Market Street on Ramp	1881	(13.2)	3243	(525.9)
NB College Road at Oleander Drive	2049	(24.8)	8775	(691.7)
NB College Road at Carolina Beach Road	1040	(75.1)	1464	(285.1)
Interstate 40 WB at Gordon Road on Ramp	*	**	889	(230.5)

* Denotes Queue does not stretch beyond limits of FRESIM links -- Queue is shorter than 6693 feet

** Denotes Standard Deviation cannot be obtained since queue contains FRESIM links

Table 5-34. With Contraflow Average Throughput Model Comparison (Vehicles)

Location	With Contraflow CORSIM Average Throughput Hrs 1-5	With Contraflow VISSIM Average Throughput Hrs 1-5	With Contraflow CORSIM Average Throughput Hrs 6-10	With Contraflow VISSIM Average Throughput Hrs 6-10	With Contraflow CORSIM Average Throughput Hrs 11-14	With Contraflow VISSIM Average Throughput Hrs 11-14
Interstate 40 Leaving New Hanover County	10416	9072	19756	17622	1622	1343
NB Through College Road at Market Street Overpass	6735	6404	11683	11338	951	913
NB Through College Road at Market Street On Ramp	6066	5727	10414	9956	416	502
NB Through College Road at Oleander Drive	6417	6714	10158	10376	372	319
NB Through College Road at Carolina Beach Road	6417	7258	10158	10548	372	283

Table 5-35. With Contraflow Average Cumulative Throughput Model Comparison

Location	MLK Contraflow 10-run Average Total CORSIM Throughput (Standard Deviation) (Vehicles)		MLK Contraflow 10-run Average Total VISSIM Throughput (Standard Deviation) (Vehicles)	
Interstate 40 WB Leaving New Hanover County	31794	(111.6)	28037	(45.6)
NB Through College Road at Market Street Overpass	19370	(74.4)	18655	(35.2)
NB Through College Road at Market Street On Ramp	16896	(57.5)	16185	(33.8)
NB Through College Road at Oleander Drive	16947	(66.1)	17409	(34.9)
NB Through College Road at Carolina Beach Road	16947	(47.0)	18089	(21.3)

Table 5-36. With Contraflow Average Speed Model Comparison (mph)

Location	With CF CORSIM Average Speeds Hrs 1-5	With CF VISSIM Average Speeds Hrs 1-5	With CF CORSIM Average Speeds Hrs 6-10	With CF VISSIM Average Speeds Hrs 6-10	With CF CORSIM Average Speeds Hr 11-14	With CF VISSIM Average Speeds Hr 11-14	CORSIM Standard Deviation (mph)	VISSIM Standard Deviation (mph)
NB Through College Rd at MLK Parkway	41.1	17.6	32.7	14.2	39.2	31.6	0.7	1.2
NB Through College Rd at Market St Overpass	51.0	19.9	48.7	15.5	49.4	30.1	0.1	1.0
NB Through College Rd at Market St On Ramp	41.8	21.2	34.9	14.4	41.7	36.0	0.3	1.3
NB Through College Rd at Oleander Dr	28.2	16.0	23.1	14.6	29.9	23.2	0.4	1.4
NB Through College Rd at Carolina Beach Rd	27.0	34.4	16.3	19.0	22.8	34.8	0.7	1.0
NB Through College Rd Entering network	49.9	41.7	47.1	25.5	50.0	39.5	0.1	0.4

5.3.4.3 Discussion

In the no contraflow scenario, the VISSIM results paint a much more pessimistic picture of the New Hanover County network than do the CORSIM results, except when traffic is flowing freely (only the last one to two hours of simulation). CORSIM queues are considerable, but do not become so severe that they stretch from intersection to intersection creating one several-mile long queue. VISSIM does produce this queue, as determined both from measuring the queue lengths output as well as in observing the models as they ran. Anecdotal accounts of previous evacuations point toward the results of the CORSIM simulation being more realistic for this evacuating traffic, but if the VISSIM model queues were to be realized, delays getting out of New Hanover County would be significant without a lane reversal in the Severe Event case. The VISSIM queue begins at the merge point of the Gordon Road on ramp with Interstate 40.

Therefore, it appears lane changing and other characteristics of the model at this merge point in the VISSIM model produce this initial queue that stretches upstream through the New Hanover County network along the College Road arterial.

When contraflow is implemented, again VISSIM shows a longer queue than does CORSIM, but the scale of this difference is much less and traffic is flowing more freely. As a result, VISSIM places a greater benefit in the implementation of contraflow in the Severe Event case.

5.3.5 Moderate and Minimal Event Cases Model Comparison

Model comparison analysis was performed for the Moderate and Minimal Event cases in the same manner as that performed for the Severe Event case. A discussion on the model comparison results for each of these cases follows.

5.3.5.1 Moderate Event Case Discussion

In the Moderate Event case, the discrepancies between the two simulation models when contraflow is not implemented remains considerable, except when traffic is flowing freely in the last one to two hours of simulation. VISSIM again produces a queue that stretches several miles from the I-40/Gordon Road merge south to the College Road/Carolina Beach Road intersection. Again, the key bottleneck and start of this queue is at the freeway merge downstream of all signals. As would be expected, this queue is not quite as long as that found in the Severe Event case, but nevertheless it remains quite substantial. CORSIM again is much more optimistic in its depiction of queues in the no contraflow scenario. Again, however, both models show a considerable benefit when the lane reversal is implemented in the Moderate Event case, with VISSIM again showing this benefit to the network as greater.

5.3.5.2 Minimal Event Case Discussion

The Minimal Event case does not result in the extreme differences between the two models that are shown in the Severe and Moderate Event cases in the no contraflow scenario. Queues do not compound to form a single long queue, and the differences between the individual intersection queues are not nearly as substantial. The two models' throughputs and average speeds are also more in agreement in this case. It appears that the models (when default parameters are used) are in better agreement when traffic is moving more freely, since the Minimal Event case as well as the final (free-flowing) hours of the Severe and Moderate Event Cases produce outputs that are much more comparable.

5.4 Phase 3 Full Reversal Simulation Runs and Measure of Effectiveness

The final simulation phase involved expanding the network model to include the entire lane reversal plan. Although the full reversal plan was added to the link-node models for both CORSIM and VISSIM, the detailed results below are based primarily on CORSIM simulation. When the discrepancies between the results of the two programs noted in the Phase 2 modeling were investigated closely, it was found that the principal cause related to the way the two programs simulate driver behavior in the vicinity of lane drops and lane merges. The VISSIM-simulated behavior in these situations resulted in unrealistically low throughputs under saturated conditions. An abbreviated effort was undertaken to modify the VISSIM vehicle fleet and driver characteristics as well as driver decision points. This effort resulted in little improvement.

Two additional factors contributed to the decision to rely on the CORSIM results for the full reversal plan analysis. First was that detailed calibration of either model was not possible given that no operational data exists for the lane reversal. This calibration issue is even more acute for VISSIM and even if the relevant observation data were available, detailed VISSIM model calibration would require time and resources beyond the scope of the project. The second factor relates to the fact than one of the main reasons for investigating the use of VISSIM for the lane reversal simulation was the possibility of taking advantage of VISSIM's dynamic traffic assignment capabilities. However, during the Phase 2 modeling effort, it was found that given the level of congestion in the network under evacuation demand (compounded by the need for extensive, detailed calibration) the dynamic assignment methods in VISSIM were not able to converge on realistic and useful results (see section 3.5.3).

