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16. Abstract


Over the last 5 years, the Departments of Transportation in 12 coastal states threatened by hurricanes have developed plans for the implementation of contraflow traffic operations on freeways during evacuations. Contraflow involves the use of one or more inbound travel lanes for the movement of traffic in the outbound direction. It is both a logical and cost effective strategy because evacuation traffic can be loaded into underutilized inbound lanes, thereby significantly increasing outbound capacity without the need to construct additional lanes.

This report presents the results of two closely related studies to evaluate the implications of contraflow evacuations on freeways. The research focused on what are widely regarded to be the most critical locations of contraflow segments, the initiation and termination points. The termini configurations are important because they effectively dictate the capacity of these segments because they control how many vehicles can get in and out. In the research, traffic simulation models were developed to simulate the operation of planned configurations under varying levels of traffic demand to assess their operating characteristics. The results showed that many of the current designs of the initiation and termination points will likely restrict the ability of these segments to be used to their maximum effectiveness. Another key finding was the extent to which the spatial and/or temporal spreading of traffic demand can yield significant benefits to the overall effectiveness of contraflow freeway evacuations. With an increased awareness of these issues, these findings can be used to enhance the effectiveness of existing evacuation plans.


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# EVALUATION OF FREEWAY CONTRAFLOW EVACUATION INITIATION AND TERMINATION POINT CONFIGURATIONS

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## ABSTRACT

Over the last 5 years, the Departments of Transportation (DOT) in 12 coastal states threatened by hurricanes have developed plans for the use of contraflow traffic operations on freeways during evacuations. Contraflow involves the use of one or more inbound travel lanes for the movement of traffic in the outbound direction. It is both a logical and cost effective strategy because evacuation traffic can be loaded into underutilized inbound lanes, thereby significantly increasing outbound capacity without the need to construct additional lanes.

Although contraflow makes sense and is widely viewed as a major advancement in the ability of emergency management and DOT agencies to increase the effectiveness of evacuations, it does have drawbacks. First, it eliminates the inbound movement of traffic into the evacuation zone. It can also be potentially confusing to drivers, increasing the likelihood of dangerous traffic conflicts. Contraflow also limits the ability of evacuees to make routing choices, because of the closure of exit and entry points along the segment. Finally, it requires longer lead times to configure the freeway for its use as well as increased levels of manpower and control equipment for both the implementation and operation of the evacuation. It is for these and other reasons that most states are only planning to use contraflow operations for the evacuation of major population centers in advance of the most extreme threat conditions.

Another limitation of contraflow evacuations is the lack of experience and familiarity with its use. Although widely planned, contraflow has only been implemented twice; one of those times was an unplanned/improvised contraflow operation in South Carolina in 1999. Because of this lack of use there is currently an absence of field data or analyses on the characteristics of contraflow evacuation traffic streams and a limited number of simulation studies to evaluate its affect at the local and system levels. This paper seeks to address the need for a better understanding of the transportation aspects of evacuation by summarizing the results of two recent studies conducted at Louisiana State University to evaluate the characteristics and implications of contraflow evacuations at the facility level.

The research focused on what are widely regarded to be the most critical locations of contraflow segments, the initiation and termination points. In theory, the termini configurations control govern the capacity of contraflow segments because they dictate how many vehicles can get in and how many vehicles can get out. To conduct the research, microlevel traffic simulation models were developed to simulate the operation of the various

configurations planned for the use across the southern hurricane-threatened states. Each of the models were run with varying levels of traffic demand to generally assess the operating speeds flows and densities within the termination vicinity, determine the level of queuing associated with each, and estimate the capacity of the various designs.

The results of these studies revealed several interesting findings relative to the evacuation sections planned for use in the southeastern United States. Among the most significant conclusions was that many of the current plans for evacuation initiation and termination points will likely restrict the ability of these segments to be used to their maximum effectiveness. A second finding was how the implementation of actions to spatially and/or temporally spread evacuation traffic demand could yield significant benefits to the overall effectiveness of contraflow freeway evacuations. A third was the level to which demand reduction (through intermediate exiting) would positively impact the operation of the various planned termination designs. Other findings included a general quantification of the relative benefits between the various design configurations planned for use and the traffic flow conditions within the vicinity of the contraflow termini. With an increased awareness of these issues and assessments of the local conditions, some of the findings of this research can be implemented to enhance the effectiveness of existing evacuation plans.

## IMPLEMENTATION STATEMENT

The knowledge and information gained from this study has already been used in practice and should be further integrated into the general practices of the DOTD and other states. In the wake for the Hurricane Ivan evacuation of southeast Louisiana in September, 2004, the Louisiana Department of Transportation and Development in conjunction with the Louisiana State Police (LSP) formed the Louisiana Evacuation Task Force to review the issues and make recommendations for improving future hurricane evacuations in the state. Between October, 2004, and February, 2005, a team that included DOTD and LSP officials as well as consultants from academia industry worked to develop strategies for more effective traffic movement. The knowledge gained from this study was used to formulate plans for and provide a quantitative basis to:

- Develop baseline assumptions and simulation models for the New Orleans evacuation;
- Improve the design of the contraflow loading area in New Orleans to spatially spread the loading of demand onto the I-10 contraflow segment out of the city;
- Demonstrate the critical need to divide, rather than merge, evacuation traffic streams as was observed in Baton Rouge at the confluence of I-10 and I-12; and
- Develop strategies for the use of contraflow to the northeast out of the New Orleans metropolitan area.

The research reported in this document is part of a more comprehensive study addressing other topics related to evacuation planning. These topics are addressed in separate LTRC reports. Specifically, LTRC Technical Report 402 documents the investigation into a mobile traffic counter capable of providing real-time traffic flow and speed information at remote locations. It describes the specification, evaluation, and acquisition of a trailer that uses radar detection of volume and speed over multiple lanes, and uses a cellular phone to transmit information back to a central location at time intervals of the user's choice. LTRC Technical Report 408 addresses the estimation of time-dependent hurricane evacuation demand and reports on the development of a sequential logit model that estimates whether a household will evacuate or not, and if it does decide to evacuate, when they will choose to leave. The development of a methodology to establish hurricane evacuation zones in a systematic and reproducible manner was also conducted as part of this study. The process is described and a sample application demonstrated in Transportation Research Record 1922. The procedure uses postal Zone Improvement Plan (ZIP) areas as basic building blocks in a GIS-based process that progressively combines these blocks into evacuation zones of similar flooding potential. The process is terminated when the homogeneity of the zones is compromised by further agglomeration, or the number and configuration of zones are considered appropriate.

## TABLE OF CONTENTS

# LIST OF TABLES

## LIST OF FIGURES

# INTRODUCTION

Over the last five years, the Departments of Transportation (DOT) in 12 coastal states threatened by hurricanes have developed plans to implement contraflow traffic operations on freeways during evacuations. Contraflow involves the use of one or more inbound travel lanes for the movement of traffic in the outbound direction. It is both a logical and cost-effective strategy because evacuation traffic can be loaded into underutilized inbound lanes, thereby significantly increasing outbound capacity without the need to construct additional lanes.

Although contraflow is widely viewed as a major advancement that allows highway agencies to increase evacuation effectiveness, it is not without its drawbacks. In fact, these negative aspects are why most states plan to use it only under the most extreme threat conditions and only for the evacuation of major population centers. Among the recognized shortcomings of contraflow evacuations are that:

- It eliminates inbound movement of traffic into the evacuation zone. This can be a problem because the early stages of evacuations typically involve a mobilization period during which people enter the threat zone to retrieve family members and property as well as to secure homes and businesses. Inbound entry is also often required by law enforcement and emergency response personnel and service vehicles that need to tend to roadway incidents on evacuation routes.
- It has the potential to be confusing to drivers and increase the likelihood of dangerous traffic conflicts.
- It often restricts the ability of evacuees to make routing choices to reach their destinations, including the closure of exit and entry points along the intermediate contraflow segment.
- It requires increased levels of manpower and material/equipment for both the implementation and operation of the evacuation as well as the need for longer lead times to configure roadways for its use.

Another limitation of contraflow is the lack of actual evacuation experience. Although widely planned, it had only been implemented twice, on a limited basis before the 2004 hurricane season. Because of this lack of use, field data and analysis are not available of the characteristics of contraflow evacuation traffic streams. Only a limited number of simulation studies have evaluated at its effect at local or system levels.

To better prepare DOTs and emergency management agencies for the use of contraflow, a series of research projects was recently undertaken. Among these were efforts to evaluate the characteristics of traffic operation within and near contraflow evacuation segments. This paper summarizes the results of two of these projects, focusing on the operational effects of the initiation point design of the New Orleans Louisiana I-10 segment and the termination designs planned for several Atlantic and Gulf Coast states.

## OBJECTIVES

This research was motivated by several factors. First, many contraflow evacuation segments have been developed by law enforcement rather than transportation agencies. While these agencies are trained to deal with a variety of emergency traffic situations, they are not trained in many key areas related to large-scale transportation planning, design, and management. Thus, the effectiveness of specific aspects of these plans has been questioned by some transportation professionals. Since evacuations are infrequent events, and the use of contraflow even rarer, many of their costs and benefits remain unknown. Perhaps most importantly, evacuations have the potential to more immediately and directly affect the lives and safety of hundreds of thousands of people than any other single transportation event and warrant the full attention of the wider transportation community.

The specific research objectives were developed to address issues of importance to emergency preparedness officials, including:

- the temporal and spatial patterns by which traffic congestion develops and abates along the segments, and
- the way in which varying levels of traffic demand impact the operational characteristics of contraflow segments.

The research effort was divided into two separate, but overlapping, projects. The first focused on issues associated with the contraflow entry area. The second focused on the vicinity of the termination where vehicles exited the segment. To limit the scope of the first project to a manageable size, the initiation point assessment focused specifically on the planned westbound Interstate 10 (I-10) contraflow evacuation segment out of New Orleans. The evaluation of termination points involved a multi-design study in which simulation models for six different types of design categories were developed. The 6"families" were created to represent the key characteristics of 13 terminations planned in 7 hurricane-threatened states. The output data from all of these various models were used to quantify the traffic conditions (i.e., queuing, delay, travel speed, travel time, and total number vehicles exiting the segments) in the vicinity of the termini and to compare the relative performance and benefits of the various the designs under different traffic demand scenarios.

The CORridor SIMulation (CORSIM) model was used to perform the research because it produces a wealth of detailed measures of effectiveness (MOE) and it is widely accepted within the transportation community. Unfortunately, CORSIM, like all traffic simulation programs, also has limitations. Most critically, it does not explicitly support the creation of reversible flow freeway segments or the behavioral characteristics of evacuation drivers.

For these and other reasons, many assumptions (discussed in a later section) were required to develop the models.

## SCOPE

The scope of this study was restricted by the amount of information currently available. Very few studies that have collected traffic flow parameters in detail during an evacuation. Consequently, the results gained here are based on simulation testing that could not be quantitatively validated against field data. Despite this fact, there is strong reason to believe that results are valid, particularly in light of the qualitative data that was collected during the evacuation for Hurricane Ivan in the fall of 2004.

## LITERATURE REVIEW

Contraflow operation on roadways is not a new concept. Many cities like Washington, D.C. and Boston have been using reverse lane operations to improve the outflow of traffic for decades. Contraflow operation has been used to accommodate morning peak periods when one or more outbound lanes are used for inbound traffic and during the evening peak periods when one or more lanes are used for outbound traffic. Contraflow operation is also used at the end of special events like concerts or football games to accommodate the outbound traffic.

Contraflow operation in case of an emergency evacuation is used very rarely. Some cities, such as Detroit, have plans for reverse laning in case of man-made calamity like nuclear reactor failure or the release of toxic gases *[1]*. Contraflow for hurricane evacuation was first used during Hurricane Floyd in 1999 to lessen the traffic congestion in Georgia and South Carolina.

However, the effectiveness of contraflow operation during emergency evacuation remains unknown. To overcome this lack of information, the use of computer simulation models has been suggested. Early simulation models were designed to anticipate traffic flow during normal conditions, but they could also be applied to model the traffic flow under emergency evacuations. Simulation models for emergency evacuation were initially developed to plan for civil defense emergencies, such as nuclear missile attacks, and more recently were applied to test operational strategies for hurricane evacuations. For the evacuation of New Orleans, these simulation models like CORSIM can help evaluate the contraflow traffic flow.

For a thorough evaluation of the contraflow operation in New Orleans, data entered into the simulation model must be as precise as possible. The initial data that had to be entered into the simulation model for New Orleans evacuation was the geometric layout of the contraflow segment. The geometric details for the initiation and termination points as well as the number of lanes and the contraflow operation during an evacuation of the City of New Orleans were described in the emergency evacuation plans of Louisiana State Police. For accurate coordinates and length of the contraflow segment, aerial photos were obtained with a Geographic Information System (GIS) and entered into the simulation model as bitmap images.

After the construction of the geometric layout into the model, the number of evacuating vehicles expected to use the contraflow segment under a major storm scenario was entered. The amount was determined using the demand estimation procedure included in the "Southeast Louisiana Hurricane Evacuation Study" prepared by the consulting firm Post, Buckley, Schuh, and Jernigan *[2]* based on the category of the hurricane. In addition, a human behavioral analysis was conducted by Baker *[3 and 4]* for human response during hurricane evacuation. These data helped to create the appropriate assumptions for the model, like the percentage of trucks from the total volume.

**Contraflow Operations**

Contraflow operation involves reversal of traffic flow of one or more inbound lanes for outbound traffic. Reverse laning has been used to reduce daily traffic congestion in many cities around the world. The Southeast Expressway (I-93) linking Boston and communities to the southeast of the city accommodates 200,000 vehicles each weekday. The expressway is an eight-lane highway and it is the second most heavily traveled highway in New England. Traffic on the expressway during peak travel times exceeds the capacity, causing serious delays. The Massachusetts Highway Department (MHD) improved the capacity of the expressway by establishing a six-mile long contraflow High Occupancy Vehicle (HOV) facility using the Quickchange Moveable Barrier (QMB). Before the morning rush, two computer-controlled transfer machines move 12 miles of concrete barrier 14 feet laterally to create an additional lane in the northbound direction. The process is reversed in the southbound direction for the evening rush, as shown in fFigure 1. Making more efficient use of the available roadway, contraflow reduced the congestion on the expressway saving up to 10 minutes during drivers commute *[5]*.

**Figure 1**
**SE Expressway on I-93**
**(Photo by Massachusetts Highway Department)**

In Hanover, Germany, the Traffic Control Center (TCC) uses a tidal flow system allowing contraflow traffic in a 12 km section of inner-urban motorway.  By joining three freeways, capacity can be raised from three to six lanes during peak hours.  The oncoming traffic is guided on to alternative parallel routes, and some of the on- and off-ramps on the freeway interchanges are also used in a contraflow manner, as shown in fFigure 2.  The tidal flow system is controlled in the TCC by two people and can switch to and from contraflow operation within 15 minutes *[6]*.


**Figure 2**
**A tidal flow operation on a urban German freeway**
*[6]*

Since contraflow operation can lessen traffic congestion during peak hours, it is now frequently used during special events such as football games or concerts.  In New Hampshire, contraflow operation is used twice a year to lessen congestion during Winston Cup NASCAR races at the New Hampshire International Speedway (NHIS).  Contraflow is also used in Baton Rouge, Louisiana, after Louisiana State University (LSU) football games to help in the egress of more than 90,000 people from the stadium.

However, there are significant differences between contraflow operation on urban arterial roadways and that on long sections of interstate freeways.  Contraflow operations occur on urban roadways during peak hours and special events, thus drivers get familiar with the location and operation.  On the other hand, contraflow operations for mass evacuation are very rare because hurricanes are not an everyday occurrence.  Additionally, accurately predicting how evacuees will react to a contraflow evacuation scenario is difficult; therefore, how effective a contraflow evacuation operation will be is still unknown.

Experiences in both Hurricane Floyd in 1999 and Hurricane Georges in 1998 *[7]*, have shown that hurricanes can result in tremendous traffic congestion. In 1999, Hurricane Floyd resulted in what is widely regarded to be the largest evacuation in U.S. history. Approximately three million people were evacuated from their homes. Hurricane Floyd mainly threatened the eastern coastline of the U.S. and was predicted to hit Florida, which led to major evacuations from Florida to Georgia. While heading north along the Florida coast, Floyd changed course, running parallel to the Atlantic coastline, threatening Georgia and South Carolina. It then turned north-northeast, making landfall near Cape Fear, North Carolina. Consequently, traffic from both Florida and Georgia contributed to massive traffic congestion on evacuation routes in South Carolina. As a result of the tremendous traffic congestion, Georgia and South Carolina initiated contraflow operation to lessen the congestion. Since Hurricane Floyd, eleven of the eighteen states threatened by hurricanes now plan to use some type of contraflow operations. These eleven states that plan to use contraflow operations include: Alabama, Delaware, Florida, Georgia, Louisiana, Maryland, New Jersey, North Carolina, South Carolina, Texas, and Virginia *[8]*.