The balance of section 5.4 is organized as follows: the network model is described in section 5.4.1, the demand estimates are detailed in section 5.4.2, and the simulation results are presented in section 5.4.3.

5.4.1 Network Model

Creation of the full reversal plan network essentially consisted of expanding the Phase 2 New Hanover County network to include realistic representations of I-40 and all intervening interchanges to a point approximately ½ mile downstream of the crossover termination. This length of I-40 was added to both the With Contraflow and No Contraflow networks.

The key feature in this expanded network is the terminating crossover located in the median approximately at the midway point (near mile marker 331) between the NC 96 interchange (interchange 344) and I-95. According to the "Conceptual Design on I-40 Median Crossover / Lane Reversal" provided by NCDOT, the crossover is constructed as

4° (1,432.39 foot radius) reverse curves with no separating tangent at the point of reverse curvature. Therefore, at best (if no adverse superelevation exists at any point along the crossover), drivers will have at least one point along the crossover curves where there is no superelevation, a cross slope of 0%. (It should be pointed out that the project team has not field verified the details of the constructed crossover.) Based on the AASHTO *A Policy on Design of Highways and Streets*, 2001 (*Green Book*) Exhibit 3-23 for e_{max} = 8%, the corresponding best case design speed for this situation would be between 15 and 20 mph. However, if *Green Book* equation 3-10 is iteratively solved for speed given a radius of 1,432.39 feet and 0% superelevation, the resulting design speed and side friction falls between 50 and 55 mph and 0.13 and 0.14, respectively. The reason for the discrepancy is that at 8% maximum superelevation (the standard used for interstate highway design), the maximum side friction factor is only used at the maximum superelevation rate.

The bottom line of this brief analysis is that the operational "free flow speed" of the crossover will not be known with any degree of certainty until actual evacuation traffic data can be gathered. Furthermore, the operating speed of the crossover could depend on factors other than geometric features, such as lateral traffic cone placement, the presence of vehicles and people in the median in close proximity to the crossover, etc.

Based on an initial assessment of the crossover design and anecdotal information on operation of the I-10 crossover in New Orleans during the Ivan evacuation (see Figure 5-2), the crossover was modeled with a free flow speed of 15 mph. As discussed in section 5.4.3.2, it will be important to maintain as high an operational speed on the crossover as possible.

Figure 5-2. I-10 Crossover in New Orleans during 2004 Ivan Evacuation (beginning of contraflow)

5.4.2 Demand Estimates

Evacuation travel demand estimates for the full reversal plan analysis were essentially the same as for the Phase 2 county-wide modeling. As noted in Chapter 4, it was estimated that approximately 94% of the evacuees who would use I-40 evacuation route would continue on I-40 all the way to I-95. The Phase 2 evacuation demand estimates were augmented in two ways. First, estimates were derived for the level of traffic entering and exiting at the intervening interchanges. Second, estimates were developed for evacuation traffic from the Jacksonville area (Onslow County) that use I-40. This traffic will approach I-40 on NC 24. The Onslow County evacuation traffic was estimated at the same level of demand as the corresponding New Hanover County evacuation. Therefore the scenarios evaluated were based on storm tracks that would yield similar evacuation orders and evacuation demand patterns for these neighboring coastal areas.

Specifically, the New Hanover County evacuation demand was distributed among the intervening interchanges as shown in Table 5-37.

Table 5-37. New Hanover County Evacuation Traffic Destination

Destination Exit	Percent	Cumulative Percent
Pender County (Exits 390 - 408)	.5	.5
Goldsboro (Exits 355 and 369)	1.6	2.1
Duplin County (Exits 364 - 385)	2.2	4.3
Sampson County (Exits 341 - 355)	2.0	6.3
Crossover and Beyond	93.7	100

At the intervening interchanges with traveler services within one-mile of I-40 (exits 408, 385, 373, 364, and 341), 10% of the approaching traffic in both the normal and reversed lanes were modeled as exiting for services and then re-entering. At exit 364, an additional 10% was modeled as exiting to access the public rest area before returning to I-40. Subsequent to completion of the simulation modeling, it was learned that the State Highway Patrol and the NCDOT decided to close the interchange 364 rest area in the event of a reversed lane evacuation due to concerns for safety and congestion within and around the rest area. This decision may reduce traffic disruption at exit 364. However, the simulation revealed no serious congestion issues even with the rest area modeled as open.

The Onslow County evacuation traffic is estimated to enter I-40 at two locations. The majority (90%) of the evacuation traffic approaching I-40 on NC 24 is modeled to access

I-40 at exit 373 via the Kenansville Bypass (NC 903). The remaining 10% is modeled to continue on NC 24 and access I-40 via interchange 364.

5.4.3 Simulation Results

5.4.3.1 Interchange Operation Results

Detailed analysis of the simulation runs in both CORSIM and VISSIM revealed no significant operational issues at any of the intervening interchanges. Some minor and expected delays are observed at interchanges 373 and 364 during times of confluence of heavy evacuation demand from both New Hanover and Onslow counties. However, the modeling revealed no persistent queue formation at these interchanges at any point during the evacuation period. Therefore, the simulation analysis provides no indication of operational problems at the intervening interchanges.

5.4.3.2 Crossover Operation Results

The principal MOE for assessing the operation of the termination crossover is maximum length of queue in both the reversed and normal flow lanes. The current plan calls for a lane drop on both sides of the median, upstream of the crossover thereby reducing reversed and normal flow to one lane each. Reversed lane traffic is then returned to the normal westbound lanes through the median crossover. Given this configuration and considering that approximately 94% of the New Hanover County evacuation traffic is bound for the lane reversal termination along with the Onslow County evacuation traffic using I-40, queues at the lane reversal termination are expected. Key to the analysis therefore is assessment of whether the queue lengths are reasonable and are reasonably balanced between the reversed and normal flow lanes.

Unfortunately, CORSIM does not provide queuing statistics on freeway (FRESIM) links either in terms of number of queued vehicles or queue lengths. Therefore, a special procedure was developed to estimate simulation queue lengths based on reported cumulative link speed. This procedure first involved subdividing the I-40 links within the zone of possible queuing into segments of approximately 1,000 feet in length. It was decided that for comparative purposes, queue lengths derived from 1,000 foot nominal segments would be sufficiently precise. The simulation outputs from 10 CORSIM runs were then analyzed on the basis of hourly cumulative link speed. Two thresholds were tested for determining when link should be considered to be in a queued condition, namely 35 mph and 45 mph. This queue analysis is presented in Appendix A.1.

Assessing the accuracy of the two threshold options was not trivial. This is the case because of a limitation of the TRAVU component of CORSIM that is used to visually inspect the simulated traffic flows. TRAVU relies on a *time step index* file to navigate the vehicle data stored in the *time step data* files. The byte index pointers are specified as 32-bit binary integers. Therefore, TRAFVU animation cannot be viewed for *time step data* files larger that approximately 2 GB for any time steps occurring past the 2 GB point in the large files. For the full reversal simulations, the *time step data* files were on the order of 12 to 15 GB.

Fortunately, the project team developed a method to extract and view one-hour slices from the individual *time step data* files based on the detailed information on the file structures given in the *TRAFVU File Description Document, Version 1.3* (ITT Industries, 2002) and using the *Perl* scripting language. Visual inspection of several specific hourly animations indicated that the 45 mph threshold was capable of identifying the maximum length of queue and the hour in which the maximum queue occurred. Therefore, the data presented below is based on the 45 mph cumulative link speed threshold method. However, it is important to remember that the simulation models have not been validated and calibrated against actual evacuation flow data. Therefore the results are useful more for comparative analysis than for assessment of expected absolute queue lengths. Also, Table 5-38 below includes data only for contraflow scenarios. This is because there are no bottlenecks in the vicinity of the crossover and therefore no queuing in the No Contraflow scenarios. The current lane reversal plan creates a four-lane to two-lane bottleneck at the lane reversal terminus. This is in essence a 90-mile translation of the two-lane constriction that occurs at the MLK intersection under the No Contraflow scenarios.

Table 5-38. Maximum Queue from the Lane Drop (miles)

Evacuation Scenario	Contraflow Lanes		Normal Lanes	
	Maximum Queue	Standard Deviation	Maximum Queue	Standard Deviation
Severe	9.5	0.4	2.2	0.3
Moderate	7.1	0.3	1.0	0.0
Minimal	1.1	0.1	0.9	0.0

For the severe event scenarios, the maximum queue occurs in simulation hour 12 on the contraflow side and simulation hour 11 in the normal lanes for all 10 runs in each case. For the moderate event scenarios, the maximum queue again occurs in simulation hour 12 on the contraflow side for all runs. However, the normal flow lanes experience moderate event maximum queue in simulation hour 10 in eight runs and hour 9 in two runs. For the minimal event case, the maximum queue occurs in simulation hour 12 in nine runs and simulation hour 13 in one run on the contraflow side. In the normal lanes, the minimal event maximum queue occurs in simulation hour 10 in six runs, hour 11 in three runs, and hour 12 in one run.

Even when taken as comparative rather than absolute results, the simulated queue length results above indicate the possibility of unacceptable queue imbalances between the contraflow and normal flow lanes along with excessive absolute queue lengths in the contraflow lanes. A logical partial explanation for this imbalanced queue is imbalanced demand created primarily by the rigid lane assignment at the MLK intersection. The evacuation scenarios do all include a degree of demand imbalance. For example, the severe event case includes a cumulative approach volume arriving at the lane reversal termination in the contraflow lanes of approximately 19,300 vehicles over the entire simulation period, while approximately 17,700 vehicles approach in the normal lanes.

However, the simulated queue discharge capacity of the crossover lane was also investigated as a contributing factor. Upon further analysis, it was determined that the queue discharge rate of the crossover as simulated with a 15 mph free flow speed, was on the order of 1,500 to 1,550 vph. Although these results are not inconsistent with the work zone crossover findings of Jiang (1999), this discharge capacity might represent an unrealistically low estimate. For the severe event case only, five additional simulation runs each were conducted with modified free flow speeds for the crossover of 25 mph and 35 mph. The queue discharge rates for the crossover increased in both cases, namely to approximately 1,800 vph for 25 mph and approximately 1,830 vph for 35 mph.

These results indicate that for simulated flow conditions, there is little decrease in queue discharge capacity if the free flow speed of the crossover is decreased from 35 mph to 25 mph and that the marked drop occurs at a speed somewhere between 25 mph and 15 mph. A brief sampling of extracted one-hour animations from the 35 mph free flow speed runs were inspected revealing that if the queue discharge capacity of the crossover can be kept near the 1,800 vph provided by a 25-35 mph design speed as opposed to the 1,500 vph rate resulting from the 15 mph design speed, the maximum queue length would be cut nearly in half (5-6 miles instead of 9-10 miles). This simulated improvement still represents an imbalance across the contraflow and normal flow lanes. However, it also represents a significant decrease in the absolute contraflow maximum queue indicated by the initial simulations. The key operational strategy is to make every effort to ensure that the bottleneck created at the lane drop is not dominated by a tighter restriction at the crossover. If the crossover queue discharge capacity can be maintained at a level higher than the upstream lane drop, the result will be essentially equal capacity for the contraflow lanes as compared to the normal lanes. For comparison, the simulated queue discharge capacity of the lane drops in both the reversed and normal lanes is on the order of 1,800 to 1,830 vph.

5.4.3.3 Overall Evacuation Travel Time

Operational effectiveness of the full lane reversal plan was also evaluated by extracting individual simulated vehicle travel times. It is an intuitive certainty that evacuees from the Wrightsville Beach area who approach the MLK intersection from the east and are directed to the normal lanes will consistently experience improvement in their travel times to I-95 under contraflow operation. This is because queues at MLK are essentially eliminated due to the free flow right turn, the evacuees then share the normal lanes with less traffic than in the No Contraflow condition, and the simulation results indicate only transitory and moderate queuing at the downstream end lane drop in the normal lanes.

On the other hand, given the extreme queuing that could be possible in the contraflow lanes upstream of the crossover under the severe event scenario, it is certainly possible that evacuees who approach the MLK intersection from the south and are directed onto the reversed lanes could experience longer travel times to I-95 than they would experience, all things being equal, under a No Contraflow option. Even if this were the case, however, it could and should be argued that travel delay experienced 90 miles inland, and before the onset of tropical storm force winds, is less of a public safety issue than delay within the coastal evacuation zone. Nonetheless, it would without question be preferable to have a reasonable level of certainty that all evacuees would experience improved travel time under reversed lane operations if and when implemented.

Table 5-39 presents the travel time analysis results for all simulated vehicles that evacuate from Carolina Beach and travel the full length of the lane reversal network through the contraflow lanes to the crossover termination. Given the large number of sampled vehicles, the results from a single run are adequate for comparative purposes. In order to lessen the effect of relying on a single run for the extreme values, the “maximum” and “minimum” travel times given below are averages of the ten longest and ten shortest travel times, respectively.

Table 5-39. Simulated Evacuation Travel Times from Carolina Beach through the Contraflow Lanes (minutes)

Operational Scenario	Number of Vehicles	Average Travel Time	Maximum Travel Time	Minimum Travel Time
15 mph Crossover	8618	183	362	111
25 mph Crossover	8463	150	231	112
No Contraflow	8636	145	357	97

Some explanation is needed on why this route was chosen and for the "number of vehicles" reported in Table 5-39. First, the entry node from Carolina Beach represents a significant entry point for evacuation traffic (approximately 19,000 vehicles over the first 13 hours of the evacuation demand curve) and the vehicles from this entry node that take I-40 are the contraflow vehicles that travel the furthest distance through the network. The reason for the difference between the total number of vehicles entering the network from Carolina Beach (approximately 19,000) and the number of these vehicles that exit the network through the crossover termination (the numbers shown in Table 5-39) can be explained by three main factors. First, approximately 5% of this traffic turns left onto the US 421 evacuation route. Of those vehicles that do enter I-40, approximately 6% leave the lane reversal at a point upstream of the crossover. The most significant contributing factor to the difference is the model specification that 10% of the I-40 traffic will depart and re-enter at the intervening interchanges where services are available. This was accomplished in CORSIM by generating new entering vehicles at these interchanges to offset the 10% exiting vehicles. These offsetting entering vehicles are "new" vehicles from the traffic simulation perspective (i.e. they have new identification numbers). Therefore, the vehicles captured in Table 5-39 are the simulated vehicles that traveled all the way from the Carolina Beach entry node to the crossover without exiting at any intervening point.