Currently, there are several forms of contraflow operations for hurricane evacuations. Figure 3 illustrates several contraflow operation configurations for four-lane freeway segments.

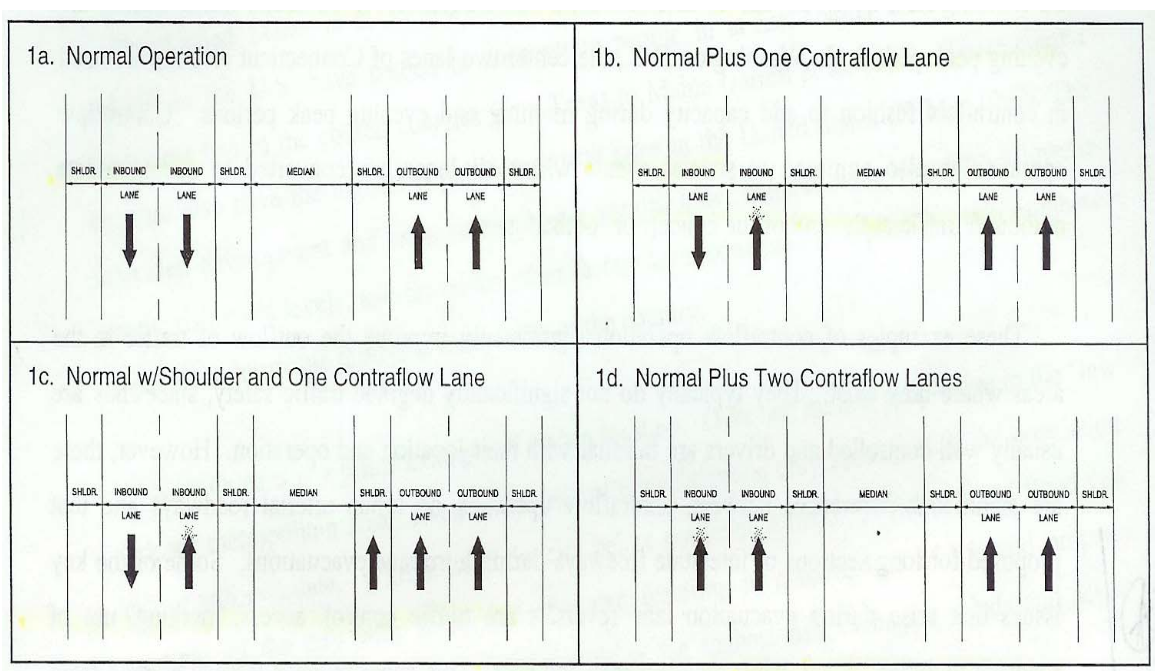


**Figure 3**
**Contraflow configurations of freeway lanes**
*[9]*

During Hurricane Floyd in 1999, the South Carolina Department of Transportation (SCDOT) analyzed traffic flow on segments of I-26 based on two permanent traffic count stations, under the four different contraflow configurations. During the normal operation as shown in 1a of fFigure 3, the estimated average outbound flow rate was 3,000 vehicles per hour. The flow rate for the normal plus one contraflow lane as shown in 1b of Figure 3 was 3,900 vehicles per hour. This represents an increase of approximately 30 percent. Two of the main reasons for the limited increase are believed to be driver unfamiliarity and uneasiness in driving in the reverse lane, with traffic in the adjacent lane continuing to travel inbound. The flow from the normal lanes and shoulder plus one contraflow lane as shown in1c of Figure 3 was 4,200 vehicles per hour. With the use of the shoulder, there was a gain of eight percent. The main reasons for this small increase are that the shoulders are narrower than the freeway lanes, are constructed with a thinner pavement and on bridges shoulder width can decrease. Lastly, for normal plus two contraflow lanes as shown in 1d of Figure 3, the flow rate was 5,000 vehicles per hour. This was a gain of 67 percent over a standard two-lane evacuation. With this type of operation no inbound vehicles are permitted on the freeway and the vehicles in the reverse lanes are prohibited from using the exits on the inbound lanes *[7]*.

Because the reverse of both inbound lanes of the freeway to the outbound direction offers the largest increase in capacity, officials in New Orleans plan to use this contraflow strategy on westbound I-10 out of the city during an evacuation. However, since major hurricanes threatening New Orleans are infrequent, no actual data of the traffic flow on the contraflow segment has been collected. Without this data it is not possible to evaluate the effectiveness of the contraflow operation. To address this problem, computer simulation models will be used in the research to estimate the traffic behavior on this segment.

**Computer Simulation Models For Evacuations**

Contraflow operations have not yet been used for the evacuation of the City of New Orleans. It is uncertain if the evacuation plans for the city would be successful during an actual hurricane. With the help of computer simulation models, estimates of traffic behavior, clearance time, average speed, and traffic congestion might be composed.

Simulation models were originally designed to analyze and resolve traffic problems in normal operation conditions, but they could also be applied under special conditions, such as emergency evacuations. Currently, traffic simulation models can be divided into two general classes: macroscopic and microscopic.

**Macroscopic**

Macroscopic models are based on the deterministic relationships between roadway and intersection characteristics with traffic flow. They consider the traffic flow to be composed of platoons of vehicles. Macroscopic models can be easily applied to test operational strategies for hurricane evacuations in large segments of roadways. One of the most recent macro-evacuation analysis tools is the Oak Ridge Evacuation Modeling System (OREMS). OREMS was developed to simulate traffic flow during various defense-oriented emergency evacuations. It can be used to estimate clearance time, identify traffic characteristics, and estimate the times necessary to develop evacuation plans and other information *[10]*. Another recent macro-level evacuation modeling and analysis system is Evacuation Travel Demand Forecasting System (ETDFS), which was developed for emergency evacuations. ETDFS was designed to allow emergency management officials to access the model on-line so that they could input the category of hurricane, expected evacuation participation rate, tourist occupancy, and destination percentages for affected counties. The output of the model includes the level of congestion on major highways and the tables of vehicle volumes that are expected to cross state lines by direction *[11]*. However, by using macroscopic simulation, the traffic flow acts like a platoon of vehicles. Macroscopic simulation models assume that all vehicles have the same driver characteristics and that they behave in the same way. These limitations affect the success of macroscopic simulation models.

### Microscopic

Microscopic models are based on car-following models, which simulate the movement of individual vehicles through a research-based evacuation plan. Microscopic models allow for a wide range of driver behaviors under various environmental conditions. They simulate individual vehicle behaviors based on the level of driver aggressiveness or other conditions. If the evacuation occurs during the night or during heavy rain, it will affect driver behavior. Drivers might be less aggressive and may drive slower. In addition to that, microscopic models are able to warn drivers of an upcoming incident through the use of appropriately placed warning sings. This will make drivers react as though they were in real situations. However, microscopic simulation models cannot account for the location, speed and direction of the drivers based on the range of aggressiveness. For example different positions of the least aggressive driver can have a considerable effect on the following drivers. Different positions of the least aggressive driver affect the level of congestion and frustration of the drivers that follow. Since it is impossible to know which element will be the critical factor for the accurate prediction of the system as a whole, it can be very difficult to build a microscopic model for complex spaces and large roads *[12]*.

Prior studies based on Texas Department of Public Safety *[13]* have shown that contraflow operations involve many traffic operation issues, including traffic control, reverse flow initiation, ramp operations, and reverse flow termination. To analyze these operations, especially in small road segments, the model should be microscopic. One of the most common microscopic simulation models is CORridor SIMulation (CORSIM). There are approximately 1,100 registered users of CORSIM worldwide (CORSIM’s manual). Among them is the Texas Department of Transportation (TxDOT), which has used CORSIM to analyze the reverse flow operations of I-37 in Corpus Christi, Texas.

Currently, the latest version of the simulation program is CORSIM 5.0, which is designed for the analysis of freeways and surface street networks. It is capable of simulating freeway lanes, ramps, surface streets, and traffic control. CORSIM is a stochastic simulation based on a link-node network model, and can be used to locate queuing problems, evaluate highway ramp operations, and estimate clearance time as well as delay time. CORSIM can handle networks of up to 500 nodes and 1000 links containing up to 20,000 vehicles at any one time (CORSIM's manual).

<u>CORSIM INPUT</u>: There are a variety of inputs or specifications that must be made, either directly or by default values provided in CORSIM. Inputs that must be made directly include the specification of the geometric layout of the network (e.g. distance between intersections, number of traffic lanes, and length of turn pockets). Also, CORSIM enables operators to choose a percentage of trucks from the total volume of vehicles, and the distribution of turning movements of vehicles for each period and node.

<u>CORSIM OUTPUT</u>: CORSIM 5.0 is included in the Traffic Software Integrated System (TSIS 5.0). The new version of TSIS provides TRAFVU, a graphic post-processor for CORSIM. TRAFVU includes the Graphical User Interface (GUI) that provides the ability to effectively manage traffic analysis projects and tools, as well as calibration and validation. The animation package (TRAFVU) enables operators to visualize the model and detect any problems and flaws. The size of the animation data file is limited to 4GB. The new versions of TSIS include TRAFED, which allows for the easy creation and editing of CORSIM traffic networks. TRAFED is able to import a bitmap image of a network to be used as a guide for laying out a network. The numerical outputs include throughput (the number of vehicles discharged on each link), average link travel time, link queue time (the sum over vehicles of the time, in minutes, during which the vehicle is stationary, or nearly so), link stop-time (sum over vehicles of stationary time), maximum queue length on each lane in the link over the simulation time, and link delays (simulated travel time minus free-flow travel time, summed over all vehicles discharging the link). Moreover, one hour of simulation takes about 40 seconds on a Pentium III-850 MHz PC (Validation of Micro models, 2001).

To conclude, even if CORSIM 5.0 seems to be a good way to evaluate the effectiveness of New Orleans contraflow segment, it is still a computer model. Simulation models cannot be effective without appropriate input data. If the data entered into the model is poor or wrong, then the output from the model will be inaccurate.

## Input Data

Input data for a simulation model is just as important as the foundation of a structure. Inaccuracy on the construction of the foundations can lead to structure failure. The same idea is share with the input data. Poor input data will lead to incorrect results from the simulation model.

In this research, the geometric layout of the contraflow segment that was provided by Louisiana State Police was coded into the model. Moreover, aerial photos were used to provide accurate coordinates of the contraflow segment. After the construction of the geometric layout into the model, the number of evacuating vehicles that will use the contraflow segment must be inserted into the model. In 2001, the consulting firm PBS&J estimated the amount of evacuees based on the category of the hurricane and tourist occupancy. Lastly and most important, since nobody knows how evacuees will react during an evacuation, previous studies based on human behavior, give an overall idea of human reactions during emergency evacuations.

### Orleans Parish Evacuation Plan on I-10

The Louisiana Department of Transportation (LADOT) along with the Louisiana State Police- TROOP “B” have formulated an emergency evacuation plan for the parishes of Plaquemine, St. Bernard, St. Charles, St. John, Jefferson, and Orleans in the event of a hurricane *[14]*.

During an evacuation of the city of New Orleans, contraflow operations will be used. Before a contraflow operation can be implemented, traffic going on I-10 Eastbound must be stopped. This will be done by applying the following procedures, evaluated by Louisiana State Police-TROOP “B”:

- I-10 East will be closed at Exit 187 and East traffic will be diverted to US 61 South through Exit 187. Moreover, the entrance ramp from US 61 to I-10 East will be closed and traffic may continue on US 61.
- Entrance ramp from LA 641 to I-10 East, Gramercy/Lutcher, will be closed and diverted to I-10 West or US 61.
- Entrance ramp from LA 3188 to I-10 East, LaPlace, will be closed and diverted to I-10 West or back to US 61.
- Entrance ramp from US 51 to I-10 East, LaPlace, will be closed and diverted to I-55 North or back to US 61.
- Entrance ramp from US 51 to I-10 West, LaPlace, will be closed and diverted to I-55 North or back to US 61.

- I-55 will be closed at Exit 1 LaPlace, and traffic will be diverted to US 51 South through the Exit 1.
- I-310 North will be closed at Exit 2 US Norco/Kenner, and traffic will be diverted to US 61 North/South. Moreover, the entrance ramp from US 61 North to I-310 will be limited to I-310 South traffic only. Entrance ramp from US 61 North to I-310 North will be closed.
- Entrance ramp from US 61 South to I-310 will be limited to I-310 South traffic only. Furthermore, entrance ramp from US 61 South to I-310 North will be closed. US 61 North traffic will continue north and may enter I-55 North from US 51, or I-10 West from LA 3188 or LA 641.

Once the traffic on I-10 East has been completely cut off, it will be necessary to initiate the movement of traffic onto the empty I-10 East travel way. To accomplish this, traffic will be split on the west side of Loyola Avenue in Kenner. The left and center lanes of I-10 West will be diverted at the median crossover and channeled to the I-10 East travel way using the following procedures established by Louisiana State Police (LSP):

At the Kenner Crossover, just west of Loyola Avenue, the left and center lanes of I-10 West will be split from I-10 West and will then be diverted through the Kenner Crossover to continue westbound on I-10 East. At the LaPlace Crossover, just west of US 51, the westbound contraflow traffic will be diverted and channeled back to I-10 West for travel to Baton Rouge and beyond. Additionally, the following entrance ramps will be blocked to prevent "wrong way" exiting: I-10 East from I-310 North, I-10 East from I-55 South, I-10 east from US 51, and I-55 North from US 51 (Appendix-7).

The remaining westbound traffic in the vicinity of Loyola Avenue, which is the right lane of I-10 West and entrance ramp from Loyola Avenue, will be allowed to continue on I-10 West. I-10 West traffic will be diverted to I-55 North for travel to Hammond, Baton Rouge, and beyond (Appendix-4).

**Aerial Photos**

In this research, aerial photos were used to provide accurate coordinates of the contraflow plan that was conducted by LSP. These aerial photos were obtained with the use of Geographic Information System (GIS). GIS is a computer system capable of assembling, storing, manipulating, and displaying geographically referenced information. Maps and other data stored as layers of information in a GIS enable it to perform complex analyses.

Using the "ATLAS" Web site provided by LSU (www.atlas.lsu.edu), aerial photos can be downloaded. Atlas is the Louisiana Statewide GIS and it can provide GIS and mapping data on the state of Louisiana. Aerial photos for the contraflow segment could be downloaded using Digital Orthophoto Quarter Quadrangles (DOQQ) images. These images were from color-infrared photography. Each downloadable archive contains an MrSID compressed image file, an MrSID world file, and several files with metadata in different formats. These MrSID files are georeferenced, to fit on the earth's surface which allows to measure distances and positions using GIS software. With GIS software, one can measure distances along features such as roads and buildings on the photographs.

These aerial photos are color photographs of a section of Louisiana taken from an airplane. Each photograph covers an area that is approximately four miles by four and a half miles. The photographs are detailed in that each pixel or block of light on the photograph represents one meter or about three feet square on the ground.

**Number of Evacuees**

The New Orleans District of the U.S. Army Corps of Engineers recognized the urgency of giving to the emergency management community some transportation guidance concerning the evacuation of the city. Therefore, they hired PBS&J to produce a transportation model tool that reflects previously developed evacuation zones and behavioral parameters, to provide a quick means of estimating what traffic levels might flow out of the region for various storm threats. This model provides socioeconomic and behavioral data, vehicle statistics, number of evacuees, and route utilization of evacuees from each parish. The model also provides the amount of evacuating vehicles by critical roadway segment. The exiting roadway segments are provided with their evacuating vehicle volume by storm category and tourist occupancy as shown in Figure 4.