The results shown above further emphasize the need to closely monitor the operation of the terminating crossover. In comparing the results it is important to remember that the normal lanes were modeled with a free flow speed of 70 mph, while the contraflow lanes were modeled with a free flow speed of 55 mph. This free flow speed specification yielded conservative modeling of reversed lane traffic flow and explains why the minimum travel time for the No Contraflow condition is lower than both the other conditions. It is noteworthy with a 25 mph free flow speed on the crossover, contraflow operation provides nearly identical average travel time (in spite of the lower free flow speed on the contraflow links) while providing a reduction in the maximum travel time of more than two hours. However, with a 15 mph free flow speed on the crossover, the simulated vehicles from Carolina Beach experience a slightly higher maximum travel time and an average travel time that is longer than the No Contraflow average travel time by more than 30 minutes.

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

Conclusions and recommendations arising from the project research findings are organized as follows. Section 6.1 addresses specific issues regarding the operation of the I-40 lane reversal plan. Section 6.2 deals with modeling tools in the context of evacuation traffic analysis. The chapter concludes with recommendations for future research in Section 6.3.

6.1 I-40 Reversal Plan Operation

6.1.1 Transition to Contraflow

As noted in section 5.2, the Phase 1 modeling efforts resulted in modifications to the lane reversal plan at the transition to contraflow. These modifications should provide significantly increased capacity at the loading point of I-40. The NCDOT and public safety personnel who set up the temporary traffic control that will aid evacuees as they travel to and through the MLK intersection will need to take great care to ensure that the deployed traffic control devices provide sufficient and clear guidance while also creating minimal traffic flow impedance. Much of the potential increase in loading capacity could be lost if evacuees are hampered by confusion or impeded by unnecessary encroachment of people, vehicles, etc. on the special evacuation lanes.

6.1.2 Intervening Interchanges

The simulation analysis did not indicate capacity-related operational problems at the intervening interchange ramps. It is likely that, as with the MLK intersection, the key issue at the interchanges will be the need for clear and sufficient positive guidance, especially for the reversed lane ramps. Nonetheless, simulation analysis can only go so far in assessing the yet to be implemented flow to and from the reversed lanes. The lane reversal plan appears to provide for sufficient onsite management of the interchanges by SHP personnel. This "on the ground" expertise will certainly be called upon to maintain safe and efficient traffic flow at the interchanges.

6.1.3 Crossover Termination

Proper set-up and real-time management of the crossover is likely to be the most critical and challenging aspect of the lane reversal plan as currently defined. As was made clear by the simulation findings detailed in section 5.4.3 above, it will be critical to maximize the discharge capacity of the crossover within the fixed constraints. Lane-side encroachment by vehicles and personnel such as is depicted for the I-10 crossover in New Orleans in Figure 5-2 will not, in all likelihood, result in acceptable operation. It is recommended that a discussion take place between –

- The ITS Operations Unit,
- The NCDOT personnel who will be responsible for deploying the crossover traffic control devices, and
- The SHP personnel who will supervise and conduct onsite monitoring.

The goal of this discussion should be the joint development of strategies and procedures to maximize the throughput of the crossover.

Even if best practices are employed to maximize the operational efficiency of the terminating crossover, unacceptable imbalances could still occur between evacuation queues in the reversed flow and normal flow lanes. The lane reversal management team should reassess the real-time monitoring plans and develop best strategies to monitor the termination queues and take corrective action in the event of imbalanced queuing. Ideally the real-time traffic managers of the lane reversal would have access to approach volumes at points sufficiently upstream to anticipate queue imbalance rather than having to respond to observed queue imbalances after they occur.

Corrected actions could include suspending re-entry to either the contraflow or normal lanes at some or all of the interchanges or the more drastic measure of forcing vehicles off of one side and back onto the other. Although it would not be prudent to base risky decisions on the evacuation demand estimates used for the simulation modeling, the NCDOT might consider only allowing the Onslow County evacuation traffic arriving at interchanges 373 and 364 to enter the normal lanes as a means of ameliorating the apparent imbalance created by the lane assignment at the MLK intersection.

6.1.4 Possible Future Modifications

A list follows of possible future modifications to the lane reversal plan that will either be necessary or may be worthy of consideration includes –

Modification to incorporate roadway construction in the New Hanover County area

Several new roadway projects will be coming online in the near-term that will require revisiting and modification of certain elements of the lane reversal plan. This process is already underway and is ongoing.

Reconstruction of the Terminating Crossover

If the operational performance of the crossover proves to be unacceptable in spite of the best efforts of all parties involved, it may be necessary to reconstruct the crossover to provide additional queue discharge capacity.

Construction of One or More Interior Crossovers

If maintaining acceptable queue balance proves to be intractable given the preventative and corrective actions possible given the current plan and constraints, construction of additional crossovers could be investigated as a way of provide more efficient options for balancing the flow.

Construction of an Additional Crossover and Additional Lane at the Termination

The current configuration of the plan at the point of loading should perform rather well at the task of loading all four outbound lanes of I-40 under reversed lane operation. Future modification, including those related to new roadway projects, will likely further enhance to ability to approach full loading capacity of these lanes. Therefore, as the population continues to grow in the New Hanover County region, it is likely that the current four-lane to two-lane bottleneck at the downstream end will no longer be acceptable in the near future (assuming that it is acceptable now). A solution that could be investigated would be to transform the current terminus into a four-lane to three-lane bottleneck by constructing a second crossover with an accompanying third lane continuing through the I-95 interchange.

Continuing Contraflow Operation beyond I-95

An alternative approach that could address the bottleneck issue mention above would be to extend contraflow operation beyond I-95. This approach would be similar to the Georgia DOTs extension of the I-16 lane reversal beyond the original termination point of US-1. If maintenance of access from I-40 eastbound to I-95 were considered essential, contraflow could be continued in only one of the eastbound lanes.

Improvement of other Routes

Roadway improvements on other routes such as US-701 could be partially justified on the basis of expediting evacuation traffic.

Integrated Use of Remotely Sensed Traffic Data

Finally, as mentioned above, the ability to exercise effective real-time management of the lane reversal operation would be greatly enhanced by the incorporation of real-time remotely-sensed traffic data. The NCDOT should carefully consider investment in adding this real-time data component to the I-40 lane reversal plan.

6.2 Modeling Tools

Microsimulation, such as was used in this research, can provide useful operational analysis and insight. For example, assessments like the emergent queue discharge capacity based on specified free flow conditions, stochastic representation of queue lengths, and travel time observations at the simulated vehicle level could not have been derived from analytical or macrosimulation techniques. Unfortunately, there is currently no ideal simulation tool. *OREMS,* for example, does not provide detail surface control modeling. *SimTraffic* did not scale well to the extensive network required for analyzing the countywide and full reversal models. *VISSIM* requires extensive calibration in order to yield realistic results.

On balance, *CORSIM* emerged as the most readily useful currently available tool for this type of analysis. Even so, *CORSIM* has some significant limitations regarding extraction and summary of information from the detailed simulated data. The necessity to develop special procedures for estimating freeway queue length and to write *Perl* scripts to extract animation file slices and extract detailed vehicle data render *CORSIM* inaccessible to a large percentage of current *CORSIM* users for this level of analysis. The need to execute sufficient multiple runs plus the extreme size of the countywide and full reversal runs also create practicality issues in terms of disk storage. The bottom line of this discussion is that while *CORSIM* is capable of supporting the kinds of operational analyses conducted in this research, there is no currently available microsimulation tool that is practically suited for widespread use.

Furthermore, dynamic traffic assignment (DTA) is a desirable feature in simulation software for evacuation traffic analysis. The hope that *VISSIM*'s DTA features would prove useful in this research did not pan out, possibly due to the calibration issues discussed earlier. *CORSIM* does not have DTA capability. Therefore, in addition to the issues of general practicality of microsimulation-based analysis, the desire for DTA empowered simulation of complex evacuation networks such as the I-40 reversal plan is unmet in currently available tools.

Finally, in terms of modeling tools that could be used in real-time management, such tools would likely not be based on detailed microsimulation. Assessment of simulation-based decision support tools for real-time management was not within the scope of this project. In general, however, it is likely that effective, real-time, proactive management can be support by tools based on macrosimulation.

6.3 Future Research

6.3.1 Evacuation Observational and Behavioral Data

There continues to be a dearth of hard observational data on evacuation traffic flow. In addition to this general need for observational data, the usefulness of the I-40 lane reversal plan model developed for this research would be immensely enhanced by the availability of detailed data on I-40 reversed lane operations. Along these lines, it is recommended that NCDOT make joint plans with the City of Wilmington to gather vehicle count and speed data during evacuations at maximum time resolution (no longer than 15-minute intervals if possible) at –

- The approaches to all key Wilmington/New Hanover County intersections
- All open interchange ramps within the scope of the lane reversal
- All available count stations along I-40
- The crossover at the reversal terminus

The critical data included in the general specifications above include –

- Approach volumes at MLK/College
- Speeds through the MLK/College intersection (to better understand the operations of the non-standard movements through the transition)
- Speeds in the non-freeway segment between MLK/College and Gordon Rd
- Counts and speeds just north of Gordon Road
- Counts and speeds just north of the new bypass interchange if it is open during the evacuation
- Counts and speeds just north of Interchange 341 (NC 55) -- This should be upstream of the most extreme possible queues from the lane drop/crossover
- Counts and speeds just north of the lane drops
- Counts and speed in the crossover

Furthermore, the continued support of behavioral evacuation studies is a necessary complement the vehicle count data. Behavioral research of the kind supported by this project provided analytical leverage to several of the issues faced by the research team. As the population in Southeastern North Carolina continues to grow, and the population experiences hurricanes of differing intensity and various evacuation scenarios, evacuation behavior is likely to evolve in ways that will be imperative to understand.

6.3.2 Analysis Tools

As discussed above, research is needed to develop practically useful microsimulation tools that include DTA capabilities. Also, research is needed to determine the best analysis tools to support real-time, data-enabled management of evacuation traffic.

In terms of microsimulation practicality, one short-term strategy would be to subdivide the network and simulate the subnetworks sequentially working upstream to downstream. However, research in this area is needed on how to maintain the integrity of the stochastic results. For example, possible protocols could include conducting multiple runs at a downstream subnetwork using the average flow profile from the upstream subnetwork or conducting single runs at the downstream subnetwork on the flow profile from each run at the upstream network. It is an open research question as to which protocol would best emulate the results that would be provided by a system-wide simulation. Furthermore, this type of subdivided analysis would require dealing with the possibility of a spillback effect crossing a subnetwork boundary.

6.3.3 Policy and Behavioral

Over the course of this project, two key non-engineering research areas have come into sharp focus. The first relates to how state government-directed initiatives such as the I-40 lane reversal plan effect and interrelate with local government decisions regarding evacuation notices and orders. The second involves how the population of potential evacuees will react to increasingly decisive government interventions in the evacuation process, especially if the public perceives, rightly or wrongly, that the government action made their situation worse. Phenomena such as “evacuation regret” come to play in this second research area. Research is critically needed in both these areas to help inform future decisions on public policy, strategy and tactics relating to evacuation transportation.

CHAPTER 7. IMPLEMENTATION AND TECHNOLOGY TRANSFER PLAN

The primary research product for this project is the project final report. This report should be used by the Intelligent Transportation Systems Unit, Division 3, Division 4 and other NCDOT units involved in the planning and execution of the I-40 lane reversal plan. The report can help inform operational and design decisions regarding the I-40 lane reversal plan as well as other special evacuation plans.

This research project also involved the development of extensive simulation models in a variety of software packages. These models will be provided to the ITS Unit. However, as explained in the report, none of the currently available simulation tools are ideal for analysis of extensive evacuation networks. Furthermore, there are scalability and output processing issues that render it impractical for the NCDOT to consider these models to be readily accessible and useful in the current state of the practice.

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APPENDICES

A.1 Termination Crossover Queue Analysis

If queues are <45mph:

Scenario	CF Lane Max Queue	CF Lane Stdev	Reg Lane Max Queue	Reg Lane Stdev
Severe	49935.6	1906.734451	11654.4	1392.713594
Moderate	37450.3	1715.261823	5416	0
Minimal	5758.6	479.7335372	4722.1	243.8116076

If queues are <35mph:

Scenario	CF Lane Max Queue	CF Lane Stdev	Reg Lane Max Queue	Reg Lane Stdev
Severe	48719.9	1518.056246	10440.4	1355.085746
Moderate	36588.8	1704.366601	4953.4	398.142688
Minimal	5387	0	***	***

** 10 run averages
***Speed never falls below 35mph on any link

Hour of max queue is located on detailed sheets following this summary sheet…

Severe Event – Contraflow Lanes

Link		Length	Cumulative Length	1	2	3	4	5	6	7	8	9	10		
298	502	887	887												
341	298	935	1822												
347	341	1105	2927												
349	347	901	3828												
614	349	805	4633												
503	614	754	5387												
616	503	929	6316												
627	616	1043	7359												
629	627	1020	8379												
631	629	913	9292												
633	631	715	10007												
504	633	833	10840												
635	504	1177	12017												
637	635	952	12969												
639	637	1067	14036												
505	639	890	14926												
641	505	914	15840												
643	641	897	16737												
645	643	921	17658												
647	645	954	18612												
649	647	872	19484												
651	649	829	20313												
653	651	793	21106												
655	653	952	22058												
658	655	743	22801												
507	658	604	23405												
660	507	861	24266												
662	660	716	24982												
664	662	727	25709												
666	664	918	26627												
668	666	812	27439												
670	668	738	28177												
508	670	772	28949												
672	508	1039	29988												
674	672	805	30793												
676	674	847	31640												
678	676	834	32474												
680	678	911	33385												
682	680	941	34326												
684	682	619	34945												
509	684	643	35588												
686	509	892	36480												
688	686	845	37325												
690	688	961	38286												
692	690	654	38940												
694	692	841	39781												
696	694	894	40675												
698	696	909	41584												
700	698	954	42538												
702	700	736	43274												
704	702	565	43839												
510	704	729	44568												
706	510	793	45361												
708	706	723	46084												
710	708	969	47053			xx	xx						xx		
712	710	818	47871			x	x	xx			xx		x		
714	712	927	48798					x			x	xx			
716	714	787	49585												
718	716	790	50375	xx	xx				xx	xx		x			
511	718	796	51171							x					
720	511	830	52001		x				x						
722	720	598	52599	x											
514	722	756	53355												
724	514	824	54179												
726	724	952	55131												
515	726	1143	56274												
728	515	956	57230												
730	728	773	58003												
732	730	790	58793												
517	732	856	59649												
734	517	977	60626												
736	734	807	61433												
738	736	856	62289												
740	738	917	63206												
742	740	742	63948												
744	742	824	64772												
518	744	650	65422												
519	518	1174	66596												
520	519	1672	68268											Avg	Std Dev
			<45 mph	52599	52001	47871	47871	48798	52001	51171	48798	50375	47871	**49935.6**	**1906.734**
			<35 mph	50375	50375	47053	47053	47871	50375	50375	47871	48798	47053	**48719.9**	**1518.056**
			Hr of Max Queue	12	12	12	12	12	12	12	12	12	12		