SE LOUISIANA STUDY AREA
EVACUATING VEHICLES BY CRITICAL ROADWAY SEGMENT
Southeast Louisiana Hurricane Evacuation Study 2000

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

**Figure 4**
**Evacuation traffic volume by storm strength and route**

### Human Behavior

Hurricane evacuation behavior is an area that has interested researchers since the mid-1950s *[3]*. According to Baker, researchers have conducted sample surveys following hurricanes from 1961 in almost every state from Massachusetts to Texas. Recent evacuation surveys and behavior analyses have provided useful information on evacuation departure time. In 2000, the U.S. Army Corps of Engineers proposed three different response curves, for slow, medium, and rapid responses respectively, based on behavioral analysis of past storms as shown in Figure 5. When the evacuation order is issued, time point 0 in the below figure, a value of 10 percent evacuate. This 10 percent is the portion of the population who elected to evacuate before the order.

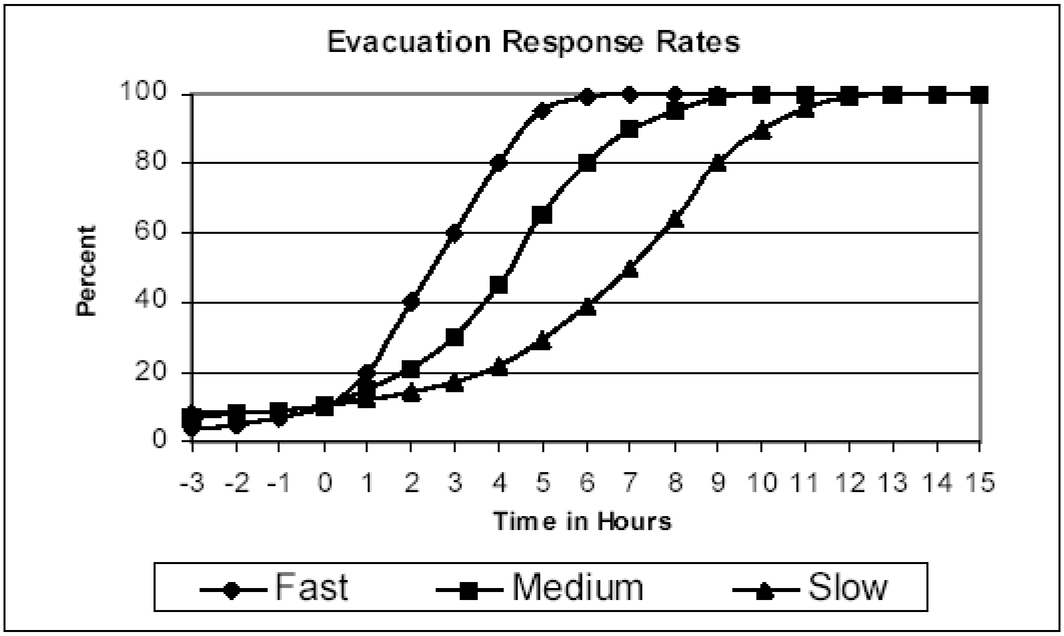


**Figure 5**
**Behavioral response curves**
*[15]*

It is generally believed that the evacuees have a tendency to fill their vehicles with pets, personal belongings, and often pull heavy trailers with them. These factors will probably make evacuees drive slower and may decrease the flow of the contraflow segment. In addition, based on behavioral analysis, the evacuees would want to stay on the normal path. They do not want to drive on the reverse lanes because markings and signs are on the opposite direction and they are not familiar with that route. TxDOT built a model for the reversal of I-37 from Corpus Christi to San Antonio and they assumed that 60 percent of the traffic demand entering the reversal entry point area on I-37 would continue on the normal flow lanes *[13]*.

Figure 6 shows the contraflow termination point plans reviewed in this study. After reviewing the available designs, contraflow traffic on the inbound lanes can either be diverted to secondary routes using reversed on-ramps or redirected to normal outbound lanes using median crossovers to terminate the contraflow traffic.

Figure 7 shows a typical design of median crossover at the contraflow termination point designs. Typically, paved median crossovers are constructed to split and direct the contraflow traffic across from and back to the normal outbound lanes. During normal traffic operation, barriers are placed at the median crossover to prohibit vehicles from using it. Crossover designs at interchanges involving multiple freeways are likely to be more complex because the reversed use of several inbound-lane on-ramps may be required to serve as contraflow off-ramp exits.

| State | Route(s) | Contraflow Termination Type |
|---|---|---|
| **Virginia** | I-64 | Median Crossover |
| **North Carolina** | I-40 | Reversed On-Ramp |
| **Georgia** | I-16 | Median Crossover |
| **Florida** | I-10 Westbound<br>I-10 Eastbound<br>I-4<br>I-75 Southbound<br>I-75 Northbound<br>FL Turnpike | Reversed On-Ramp<br>Reversed On-Ramp<br>Median Crossover<br>Median Crossover<br>Reversed On-Ramp<br>Median Crossover |
| **Alabama** | I-65 | Median Crossover |
| **Louisiana** | I-10 Westbound<br>I-10/I-59 (east/north) | Median Crossover<br>Median Crossover |
| **Texas** | I-37 | Reversed On-Ramp |

**Figure 6**
**Review of contraflow termination point designs**

The location and configuration of a termination point is usually determined in a way that merging congestion can be minimized *[9]*. The method applied to a shorter segment is to split the traffic flow permanently. This design diverts one traffic stream onto a separate roadway, while the other continues travel on the original route. Another method applied to a longer segment is the attrition-merge. These designs normally allow vehicles to exit to the secondary routes along the contraflow segments. Through a process of exit attrition, it is assumed that traffic would be reduced at the end of the contraflow segment that would allow a merging of the traffic streams without causing merging congestion *[16]*.

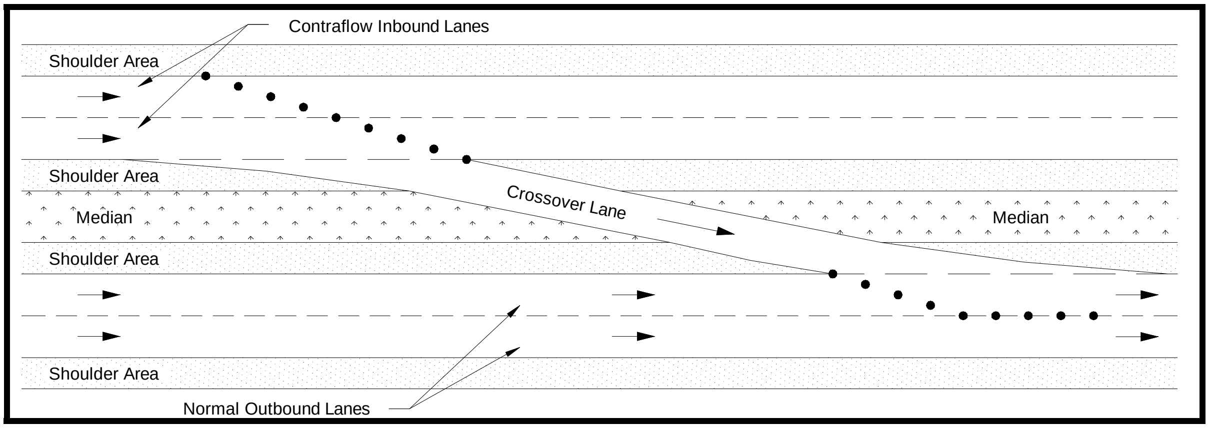


**Figure 7**
**Typical median crossover at an evacuation contraflow termination**

## Contraflow Termination Points with Median Crossover

Figure 8 shows six schematic contraflow termination designs that use a median crossover to redirect the contraflow traffic at its terminations, named in the order of Type A, B, C, D, E, and F model, respectively.

The Type A model is the design planned for the I-10/I-55 interchange in Louisiana (LSP, 2000), I-4 at SR 417 interchange in Florida (FDOT, 2000c), and I-64/I-295 interchange in Virginia (VDOT, 2001). Figures 9, 10, and 11 show detailed plan for each state. The first two plans use police enforcement units at the termination points and closed exit-ramps. All traffic moving in the normal outbound lanes will be forced to exit using the two-lane off-ramp at the interchange. After the interchange, the contraflow traffic in the inbound lanes will cross back into the normal outbound lanes using two-lane median crossover. This configuration is assumed to have less traffic congestion because it does not necessitate a merging point at its termination.

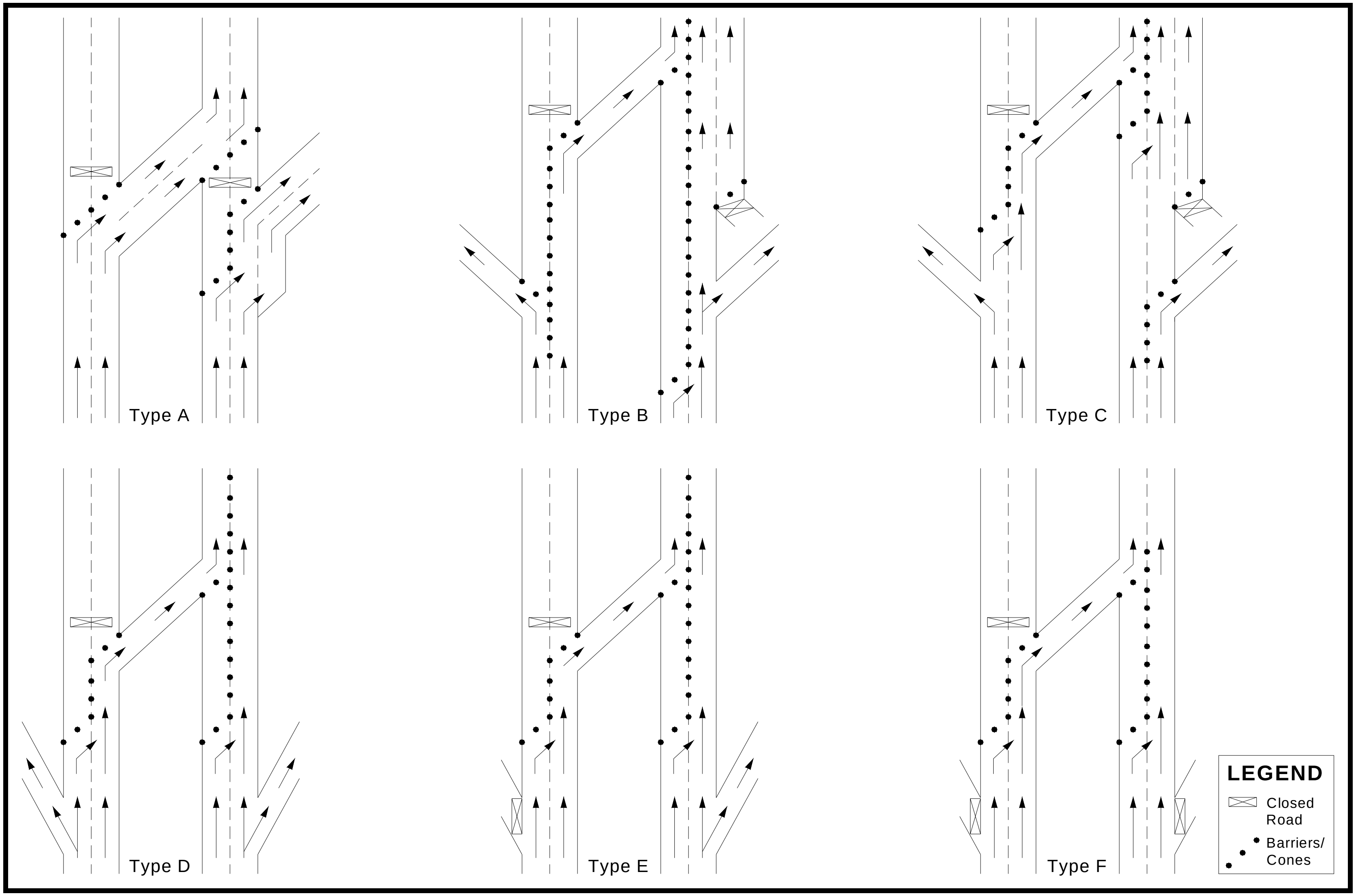


**Figure 8**
**Schematic termination point designs**

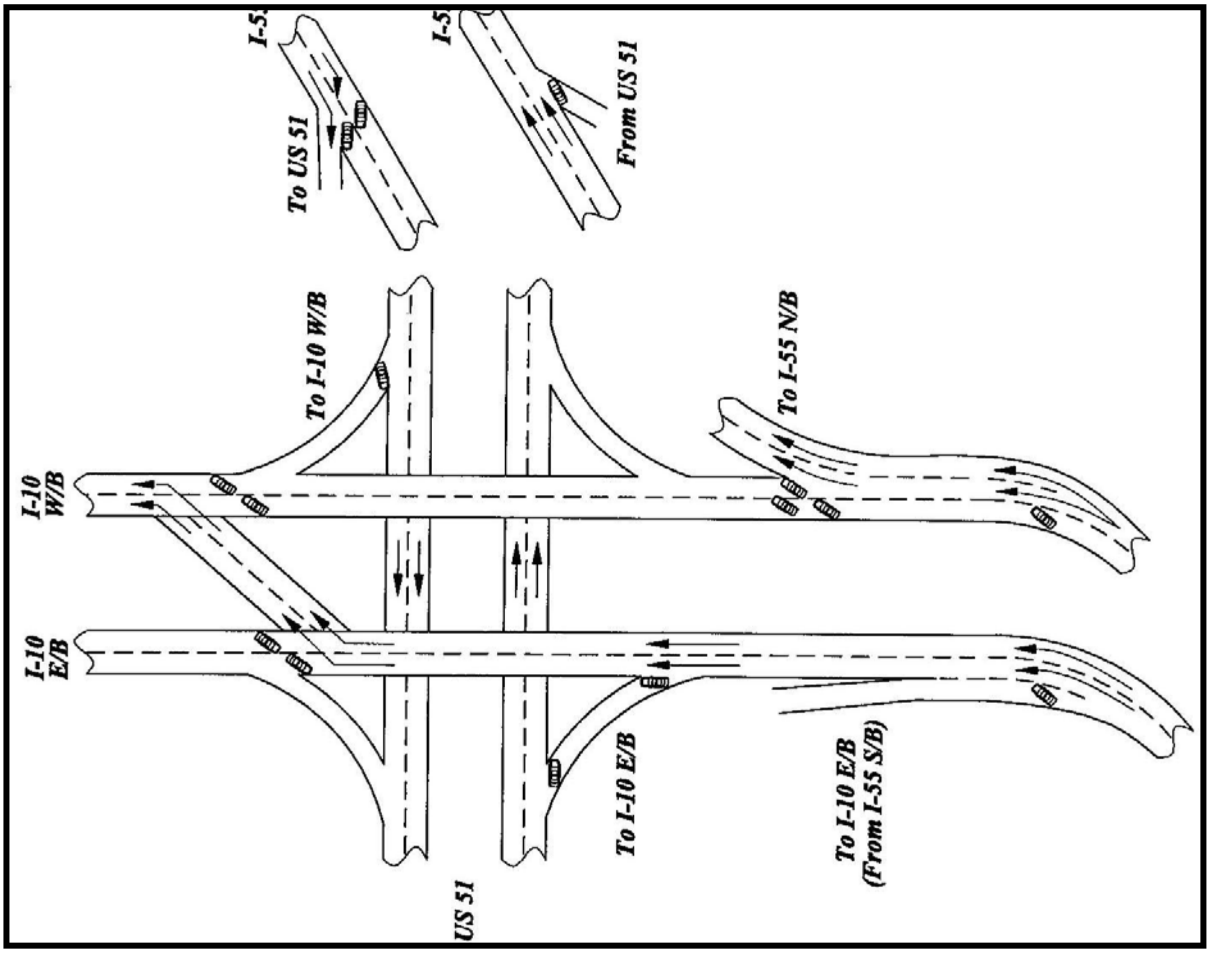


**Figure 9**
**Louisiana I-10/I-55 contraflow termination location**
**(Source: Louisiana State Police)**

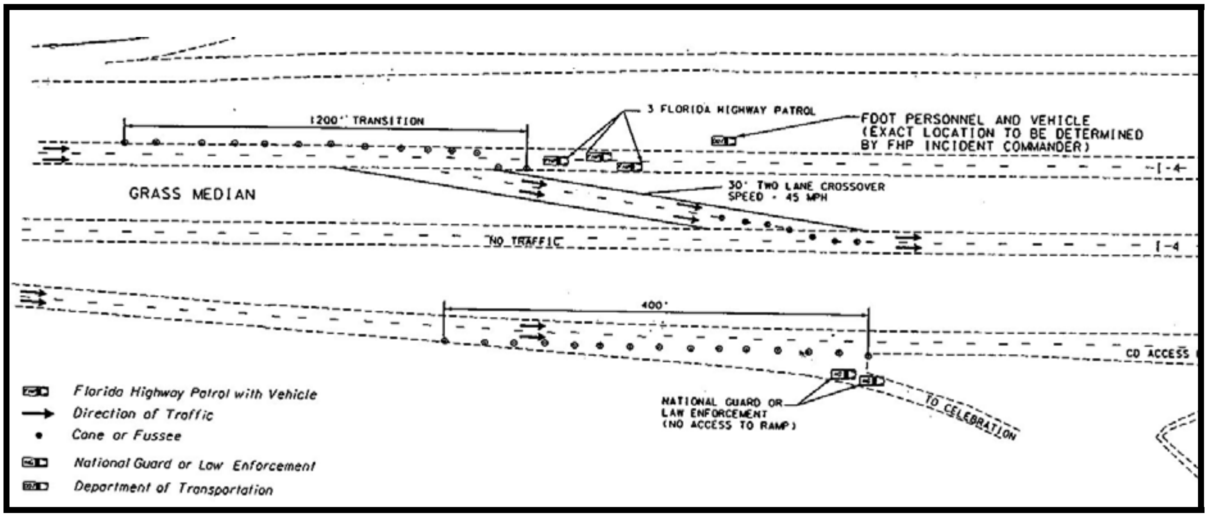


**Figure 10**
**Florida I-4 eastbound contraflow termination location**
**(Source: Florida Department of Transportation)**

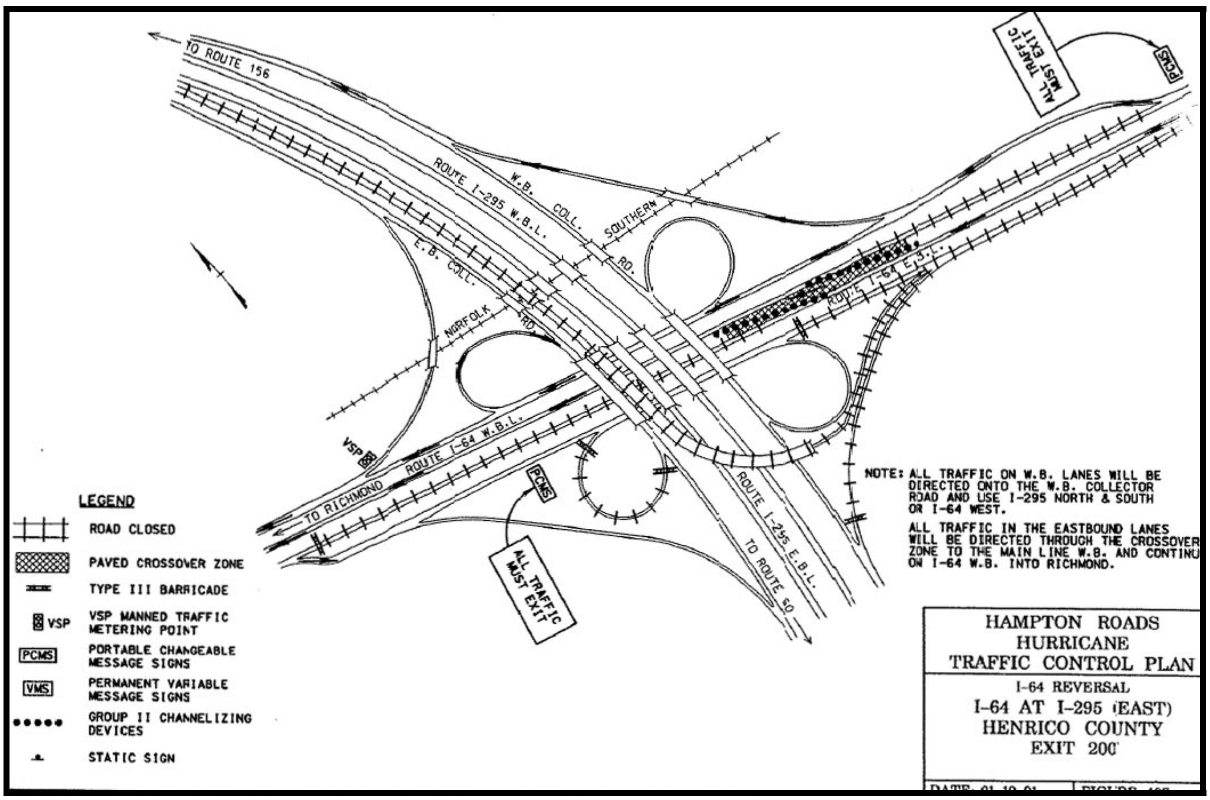


**Figure 11**
**Virginia I-64/I-295 westbound contraflow termination location**
**(Source: Virginia Department of Transportation)**

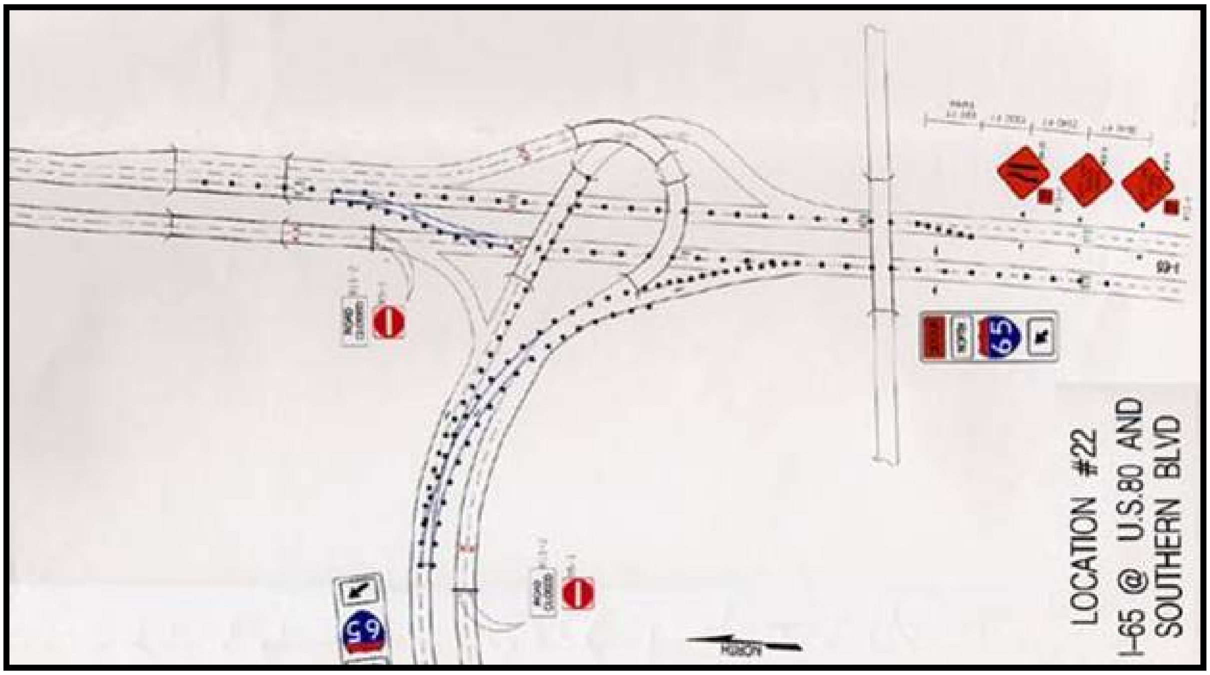


**Figure 12**
**Alabama I-65 contraflow termination location**
**(Source: Alabama Department of Transportation)**

The Type B model is the design planned for the I-65/US80 interchange in Alabama *[17 and 18]*. As shown in figure 12, traffic control devices such as lane reduction signs and left-lane-closed signs will be placed to advise a driver to merge from two lanes to one lane. Lane reduction signs are placed 1,500 feet in advance of the taper and the left-lane-closed signs are located 1 mile in advance of the lane reduction signs. All traffic moving in the two normal outbound lanes will be merged into one lane and allowed to continue outbound or to exit using the off-ramp at the interchange. One lane of the contraflow traffic in the inbound lanes will be forced to exit with the reversed on-ramp at the interchange. The other lane of contraflow traffic will be forced to merge back into normal outbound lanes using one-lane median crossover after the interchange.

Figure 13 shows the Florida I-75 Southbound contraflow termination plan. The right lane traffic in normal outbound lane will be forced to exit with the off-ramp at the interchange, and the left-lane traffic in the normal outbound lane will continue to travel. On the other side of the freeway, the contraflow traffic in inbound lanes is allowed to exit with the reversed on-ramp at the interchange. After passing the interchange, the two-lane contraflow traffic will be merged into one-lane contraflow and redirected back into normal outbound lanes using a one-lane median crossover. As shown in the plan, a Florida highway trooper was required at the lane-drop area. This model has three normal outbound lanes available at the median crossover to accommodate the merging contraflow and normal traffic flow.

The Type D model is the design planned for the Florida Turnpike freeway in Florida *[19]*. Figure 14 shows the detailed design at the lane-drop area for the Florida Turnpike contraflow termination location. Traffic on the normal and contraflow flow directions is allowed to exit with using the off-ramp and reversed on-ramp. Lane reduction sign and left lane closed sign will be placed in advance to advise drivers of merging from two lanes to one lane conditions on the inbound and outbound directions. After passing the interchange, the two-lane contraflow traffic on the contraflow inbound lanes will be merged into one-lane contraflow and redirected back into normal outbound lanes using one-lane median crossover. The two-lane normal outbound flow traffic will be merged into one-lane traffic to accommodate the redirected contraflow traffic after the median crossover. This model initiates two lane-drop areas on contraflow and normal flow directions.

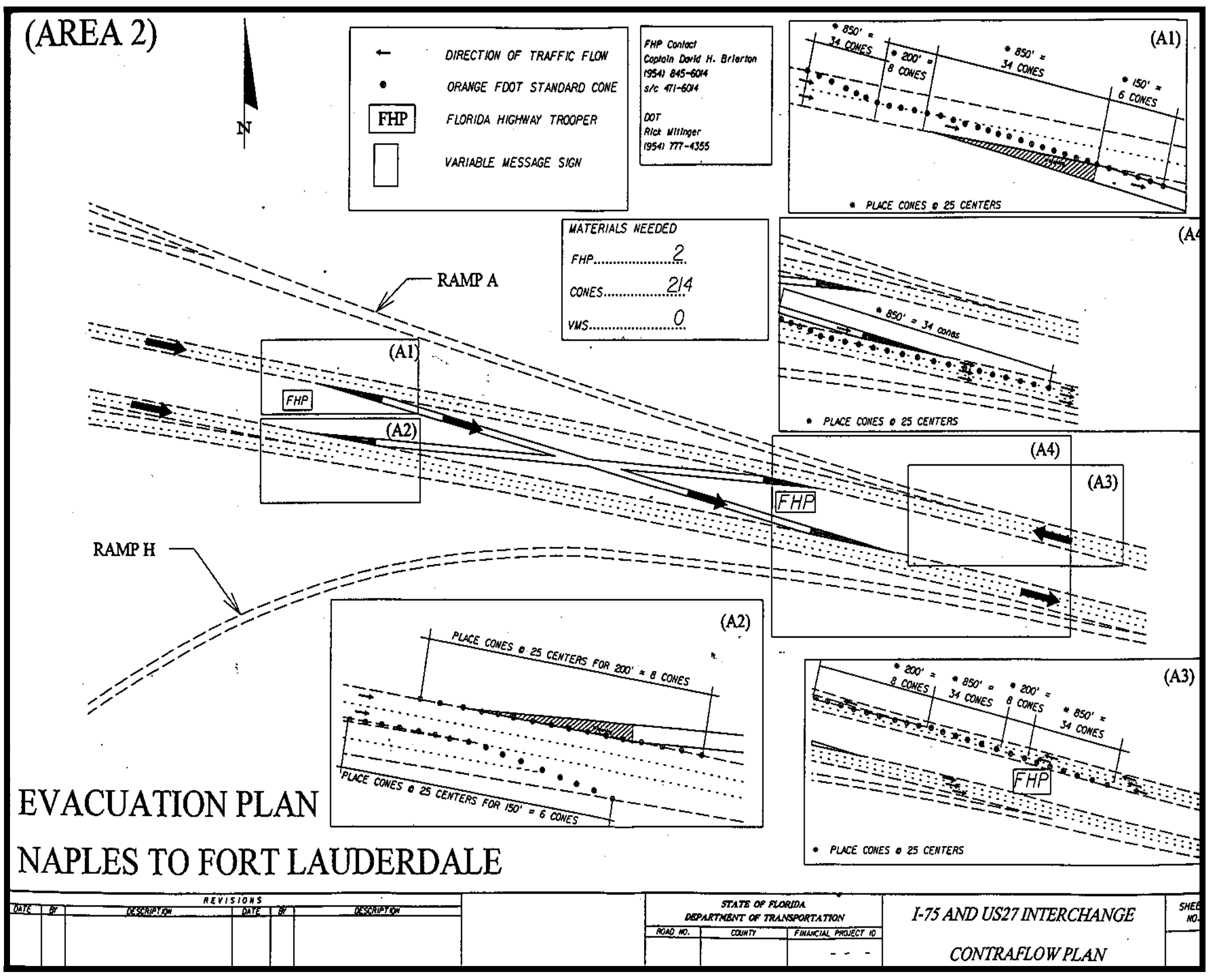


**Figure 13**
**Florida I-75 southbound contraflow termination plan**
**(Source: Florida Department of Transportation)**

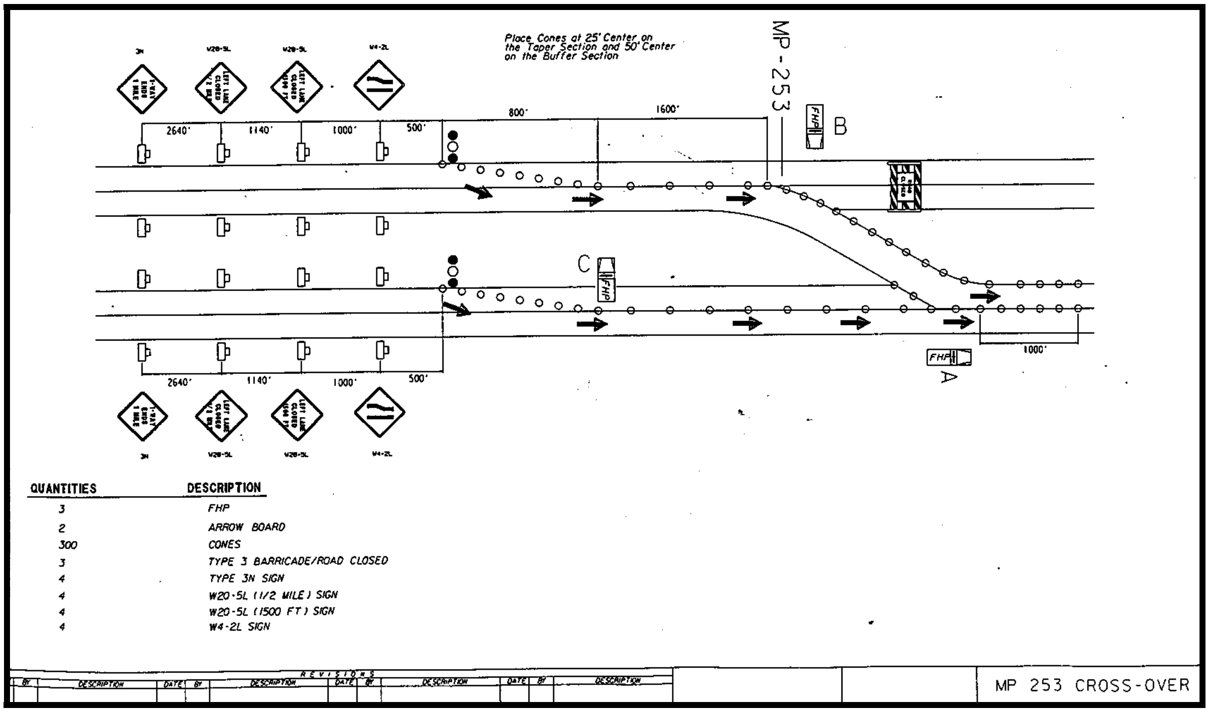

**Figure 14**
**Florida Turnpike contraflow termination location**
**(Source: Florida Department of Transportation)**

The Type E model is the design planned for the I-16/US441(SR31) interchange in Georgia *[20]* and at I-59/MS589 interchange in Louisiana and Mississippi border *[14]*. Figure 15 and Figure 16 show the detailed plans for Georgia I-16/US441 and Louisiana I-59/MS-589 contraflow terminations. Traffic moving in normal outbound lanes can exit with the exit ramp at the interchange. However, contraflow traffic in inbound lanes is not allowed to exit at the interchange and will be forced to merge back into normal outbound lanes using a one-lane median crossover after the interchange. This configuration is assumed to have more traffic congestion on the contraflow inbound lanes than previous models.