Moderate Event – Contraflow Lanes

Link		Length	Cumulative Length	1	2	3	4	5	6	7	8	9	10		
298	502	887	887												
341	298	935	1822												
347	341	1105	2927												
349	347	901	3828												
614	349	805	4633												
503	614	754	5387												
616	503	929	6316												
627	616	1043	7359												
629	627	1020	8379												
631	629	913	9292												
633	631	715	10007												
504	633	833	10840												
635	504	1177	12017												
637	635	952	12969												
639	637	1067	14036												
505	639	890	14926												
641	505	914	15840												
643	641	897	16737												
645	643	921	17658												
647	645	954	18612												
649	647	872	19484												
651	649	829	20313												
653	651	793	21106												
655	653	952	22058												
658	655	743	22801												
507	658	604	23405												
660	507	861	24266												
662	660	716	24982												
664	662	727	25709												
666	664	918	26627												
668	666	812	27439												
670	668	738	28177												
508	670	772	28949												
672	508	1039	29988												
674	672	805	30793												
676	674	847	31640												
678	676	834	32474												
680	678	911	33385				xx								
682	680	941	34326				x								
684	682	619	34945									xx			
509	684	643	35588			xx						x			
686	509	892	36480 xx			x			xx	xx					
688	686	845	37325 x		xx			xx	x	x					
690	688	961	38286		x			x							
692	690	654	38940	xx							xx				
694	692	841	39781	x							x				
696	694	894	40675												
698	696	909	41584												
700	698	954	42538												
702	700	736	43274												
704	702	565	43839												
510	704	729	44568												
706	510	793	45361												
708	706	723	46084												
710	708	969	47053												
712	710	818	47871												
714	712	927	48798												
716	714	787	49585												
718	716	790	50375												
511	718	796	51171												
720	511	830	52001												
722	720	598	52599												
514	722	756	53355												
724	514	824	54179												
726	724	952	55131												
515	726	1143	56274												
728	515	956	57230												
730	728	773	58003												
732	730	790	58793												
517	732	856	59649												
734	517	977	60626												
736	734	807	61433												
738	736	856	62289												
740	738	917	63206												
742	740	742	63948												
744	742	824	64772												
518	744	650	65422												
519	518	1174	66596												
520	519	1672	68268											Avg	Std Dev
			<45 mph	37325	39781	38286	36480	34326	38286	37325	37325	39781	35588	**37450.3**	**1715.262**
			<35 mph	36480	38940	37325	35588	33385	37325	36480	36480	38940	34945	**36588.8**	**1704.367**
			Hr of Max Queue	12	12	12	12	12	12	12	12	12	12		

Minimal Event – Contraflow Lanes

Link		Length	Cumulative Length	1	2	3	4	5	6	7	8	9	10		
298	502	887	887												
341	298	935	1822												
347	341	1105	2927												
349	347	901	3828												
614	349	805	4633												
503	614	754	5387	xx	xxx	xxx	xxx	xxx	xx	xx	xx	xxx	xxx		
616	503	929	6316	x					x	x	x				
627	616	1043	7359												
629	627	1020	8379												
631	629	913	9292												
633	631	715	10007												
504	633	833	10840												
635	504	1177	12017												
637	635	952	12969												
639	637	1067	14036												
505	639	890	14926												
641	505	914	15840												
643	641	897	16737												
645	643	921	17658												
647	645	954	18612												
649	647	872	19484												
651	649	829	20313												
653	651	793	21106												
655	653	952	22058												
658	655	743	22801												
507	658	604	23405												
660	507	861	24266												
662	660	716	24982												
664	662	727	25709												
666	664	918	26627												
668	666	812	27439												
670	668	738	28177												
508	670	772	28949												
672	508	1039	29988												
674	672	805	30793												
676	674	847	31640												
678	676	834	32474												
680	678	911	33385												
682	680	941	34326												
684	682	619	34945												
509	684	643	35588												
686	509	892	36480												
688	686	845	37325												
690	688	961	38286												
692	690	654	38940												
694	692	841	39781												
696	694	894	40675												
698	696	909	41584												
700	698	954	42538												
702	700	736	43274												
704	702	565	43839												
510	704	729	44568												
706	510	793	45361												
708	706	723	46084												
710	708	969	47053												
712	710	818	47871												
714	712	927	48798												
716	714	787	49585												
718	716	790	50375												
511	718	796	51171												
720	511	830	52001												
722	720	598	52599												
514	722	756	53355												
724	514	824	54179												
726	724	952	55131												
515	726	1143	56274												
728	515	956	57230												
730	728	773	58003												
732	730	790	58793												
517	732	856	59649												
734	517	977	60626												
736	734	807	61433												
738	736	856	62289												
740	738	917	63206												
742	740	742	63948												
744	742	824	64772												
518	744	650	65422												
519	518	1174	66596												
520	519	1672	68268											Avg	Std Dev
			<45 mph	6316	5387	5387	5387	5387	6316	6316	6316	5387	5387	**5758.6**	**479.7335**
			<35 mph	5387	5387	5387	5387	5387	5387	5387	5387	5387	5387	**5387**	**0**
			Hr of Max Queue	12	12	12	12	12	13	12	12	12	12		

Severe Event – Normal Flow Lanes

Link		Length	Cumulative Length	1	2	3	4	5	6	7	8	9	10		
169	498	887	887												
340	169	907	1794												
342	340	1119	2913												
348	342	912	3825												
597	348	820	4645												
499	597	771	5416												
615	499	905	6321												
617	615	1032	7353												
628	617	1009	8362								xx				
630	628	931	9293			xx			xx		x				
632	630	710	10003				xx					xx			
496	632	831	10834		xx	x	x	xx	x	xx		x			
634	496	1163	11997		x					x			xx		
636	634	954	12951	xx				x					x		
638	636	1068	14019	x											
491	638	895	14914												
640	491	912	15826												
642	640	886	16712												
644	642	927	17639												
646	644	942	18581												
648	646	883	19464												
650	648	833	20297												
652	650	790	21087												
654	652	962	22049												
656	654	731	22780												
490	656	663	23443												
659	490	865	24308												
661	659	733	25041												
663	661	700	25741												
665	663	946	26687												
667	665	768	27455												
669	667	756	28211												
489	669	827	29038												
671	489	964	30002												
673	671	829	30831												
675	673	828	31659												
677	675	863	32522												
679	677	898	33420												
681	679	937	34357												
683	681	623	34980												
488	683	697	35677												
685	488	863	36540												
687	685	847	37387												
689	687	975	38362												
691	689	643	39005												
693	691	839	39844												
695	693	874	40718												
697	695	939	41657												
699	697	959	42616												
701	699	715	43331												
703	701	590	43921												
487	703	750	44671												
705	487	767	45438												
707	705	723	46161												
709	707	953	47114												
711	709	826	47940												
713	711	930	48870												
715	713	801	49671												
717	715	752	50423												
486	717	857	51280												
719	486	792	52072												
721	719	596	52668												
512	721	812	53480												
723	512	778	54258												
725	723	945	55203												
475	725	1183	56386												
727	475	938	57324												
729	727	748	58072												
731	729	782	58854												
476	731	851	59705												
733	476	868	60573												
735	733	832	61405												
737	735	851	62256												
739	737	901	63157												
741	739	755	63912												
743	741	839	64751												
473	743	700	65451												
478	473	1089	66540												
466	478	1779	68319											Avg	Std Dev
			<45 mph	14019	11997	10834	10834	12951	10834	11997	9293	10834	12951	**11654.4**	**1392.714**
			<35 mph	12951	10834	9293	10003	10834	9293	10834	8362	10003	11997	**10440.4**	**1355.086**
			Hr of Max Queue	11	11	11	11	11	11	11	11	11	11		