The Type F model is a hypothetical design. In this study, it is assumed no exit ramp or reversed on-ramp is available along the contraflow segment. Traffic moving in normal outbound lanes and reversed inbound lanes is not allowed to exit at the interchange. The only way to end the contraflow is forcing the contraflow traffic in inbound lanes to merge back into normal outbound lanes using a one-lane median crossover. This configuration is assumed to have the highest traffic congestion because four lanes of traffic will be merged into two lanes, and it necessitates two merging points at its termination. The Type F model will be the worst design and serve as a basis for comparison for the other designs.

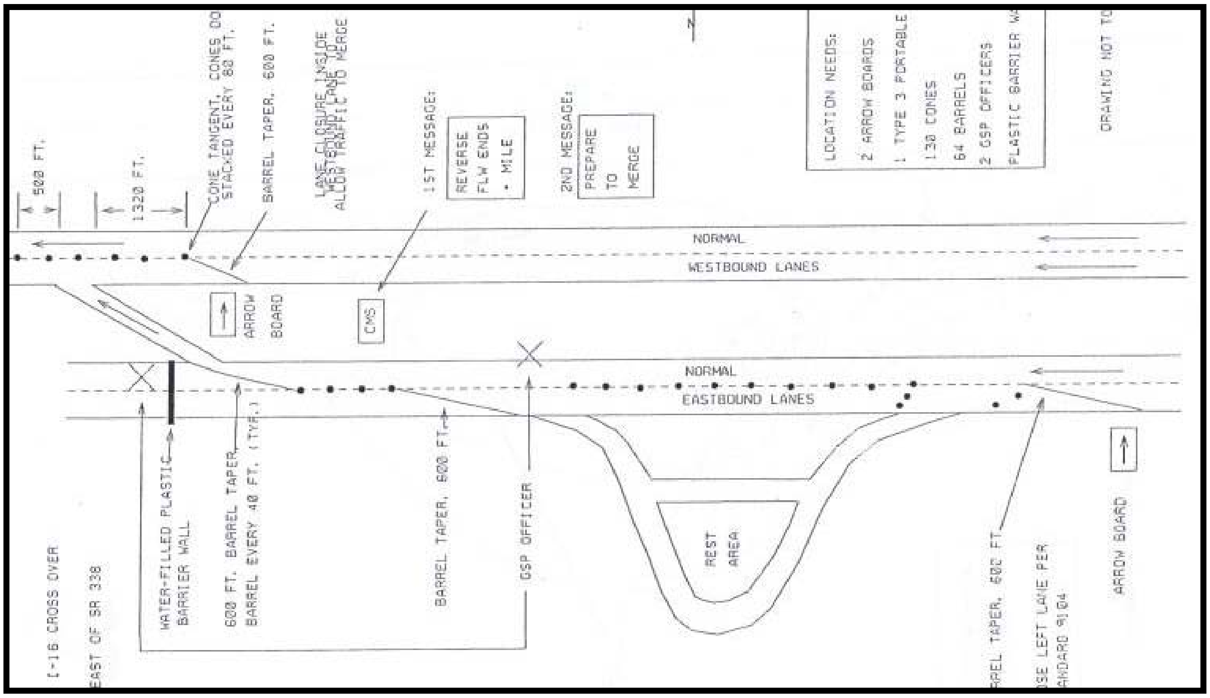


**Figure 15**
**Georgia I-16/US441(SR31) westbound contraflow termination location**
**(Source: Georgia Department of Transportation)**

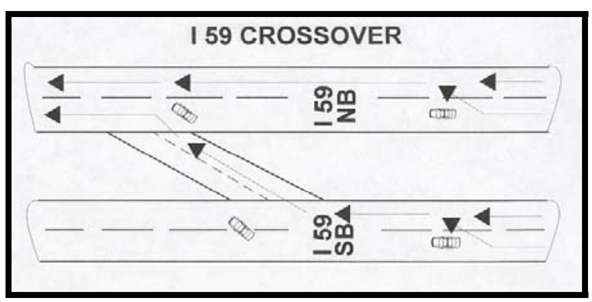


**Figure 16**
**Louisiana I-59/MS-589 contraflow termination location**
**(Source: Louisiana State Police)**

## Contraflow Termination Points without Median Crossover

Figure 17, Figure 18, and Figure 19 show the North Carolina I-40 contraflow termination location, Florida I-10 Eastbound contraflow termination location, and Florida I-75 Northbound contraflow termination location, respectively [*21*, *22*, and *23*]. These three contraflow termination locations did not use median crossover to redirect the contraflow traffic on the inbound direction. However, these locations planned to use the existing inbound on-ramp as a reversed on-ramp (exit-ramp) to divert the contraflow traffic to secondary routes.

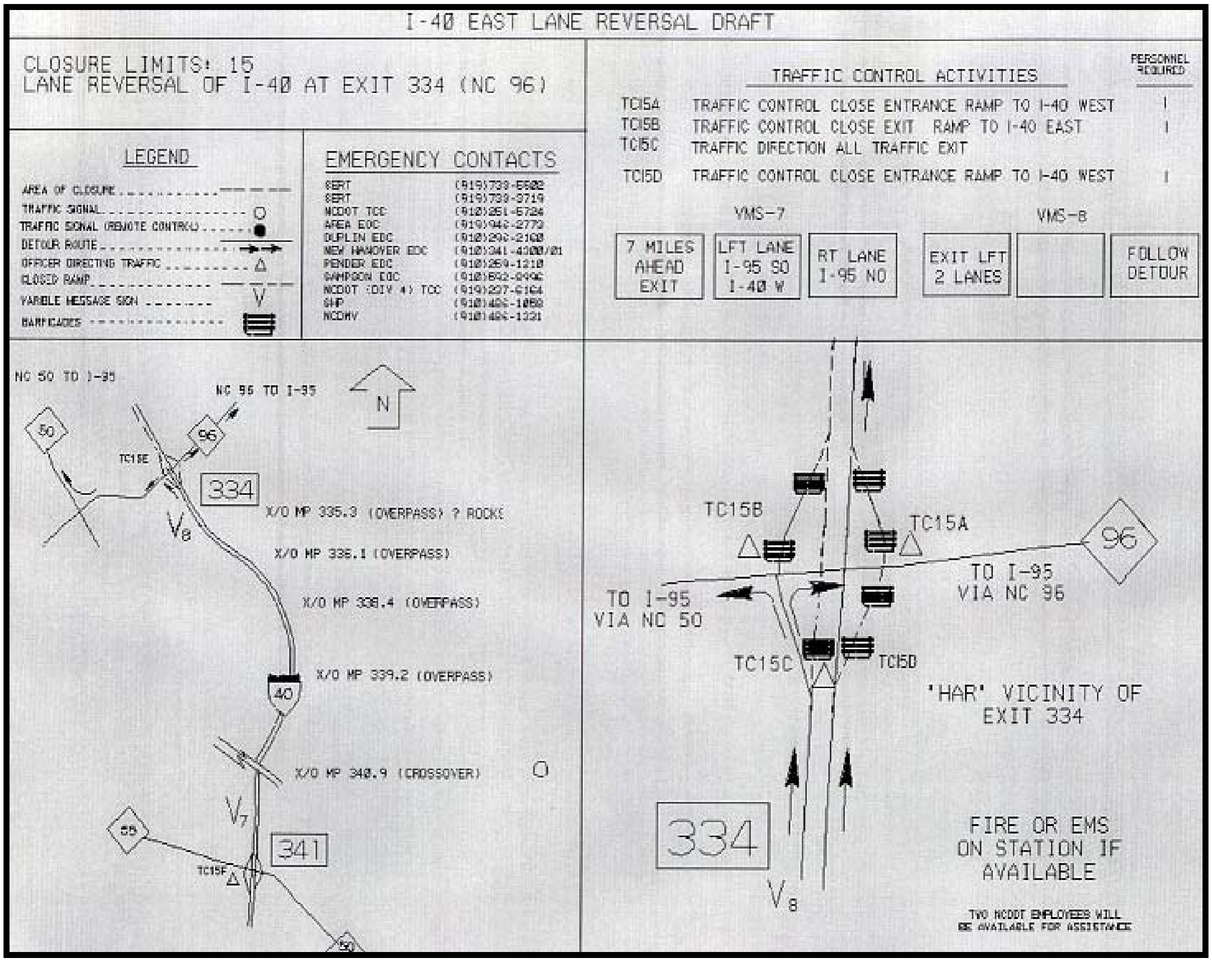


**Figure 17**
**North Carolina I-40 contraflow termination location**
**(Source: North Carolina Department of Transportation)**

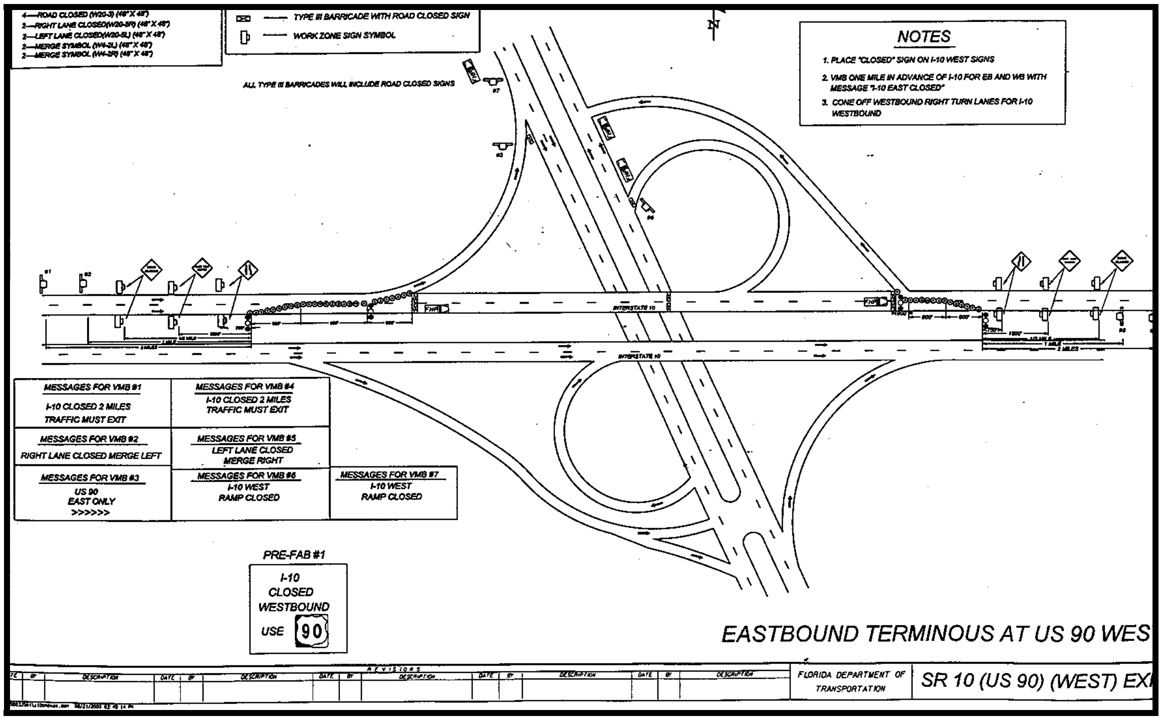


**Figure 18**
**Florida I-10 eastbound contraflow termination location**
**(Source: Florida Department of Transportation)**

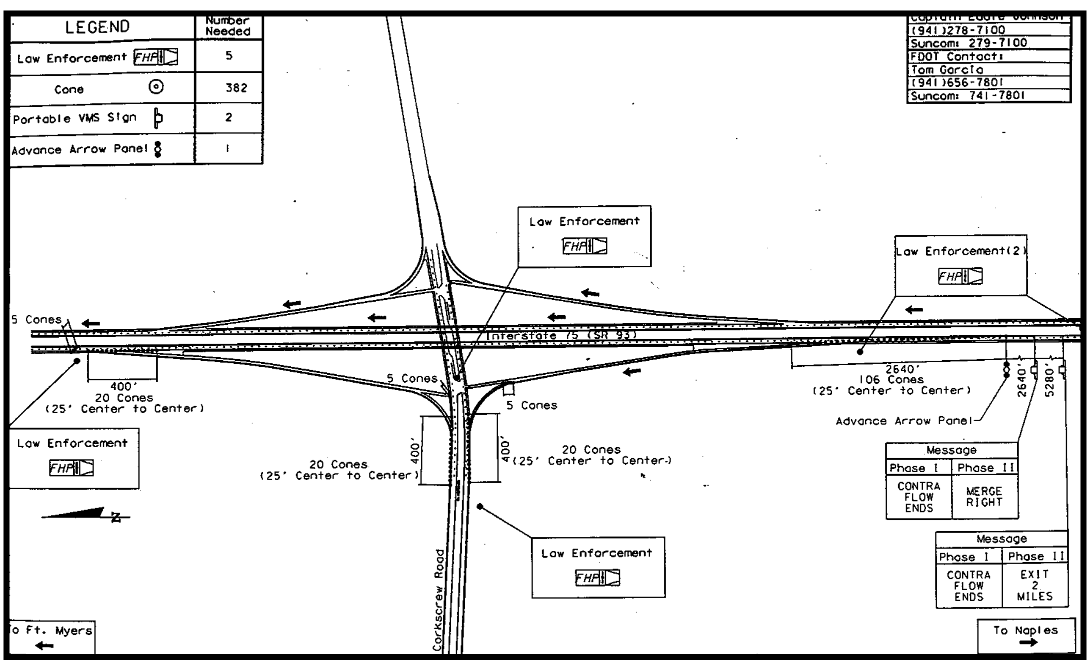


**Figure 19**
**Florida I-75 northbound contraflow termination location**
**(Source: North Carolina Department of Transportation)**

**Single-Lane Closure Traffic Flow Characteristics**

When traffic on the contraflow inbound lanes approaches the termination point, single-lane (one-lane) closure operation is generally used to merge the traffic from two lanes to one lane before using the median crossover. This method can also be used on the normal outbound lanes to reserve one-lane for accommodating the diverted contraflow traffic to continue traveling on the normal outbound direction.

The traffic control plan most commonly used to advise drivers of lane closures is to place LANE CLOSED signs beside the roadway at 1 mile and ½ mile in advance of the taper. In addition, portable changeable message signs, VMS, illuminated flashing or sequential amber arrow signs, barrels, cones, or barricades will be setup along the termination points. Police enforcement officers and DOT personnel may be available onsite to direct the traffic in some termination point plans.

Single-lane closure operation is similar to lane closures at work zone areas where one lane is normally closed to provide workspace purpose. When the traffic demand exceeds the capacity of the lane closure area, congestion problems, merging problems, and queues may occur before the single-lane closure. A study of traffic flow characteristics of the late merge work zone control strategy *[24]* stated the following problems connected with congestion in advance of lane closures:

- Higher rear-end accident potential associated with the congestion,
- Difficulty drivers have in knowing which lane is closed when stopped queues extend upstream past the advance warning signs,
- Frustration experienced by drivers in the open lane who are passed by drivers remaining in the closed lane and merge into the open lane ahead of them, and
- Frustrated drivers in the closed lane who are blocked by slower vehicles straddling the two lanes and preventing them from passing and merging into the open lane ahead.

The same study stated that a sharp decrease in speed can be observed during congested periods when the volume exceeds and stays consistently above the suggested capacity of approximately 1,400 passenger cars per hour (pcph) at the work zone area. Three main types of traffic conflicts observed from the study were forced merges, lane straddles, and lane blocking. The study stated that each traffic conflict increased with density as expected. When the densities were below approximately 20 passenger cars per mile (pcpm), neither of these traffic conflicts occurred. Additionally, the study anticipated that at an average speed of 50 miles per hour (mph), none of these three conflicts will occur if the volume does not exceed 1,000 pcph.

# METHODOLOGY

Based on the literature review and an examination of prior contraflow evacuation simulation models, a methodology was developed to estimate traffic flow, average speed, density, delay time, and amount of time required to discharge the contraflow segment on westbound I-10 out of New Orleans during an evacuation. Since the contraflow operation covers a small area, it was suggested to use microscopic simulations to evaluate the effectiveness of the segment. In this study, CORSIM 5.0 microscopic simulation model was used to achieve the research objectives.

This chapter describes the steps that were taken to achieve the objectives of this study. Data were collected for the construction of the model, and the appropriate adjustments were made so that the contraflow model would simulate conditions in the proposed contraflow evacuation plan in New Orleans.

## Network Construction

In order to construct the CORSIM network model, several pieces of information were needed. This information included aerial photos and evacuation plans. Assumptions were also made based on prior behavioral studies and traffic analyses of contraflow and major events.

### Aerial Photos

To construct the model, a number of aerial photos of the contraflow segment were obtained using the Geographic Information System (GIS) and inserted as bitmap images into TRAFED. These bitmap images were sufficient to be used as a guide for laying out the link node diagram, as shown in Figure 20. In this figure, the red line represents the contraflow segment and the circles show the I-10/I-55 and I-10/I-310 interchanges.

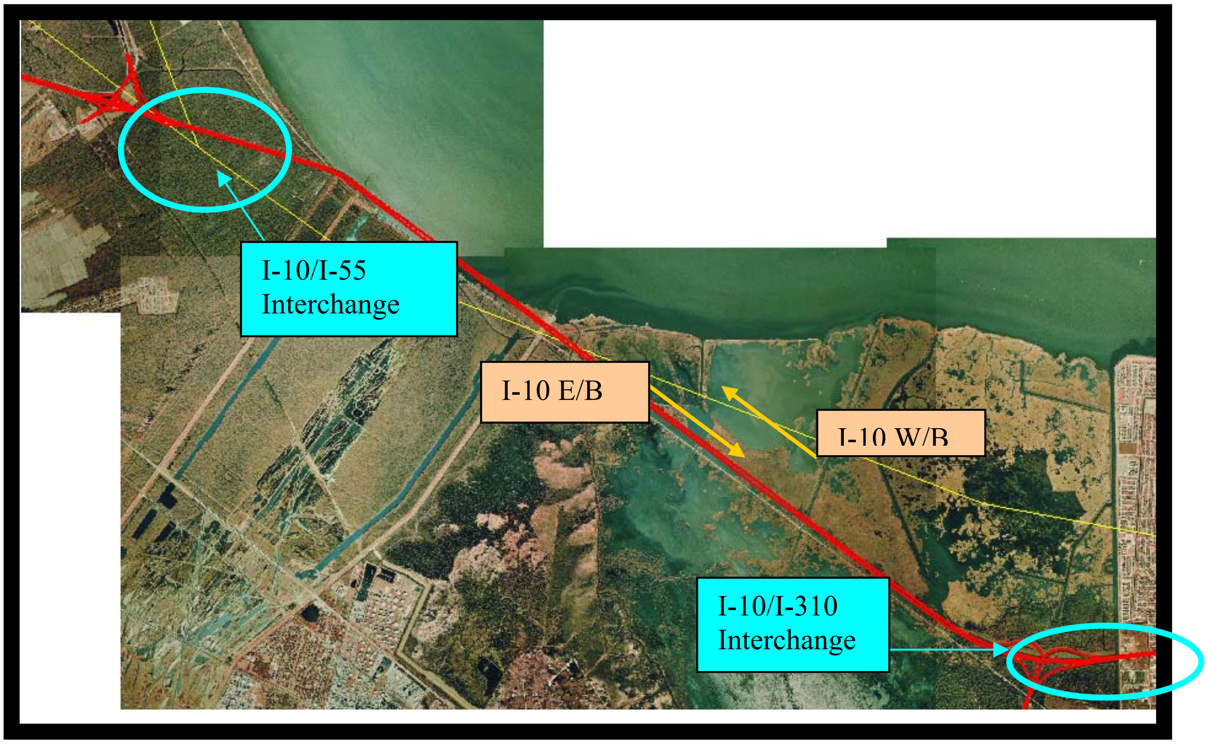


**Figure 20**
**Aerial photo of the contraflow segment**

However, Figure 20 did not provide sufficient details for the interchanges of the segment. To address this problem, three aerial photos of one meter resolution were used for the construction of the model. The first photo was of Loyola Avenue Interchange, east of the Kenner crossover, as shown in Figure 21. The second was of the I-10/I-310 interchange, as shown in Figure 22, and the third was of the I-10/I-55 interchange as shown in Figure 23.

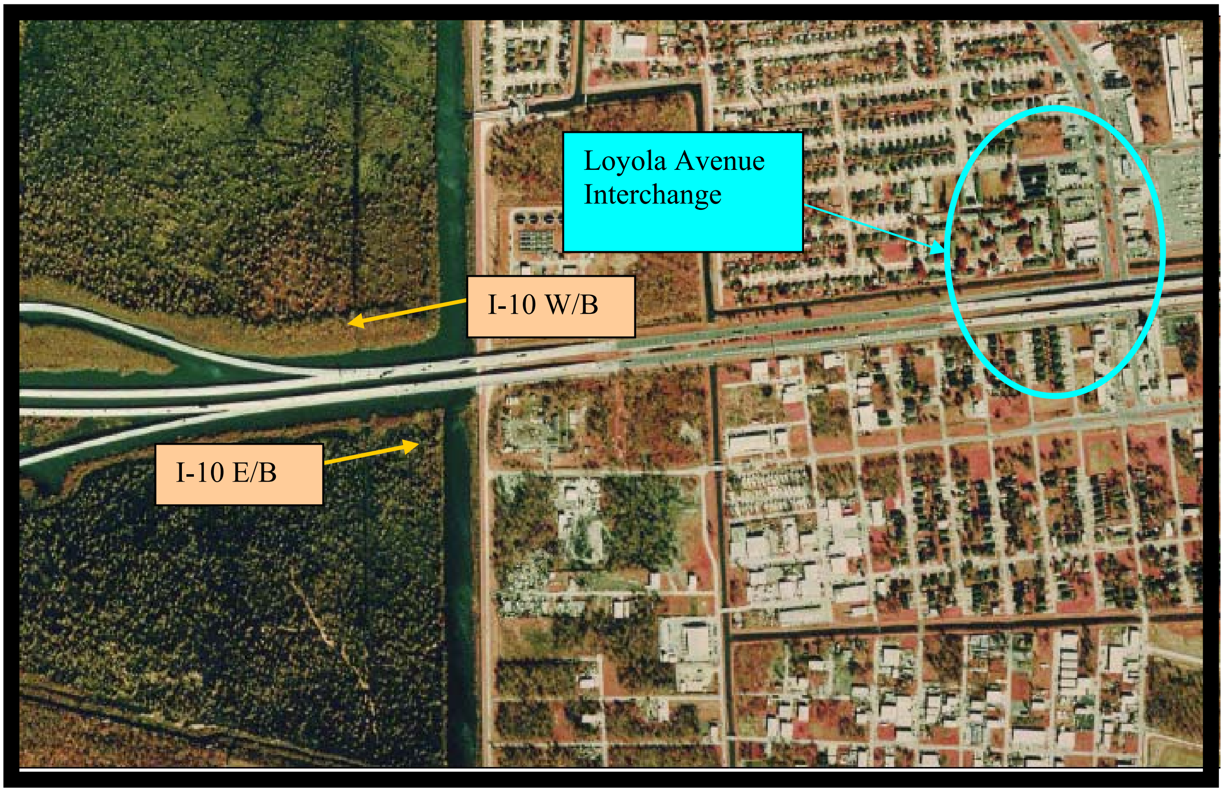


**Figure 21**
**Loyola entrance ramp in westbound I-10**

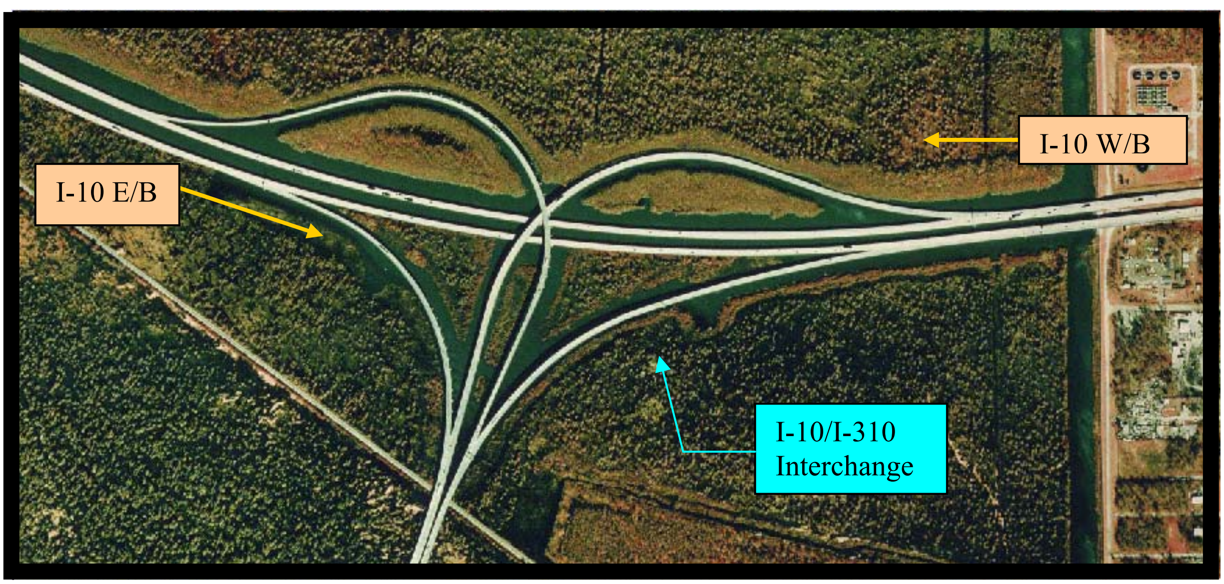


**Figure 22**
**I-10/I-310 Interchange**

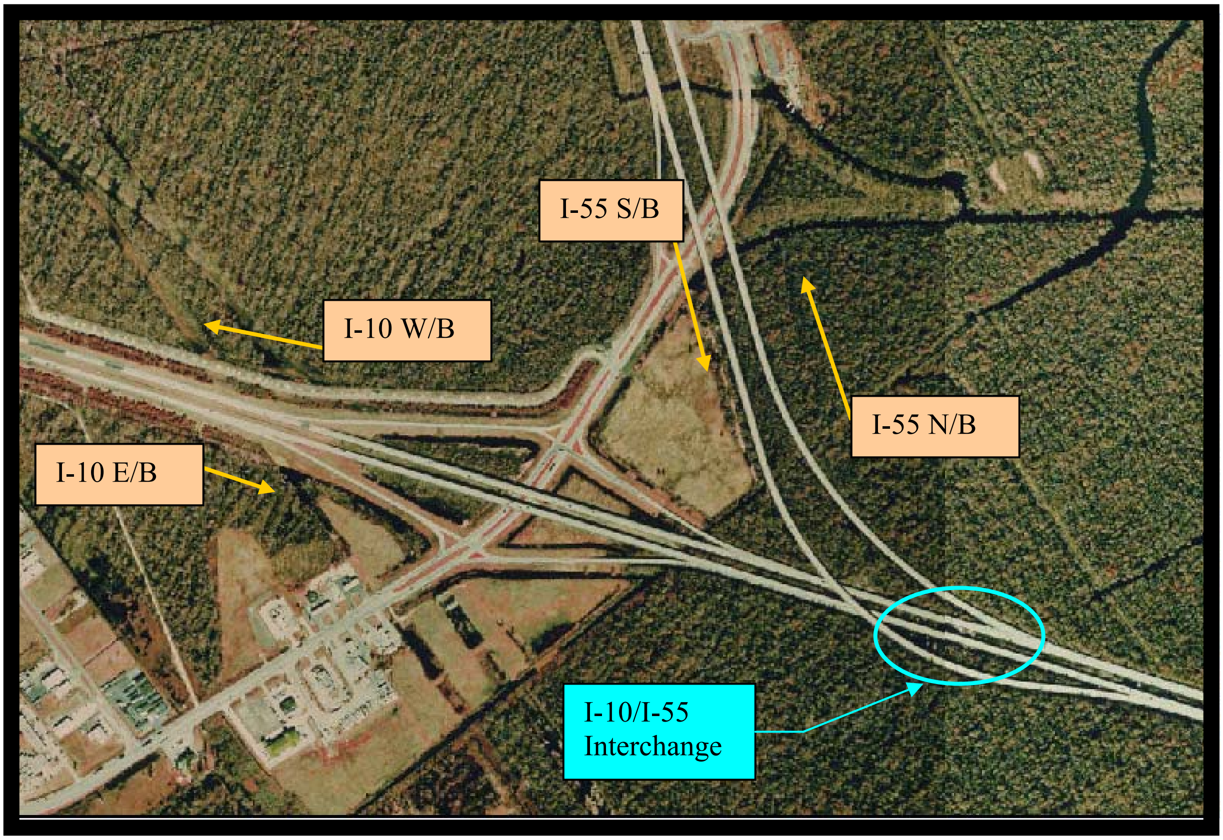


**Figure 23**
**I-10/I-55 Interchange**

### Geometric Layout

Although the aerial photos in Figure 20 to Figure 24 had an accuracy of one meter, they were not detailed to estimate the number of lanes in the contraflow segment. Therefore, the geometric layout of the segment was based on the emergency evacuation plans of the LSP. LSP provided geometric details for the initiation and termination points of the contraflow segment. In addition, the LSP report contained information about the number of lanes and the traffic control that will be used during evacuations. The details of these plans have been included in Appendixes 4, 5, and 6 of this report. Finally, a free flow operating speed of 40 mph was assigned to the road segment of the two median crossovers. This free flow speed was based on similar studies that were conducted by the Departments of Transportation in Florida, Alabama, and Georgia.

### Behavioral Input Information

The "Southeast Louisiana Hurricane Evacuation Study," *[25]* was used to determine the amount of evacuation traffic from the City of New Orleans used in this study. The data were developed based on varying categories of the hurricane and tourist occupancy. In this study, evacuation traffic volumes from a Category 5 hurricane were used as a worst-case scenario. These volumes, as well the volumes associated with other storm scenarios are shown in figure 5. In the report, the evacuating traffic volume for a Category 5 hurricane was estimated to be 124,334 vehicles. Based on the Behavioral Cumulative Evacuation Curve shown in Figure 5, 10 percent of evacuees would leave home before the order to evacuate. Therefore, 111,901 vehicles were used in the CORSIM network as the volume entering the system after the evacuation order. One entry node was on Loyola Avenue entrance ramp on I-10 and the other entry node was on westbound I-10, just before the Kenner crossover.

Studies by TXDPS *[13]* and Baker *[3 and 4]*, showed that evacuees have a tendency to take all of their belongings that they can carry during an evacuation. These factors were assumed to affect driver characteristics. It was also assumed that evacuees would feel uncomfortable while driving and would not have a clear view of the road. Finally, it was assumed that 15 percent of the total evacuation volume would be heavy vehicles such as trucks, recreational vehicles, or vehicles with trailers, boats, etc.

Since microscopic simulation models cannot account for the location, speed, and direction of the least aggressive driver, the model was simulated 30 times with different seed numbers. This offered a large range of values regarding the traffic characteristics. Therefore, multiple runs allowed better evaluations for the effectiveness of the contraflow operation.

### Addressing the Limitations of CORSIM

In this study, efforts were made to reproduce contraflow operations in the simulation model. Some of the main limitations of CORSIM in modeling reverse lanes and coding the termination point are described in the following paragraphs.

### Reverse Lanes

One primary limitation of CORSIM is that it does not allow flow simulation on reverse lanes. Therefore, the reverse lanes that were used for contraflow traffic were entered as normal outbound lanes in our application. Since most traffic signs and markings are only visible in the normal direction of traffic and shoulders are on the left side of the travel way rather than on the right side, studies such as “Hurricane Evacuation Behavior” *[3]* and “Hurricane Evacuations in the United States” *[4]*, establish that drivers tend to reduce their speed in these situations. Thus, in the CORSIM model the operational free flow speed was reduced from 65 to 55 mph for the reverse lanes.