Moderate Event – Normal Flow Lanes

Link		Length	Cumulative Length	1	2	3	4	5	6	7	8	9	10		
169	498	887	887												
340	169	907	1794												
342	340	1119	2913												
348	342	912	3825												
597	348	820	4645		xx		xx	xx	xx		xx	xx			
499	597	771	5416	xxx	x	xxx	x	x	x	xxx	x	x	xxx		
615	499	905	6321												
617	615	1032	7353												
628	617	1009	8362												
630	628	931	9293												
632	630	710	10003												
496	632	831	10834												
634	496	1163	11997												
636	634	954	12951												
638	636	1068	14019												
491	638	895	14914												
640	491	912	15826												
642	640	886	16712												
644	642	927	17639												
646	644	942	18581												
648	646	883	19464												
650	648	833	20297												
652	650	790	21087												
654	652	962	22049												
656	654	731	22780												
490	656	663	23443												
659	490	865	24308												
661	659	733	25041												
663	661	700	25741												
665	663	946	26687												
667	665	768	27455												
669	667	756	28211												
489	669	827	29038												
671	489	964	30002												
673	671	829	30831												
675	673	828	31659												
677	675	863	32522												
679	677	898	33420												
681	679	937	34357												
683	681	623	34980												
488	683	697	35677												
685	488	863	36540												
687	685	847	37387												
689	687	975	38362												
691	689	643	39005												
693	691	839	39844												
695	693	874	40718												
697	695	939	41657												
699	697	959	42616												
701	699	715	43331												
703	701	590	43921												
487	703	750	44671												
705	487	767	45438												
707	705	723	46161												
709	707	953	47114												
711	709	826	47940												
713	711	930	48870												
715	713	801	49671												
717	715	752	50423												
486	717	857	51280												
719	486	792	52072												
721	719	596	52668												
512	721	812	53480												
723	512	778	54258												
725	723	945	55203												
475	725	1183	56386												
727	475	938	57324												
729	727	748	58072												
731	729	782	58854												
476	731	851	59705												
733	476	868	60573												
735	733	832	61405												
737	735	851	62256												
739	737	901	63157												
741	739	755	63912												
743	741	839	64751												
473	743	700	65451												
478	473	1089	66540												
466	478	1779	68319											Avg	Std Dev
			<45 mph	5416	5416	5416	5416	5416	5416	5416	5416	5416	5416	**5416**	**0**
			<35 mph	5416	4645	5416	4645	4645	4645	5416	4645	4645	5416	**4953.4**	**398.1427**
			Hr of Max Queue	9	10	10	10	9	10	10	10	10	10		

Minimal Event – Normal Flow Lanes

Link		Length	Cumulative Length	1	2	3	4	5	6	7	8	9	10		
169	498	887	887												
340	169	907	1794												
342	340	1119	2913												
348	342	912	3825												
597	348	820	4645	x	x	x	x		x	x	x	x	x		
499	597	771	5416					x							
615	499	905	6321												
617	615	1032	7353												
628	617	1009	8362												
630	628	931	9293												
632	630	710	10003												
496	632	831	10834												
634	496	1163	11997												
636	634	954	12951												
638	636	1068	14019												
491	638	895	14914												
640	491	912	15826												
642	640	886	16712												
644	642	927	17639												
646	644	942	18581												
648	646	883	19464												
650	648	833	20297												
652	650	790	21087												
654	652	962	22049												
656	654	731	22780												
490	656	663	23443												
659	490	865	24308												
661	659	733	25041												
663	661	700	25741												
665	663	946	26687												
667	665	768	27455												
669	667	756	28211												
489	669	827	29038												
671	489	964	30002												
673	671	829	30831												
675	673	828	31659												
677	675	863	32522												
679	677	898	33420												
681	679	937	34357												
683	681	623	34980												
488	683	697	35677												
685	488	863	36540												
687	685	847	37387												
689	687	975	38362												
691	689	643	39005												
693	691	839	39844												
695	693	874	40718												
697	695	939	41657												
699	697	959	42616												
701	699	715	43331												
703	701	590	43921												
487	703	750	44671												
705	487	767	45438												
707	705	723	46161												
709	707	953	47114												
711	709	826	47940												
713	711	930	48870												
715	713	801	49671												
717	715	752	50423												
486	717	857	51280												
719	486	792	52072												
721	719	596	52668												
512	721	812	53480												
723	512	778	54258												
725	723	945	55203												
475	725	1183	56386												
727	475	938	57324												
729	727	748	58072												
731	729	782	58854												
476	731	851	59705												
733	476	868	60573												
735	733	832	61405												
737	735	851	62256												
739	737	901	63157												
741	739	755	63912												
743	741	839	64751												
473	743	700	65451												
478	473	1089	66540												
466	478	1779	68319											Avg	Std Dev
			<45 mph	4645	4645	4645	4645	5416	4645	4645	4645	4645	4645	**4722.1**	**243.8116**
			<35 mph					** DOES NOT OCCUR **							
			Hr of Max Queue	10	11	11	10	10	11	12	10	10	10		

A.2 Simulation Program File List

The following pages provide lists of the simulation files provided to the NCDOT for the CORSIM and VISSIM modeling. The very large size of the simulation output files rendered it impractical to provide program outputs. However, the input and random number seed files delivered to NCDOT provide both complete documentation of the simulation modeling conducted for the I-40 Lane Reversal Analysis Project as well as provided base models that can be modified as the transportation network changes in the New Hanover County area. The random number seeds and the procedures used for conducting the multiple VISSIM runs are documented in the file titled – Running VISSIM for I-40.doc