The LSP plan calls for police cars to force traffic in the left and center lanes of westbound I-10 to continue on the contraflow lanes through the Kenner crossover. To code this in CORSIM, barricades were used between the center and rightmost lanes of westbound I-10, just east of Loyola Avenue. This would force vehicles in the left and center lanes to divert through the crossover to the contraflow lanes, as shown in Figure 25. In addition, since the left and center lanes of westbound I-10 were forced in to the contraflow direction, the traffic in the vicinity of Loyola Avenue enters in the normal flow lanes with two lanes added at 150 ft and 250 ft, respectively, after the Kenner crossover as shown in Figure 24 to form the four-lane freeway on westbound I-10 West based on the LSP plan.

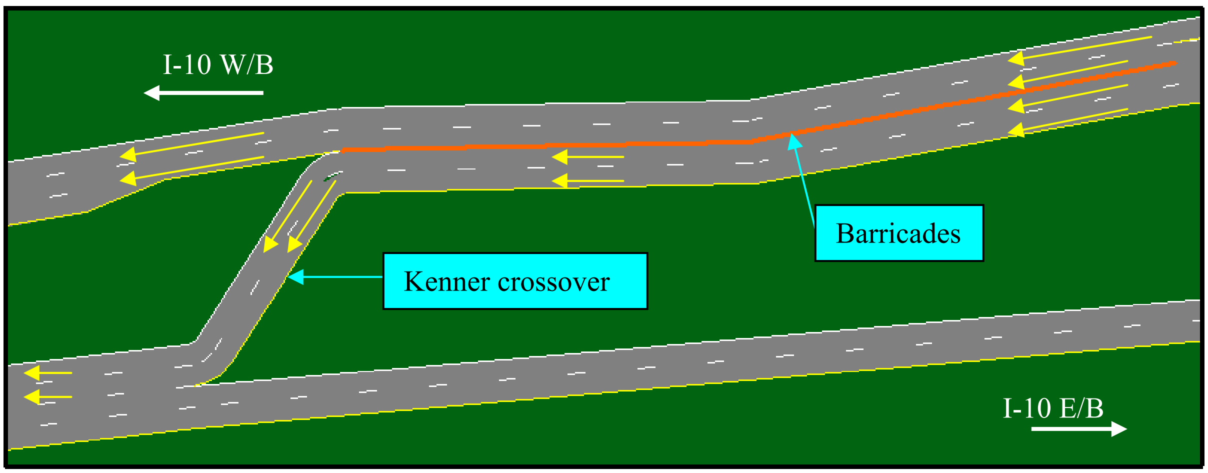


**Figure 24**
**Representation of the Kenner crossover in the CORSIM model**

At the I-10/I-310 Interchange, the entrance ramp will be blocked by the LSP to prevent "wrong way" exiting. To code this in the CORSIM, northbound I-310 was not joined with eastbound I-10. At the La Place crossover, just west of US 51, the westbound contraflow traffic will be diverted and channeled back to westbound I-10 for travel to Baton Rouge and beyond as shown in Appendix 4. To represent this condition in CORSIM, the contraflow lanes were continued through the median crossover in westbound I-10. The normal flow lanes of westbound I-10, just before the La Place crossover, were discontinued to represent the LSP plans, as shown in Figure 25.

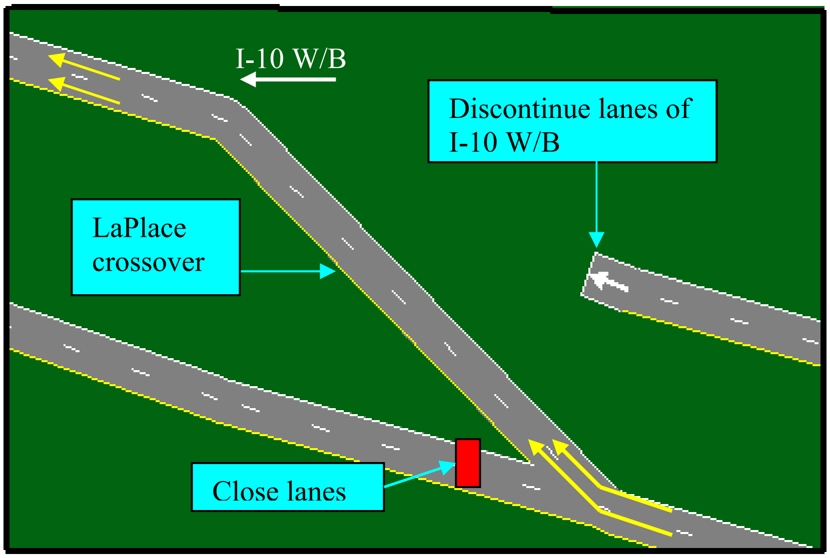


**Figure 25**
**Representation of LaPlace crossover in the CORSIM model**

### Termination Point

The normal outbound traffic of westbound I-10 will be diverted to I-55 North, to travel to Hammond, Baton Rouge, and beyond. To build this in CORSIM 5.0, a condition analogous to a construction zone was assumed *[26]*. In this research a transition area was used in the construction zone. The transition area is a section of highway where road users are redirected out of their normal path as shown in Figure 26. To code this in CORSIM, a reduction of speed to 55 mph was necessary in the redirected segment of I-10/I-55 Interchange, based on the 2000 edition of the MUTCD. Moreover, incidents were set on the closed lanes at LaPlace crossover, as shown in Figure 25 and at the I-10/I-55 interchange, as shown in Figure 27, to represent the closed lanes in the LSP plan.

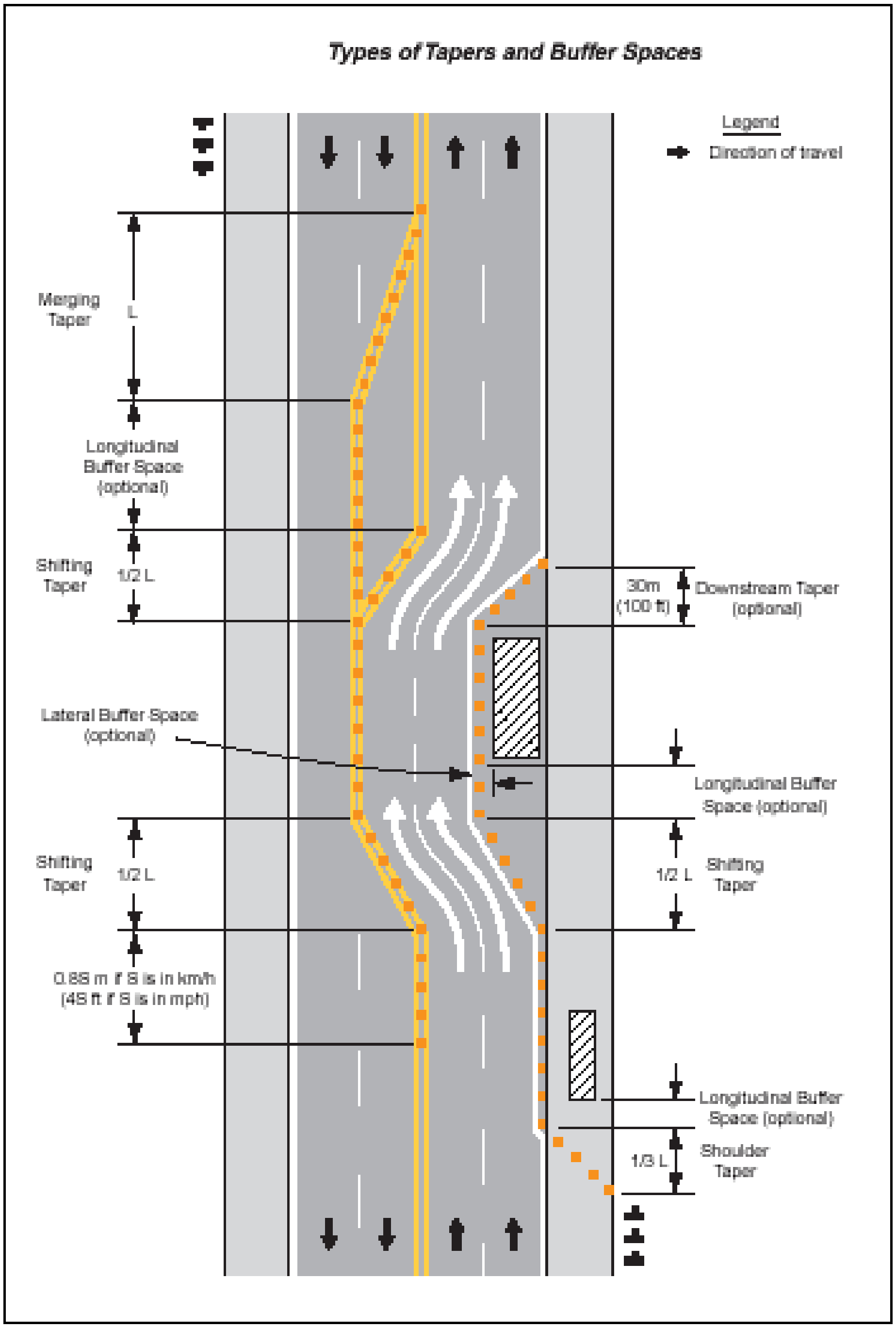


**Figure 26**
**Transition area in a construction zone**
*[26]*

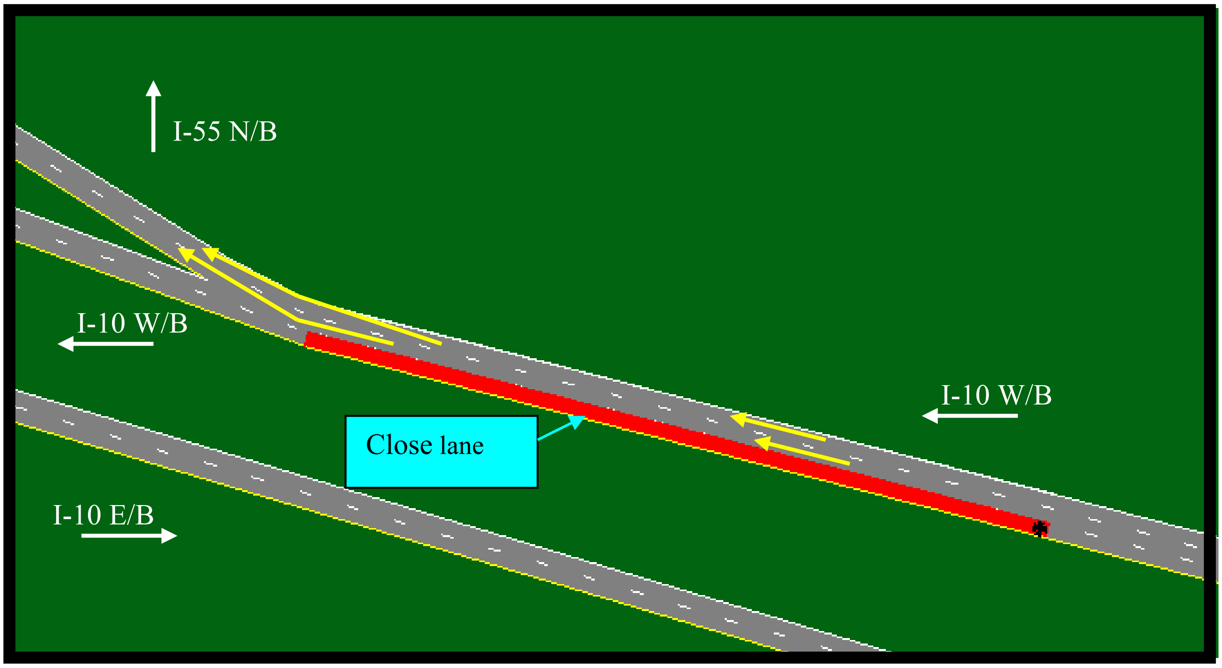


**Figure 27**
**Representation of the closed lane at I-10/I-55 Interchange**

During normal operations, if one lane is closed, drivers on the free lanes have the tendency to reduce speed. To code this tendency of the drivers in the network, an incident was used with the same duration time as the duration of the simulation, as shown in figure 27.

**Capacity Limitations**

In CORSIM the entry node for vehicles cannot exceed the capacity of the road. Based on the HCM, at a speed of 65 mph, the assumed capacity of a freeway lane is 2,250 vehicles per hour. Therefore, since the starting point of the contraflow operation on I-10 has three lanes, the entry node cannot exceed a generation rate of 6,750 vehicles per hour. If the flow in the entry node exceeds this capacity, a backup would be created. If a backup exceeds 9,999 vehicles, it would result in a CORSIM failure. To avoid having backups in this study, the evacuating vehicles were distributed based on the discharge rate matching the capacity of the road, which was 2,250 vehicles per hour per lane. Thus, the capacity of westbound I-10 was assumed to be 6,750 vehicles per hour and the capacity of the Loyola Avenue entrance ramp was assumed to be 1,250 vehicles per hour. Therefore, the total discharge rate of westbound I-10 just after the Loyola Avenue Interchange was assumed to be equal to 8,000 vehicles per hour.

Using the fast response behavioral curve of Figure 5, it is assumed that 10 percent of the total evacuation volume would depart prior to an order being issued. This would result in a demand of nearly 12,000 vehicles prior to the start of the simulation period. Thus, 111,901 vehicles were generated and used in the model. However, this amount was larger than the CORSIM's maximum allowable discharge rate of 8,000 vehicles per hour. To avoid having backups, a constant evacuation response rate of 8,000 vehicles per hour was used for the duration of the simulation. Using a total demand of 111,901 evacuation vehicles and a discharge rate of 8,000 vehicles per hour, 14 one-hour periods were needed. Consequently, a simulation of 19 one-hour periods was used in CORSIM assuming a start time of 8:00am. It should also be noted that the first 14 periods of the simulation used a volume of 8,000 vehicles per hour, and the last five periods had zero volume. These five extra periods were used to estimate clearance time since CORSIM can have a maximum of 19 periods of simulation.

However, a test simulation showed that it was not possible to achieve the maximum flow within this segment. Backups exceeded the 9,999 vehicles, and that lead to CORSIM failure. This was partly because the barriers and the median crossover restricted the flow into the contraflow segment creating queues. Consequently, CORSIM was not possible to evaluate the expected demand of 111,901 vehicles in the limitation of 19 periods. Based on the output during the 19 periods, CORSIM was able to process 92,650 vehicles.

Also, a backup of 2,250 vehicles per hour on I-10 prior to the crossover and 300 vehicles per hour on the Loyola Avenue entrance ramp was created. Therefore, the new calculated total discharge rate was 5,450 vehicles per hour: 4,500 vehicles per hour on westbound I-10 and 950 vehicles per hour on the Loyola entrance ramp. This discharge rate was used to run another CORSIM simulation with the 19 one-hour periods starting at 8:00am and ending at 3:00am the next morning. The first 17 periods include 5,450 vehicles per hour and the last 2 one-hour periods had zero volume to estimate the clearance time.

**Termination Point Analysis**

To evaluate the various contraflow termination point designs, the microscopic computer traffic simulation software package, CORSIM, was used to build and simulate the network models. The flowchart (see figure 28) shows the step-by-step procedure of preliminary network configurations selection as well as the development of the preliminary network configurations selection into final network models.