CORSIM Files

File Date	Time	Size (Bytes)	File Name
1/5/2006	2:11 PM	284	CORSIM Random Number Seeds.rns
6/23/2005	2:56 PM	31,479,476	Full Reversal MLK Contraflow 25Xover Severe Event.tno
6/23/2005	2:57 PM	527,506	Full Reversal MLK Contraflow 25Xover Severe Event.trf
8/26/2005	9:59 AM	31,479,424	Full Reversal MLK Contraflow 35Xover Severe Event.tno
6/22/2005	3:19 PM	527,506	Full Reversal MLK Contraflow 35Xover Severe Event.trf
4/27/2005	4:57 PM	31,477,092	Full Reversal MLK Contraflow Minimal Event.tno
4/27/2005	4:56 PM	525,372	Full Reversal MLK Contraflow Minimal Event.trf
4/27/2005	4:15 PM	32,034,099	Full Reversal MLK Contraflow Moderate Event.tno
4/27/2005	4:14 PM	764,894	Full Reversal MLK Contraflow Moderate Event.trf
4/27/2005	2:13 PM	31,479,476	Full Reversal MLK Contraflow Severe Event.tno
4/27/2005	2:16 PM	527,506	Full Reversal MLK Contraflow Severe Event.trf
4/27/2005	1:26 PM	32,465,624	Full Reversal No Contraflow Minimal Event.tno
4/27/2005	1:27 PM	503,316	Full Reversal No Contraflow Minimal Event.trf
4/27/2005	1:15 PM	32,465,630	Full Reversal No Contraflow Moderate Event.tno
4/27/2005	1:16 PM	503,316	Full Reversal No Contraflow Moderate Event.trf
4/27/2005	1:13 PM	23,798,023	Full Reversal No Contraflow Severe Event.tno
4/27/2005	1:17 PM	503,234	Full Reversal No Contraflow Severe Event.trf

VISSIM Files

General Files

File Date	Time	Size (Bytes)	File Name
1/5/2006	3:01 PM	26,112	Running VISSIM for I-40.doc
1/5/2006	2:59 PM	5,503	vissim.ini

No Contraflow Files

File Date	Time	Size (Bytes)	File Name
5/12/2005	12:24 PM	2,106,115	full reversal no contraflow minimal.in0
5/12/2005	12:24 PM	2,106,115	full reversal no contraflow minimal.inp
5/12/2005	12:24 PM	2,109,803	full reversal no contraflow moderate.in0
5/12/2005	12:24 PM	2,109,803	full reversal no contraflow moderate.inp
5/12/2005	12:24 PM	2,109,598	full reversal no contraflow severe.in0
5/12/2005	12:24 PM	2,109,598	full reversal no contraflow severe.inp
2/4/2005	12:31 AM	4,158	NEMA_1.NSE
4/28/2005	2:31 PM	4,144	NEMA_101.NSE
4/5/2005	10:37 AM	4,142	NEMA_102.NSE
8/24/2004	8:53 AM	1,851	NEMA_19.NSE
8/24/2004	8:53 AM	1,873	NEMA_25.NSE
2/4/2005	1:30 PM	4,155	NEMA_26.NSE
8/24/2004	8:53 AM	1,777	NEMA_32.NSE
8/24/2004	8:53 AM	1,777	NEMA_33.NSE
2/2/2005	9:42 PM	4,169	NEMA_35.NSE
2/4/2005	12:13 AM	4,169	NEMA_38.NSE
2/4/2005	12:32 AM	4,182	NEMA_43.NSE
8/24/2004	8:53 AM	1,952	NEMA_44.NSE
8/24/2004	8:53 AM	2,053	NEMA_45.NSE
8/24/2004	8:53 AM	1,759	NEMA_46.NSE
8/24/2004	8:53 AM	1,759	NEMA_47.NSE
8/24/2004	8:53 AM	1,942	NEMA_48.NSE
8/24/2004	8:53 AM	1,756	NEMA_58.NSE
8/24/2004	8:53 AM	1,661	NEMA_59.NSE
8/24/2004	8:53 AM	1,661	NEMA_60.NSE

8/24/2004	8:53 AM	1,663	NEMA_61.NSE
8/24/2004	8:53 AM	1,664	NEMA_62.NSE
8/24/2004	8:53 AM	1,664	NEMA_63.NSE
8/24/2004	8:53 AM	1,664	NEMA_64.NSE
8/24/2004	8:53 AM	1,664	NEMA_65.NSE
8/24/2004	8:53 AM	2,040	NEMA_67.NSE
8/24/2004	8:53 AM	1,660	NEMA_68.NSE
8/24/2004	8:53 AM	2,051	NEMA_69.NSE
8/24/2004	8:53 AM	1,756	NEMA_70.NSE
8/24/2004	8:53 AM	1,756	NEMA_71.NSE
8/24/2004	8:53 AM	2,053	NEMA_72.NSE
2/4/2005	10:03 PM	4,169	NEMA_73.NSE
2/4/2005	10:26 AM	4,162	NEMA_74.NSE
8/24/2004	8:53 AM	1,777	NEMA_75.NSE
8/24/2004	8:53 AM	2,047	NEMA_76.NSE
8/24/2004	8:53 AM	1,761	NEMA_77.NSE
8/24/2004	8:53 AM	1,763	NEMA_78.NSE

With Contraflow Files

File Date	Time	Size (Bytes)	File Name
5/12/2005	11:54 PM	1,944,755	full reversal with contraflow minimal.in0
5/12/2005	11:54 PM	1,944,755	full reversal with contraflow minimal.inp
5/12/2005	11:52 PM	1,947,427	full reversal with contraflow moderate.in0
5/12/2005	11:52 PM	1,947,427	full reversal with contraflow moderate.inp
5/12/2005	9:15 PM	1,947,428	full reversal with contraflow severe.in0
5/12/2005	9:15 PM	1,947,428	full reversal with contraflow severe.inp
3/11/2005	10:46 PM	4,158	NEMA_1.NSE
12/6/2004	3:01 PM	1,665	NEMA_19.NSE
3/3/2005	6:12 PM	3,573	NEMA_26.NSE
12/6/2004	3:01 PM	1,777	NEMA_32.NSE
1/5/2005	11:24 PM	3,733	NEMA_33.NSE
3/3/2005	6:12 PM	4,169	NEMA_35.NSE
2/4/2005	12:13 AM	4,169	NEMA_38.NSE
2/4/2005	12:32 AM	4,182	NEMA_43.NSE

12/6/2004	3:01 PM	1,952	NEMA_44.NSE
12/6/2004	3:01 PM	2,053	NEMA_45.NSE
12/6/2004	3:01 PM	1,759	NEMA_46.NSE
12/6/2004	3:01 PM	1,759	NEMA_47.NSE
12/6/2004	3:01 PM	1,942	NEMA_48.NSE
12/6/2004	3:01 PM	1,756	NEMA_58.NSE
12/6/2004	3:01 PM	1,661	NEMA_59.NSE
12/6/2004	3:01 PM	1,661	NEMA_60.NSE
12/6/2004	3:01 PM	1,663	NEMA_61.NSE
12/6/2004	3:01 PM	1,664	NEMA_62.NSE
12/6/2004	3:01 PM	1,664	NEMA_63.NSE
12/6/2004	3:01 PM	1,664	NEMA_64.NSE
12/6/2004	3:01 PM	1,664	NEMA_65.NSE
12/6/2004	3:01 PM	2,040	NEMA_67.NSE
12/6/2004	3:01 PM	1,660	NEMA_68.NSE
12/6/2004	3:01 PM	2,051	NEMA_69.NSE
1/5/2005	11:24 PM	3,712	NEMA_70.NSE
12/6/2004	3:01 PM	1,756	NEMA_71.NSE
12/6/2004	3:01 PM	2,053	NEMA_72.NSE
2/4/2005	10:03 PM	4,169	NEMA_73.NSE
2/4/2005	10:26 AM	4,162	NEMA_74.NSE
12/6/2004	3:01 PM	1,777	NEMA_75.NSE
12/6/2004	3:01 PM	2,047	NEMA_76.NSE
1/5/2005	11:24 PM	3,717	NEMA_77.NSE
12/6/2004	3:01 PM	1,763	NEMA_78.NSE