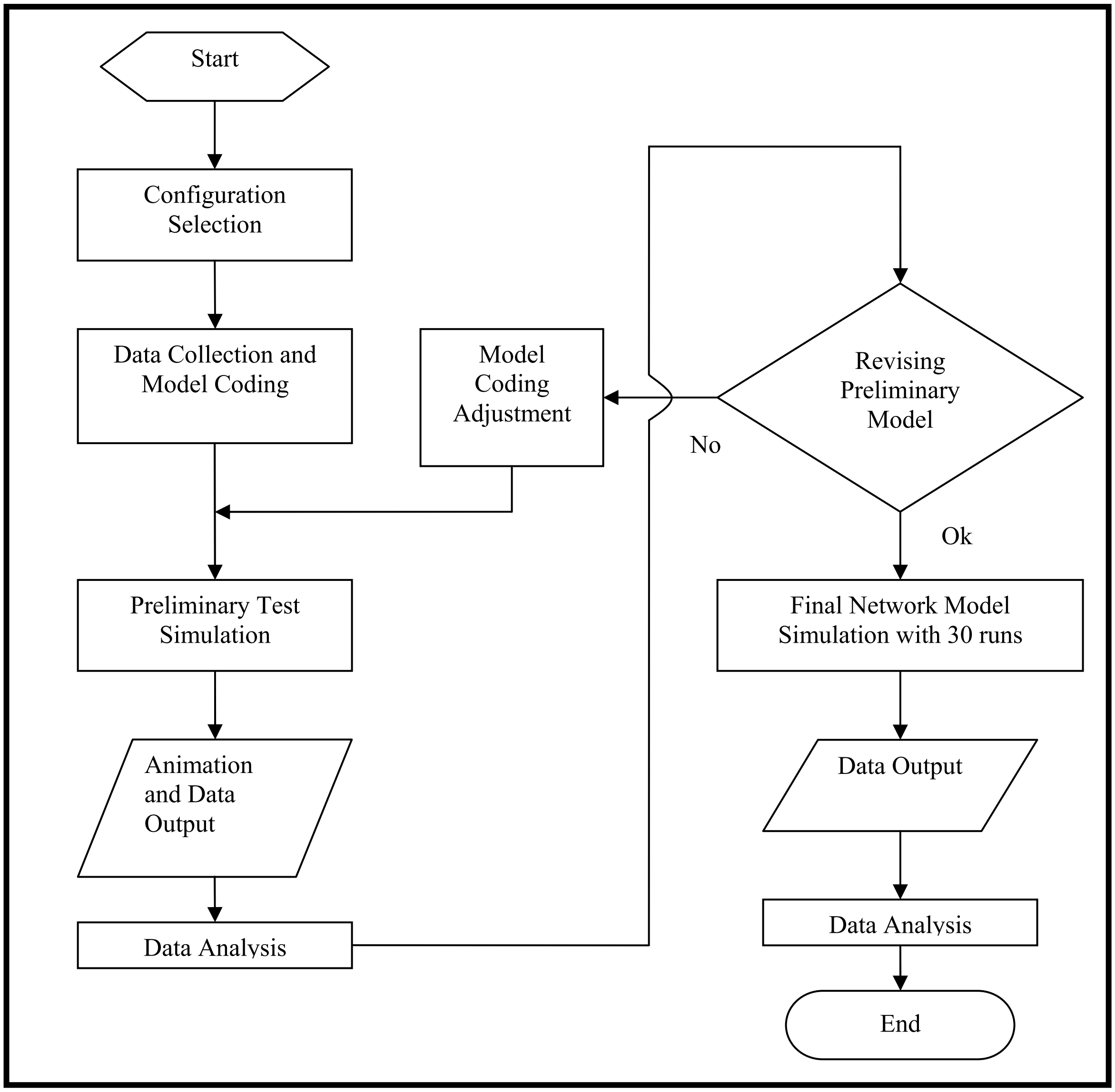


**Figure 28**
**Model building flowchart**

### Configuration Selection

A review of the existing designs of contraflow termination points available from a prior survey *[8]* found that six types of contraflow termination designs use a median crossover or freeway interchange to redirect the contraflow traffic. Figure 29 to Figure 34 show the six detailed configurations of design in the order of A, B, C, D, E, and F models. These figures show the node and link number that used to build the CORSIM models. The operating description of each model and input parameters assumption are discussed in the previous section and the following sections, respectively.

The first three designs, Type A, B, and C models, use a median crossover after the upstream interchange to end the contraflow where the distance between the median crossover and upstream interchange is separated within one mile. The next two designs, Type D and E models, have the median crossover and the upstream interchanged separated more than six miles. Lastly, the Type F model does not have open interchange for exit.

Although they all use a median crossover to redirect the traffic, some of the detailed designs are different from one another. These six schematic configurations with median crossovers were selected to run traffic network simulations using CORSIM. The other designs of contraflow termination point were not considered in this study because those designs do not use a median crossover to redirect the contraflow traffic.

### Data Collection and Model Coding

TRAFED was used to create the six basic designs of contraflow termination point into CORSIM simulation network models. To build each model, general input data were collected, assumed or researched. These included the following:

- Detailed geometry of each contraflow termination point design,
- Traffic volumes,
- Traffic components (cars, trucks, buses, trailers, etc.), and
- Traffic turning movements at exit ramp.

To simulate and compare the simulation network models, the models were generalized to have the same link distances and speed limits. Various detailed aspects of the roadway design geometry for each contraflow termination point design were based on American Association of State Highway and Transportation Officials standard criteria *[27]*. The major assumptions made in this study for the CORSIM input data were listed below:

- 45/55 distribution of traffic was loaded on reversed lanes and normal lanes,
- A truck percentage of 15 percent,
- 25 and 50 percent of traffic turning movement at exit ramp,
- Total traffic volume of 6,000 vehicles per hour (vph) coming from upstream of the study area on all the four lanes,
- A generic 13 mile segment network from the contraflow termination point,
- Free flow speeds of 65mph on freeway, 45mph on median crossover, and 35mph on exit ramp.

The details of these assumptions are discussed in next sections.

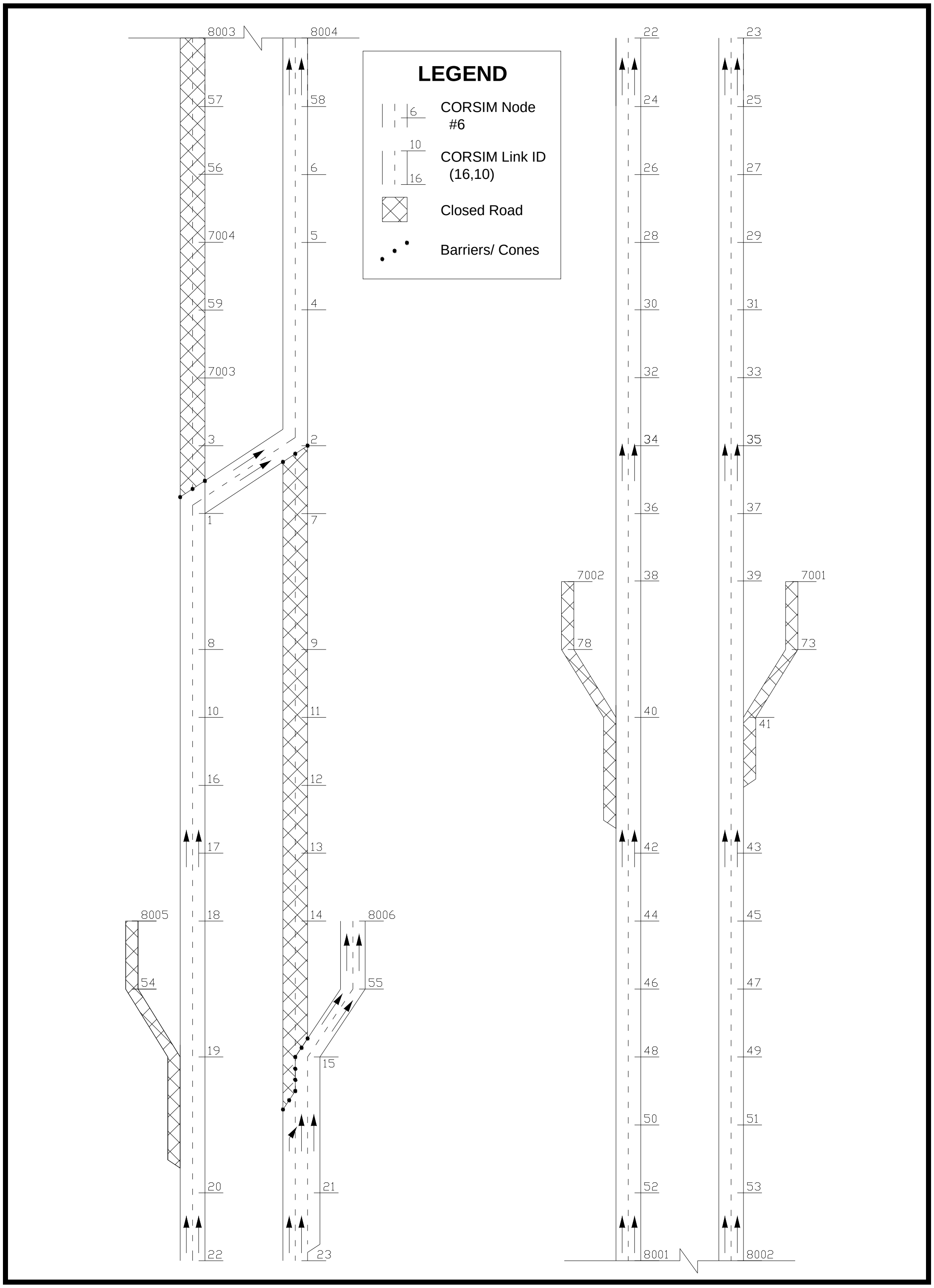


**Figure 29**
**Type A model**

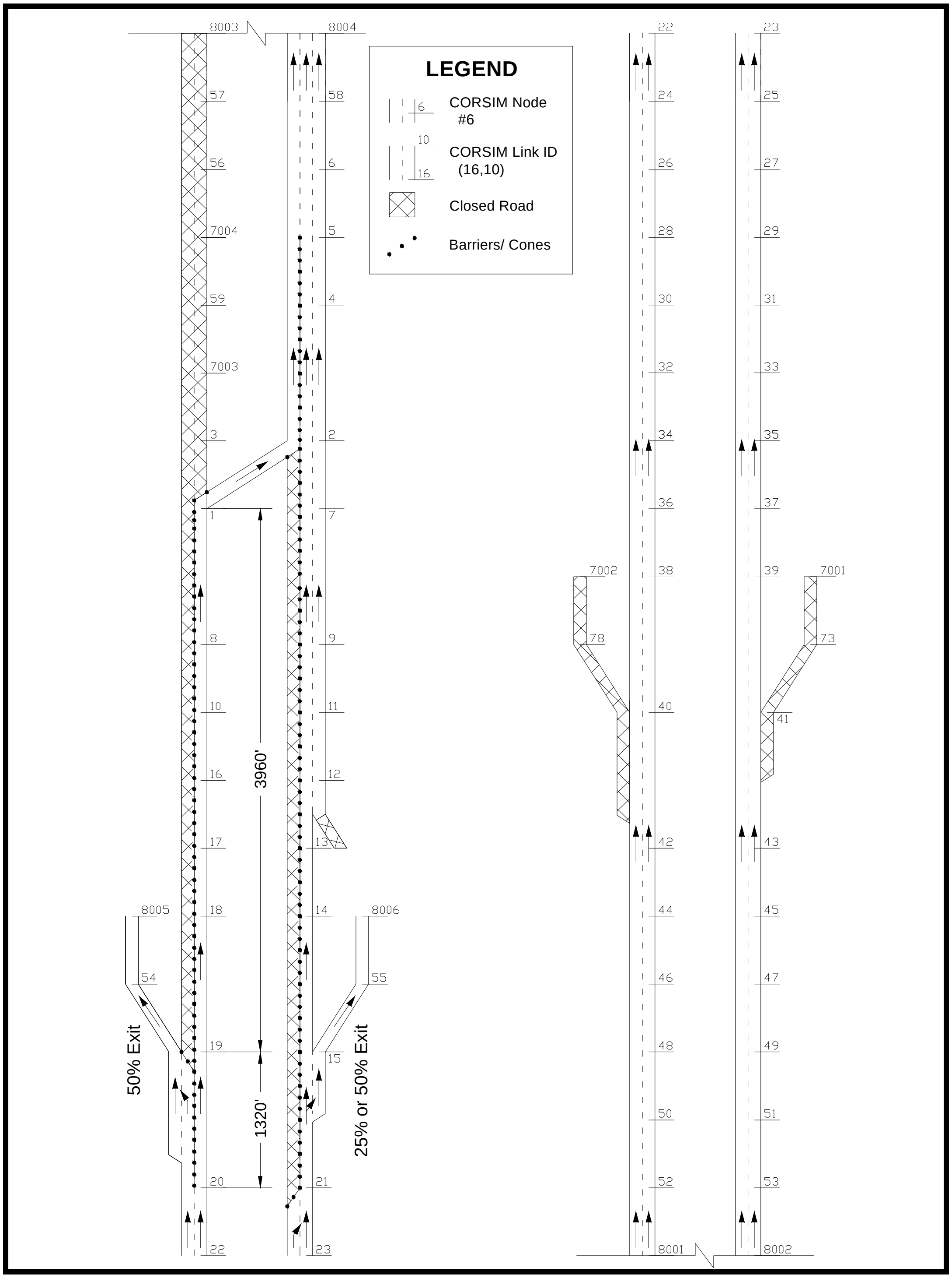


**Figure 30**
**Type B ($B_{25}$, $B_{50}$) model**

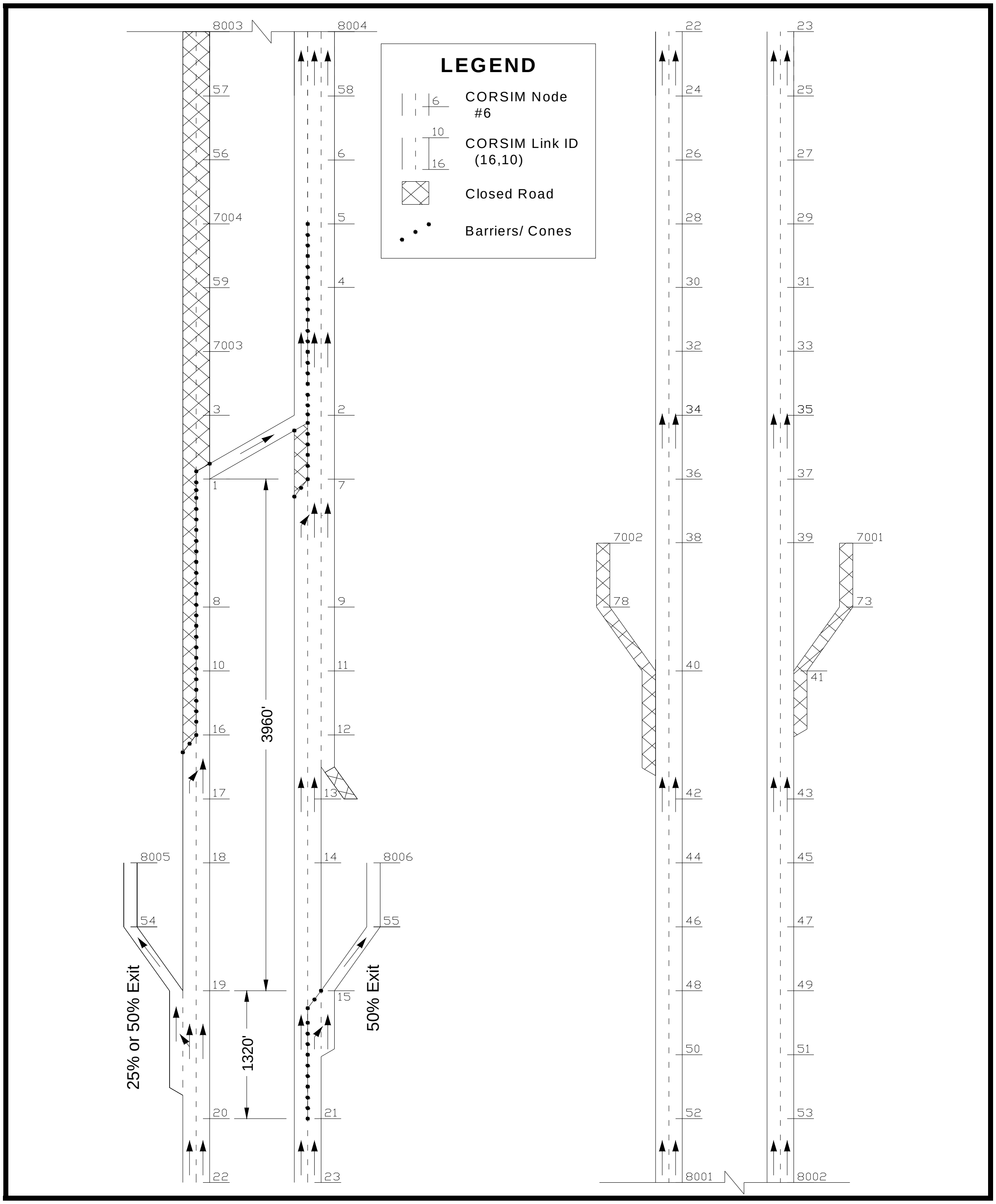


**Figure 31**
**Type C ($C_{25}$, $C_{50}$) model**

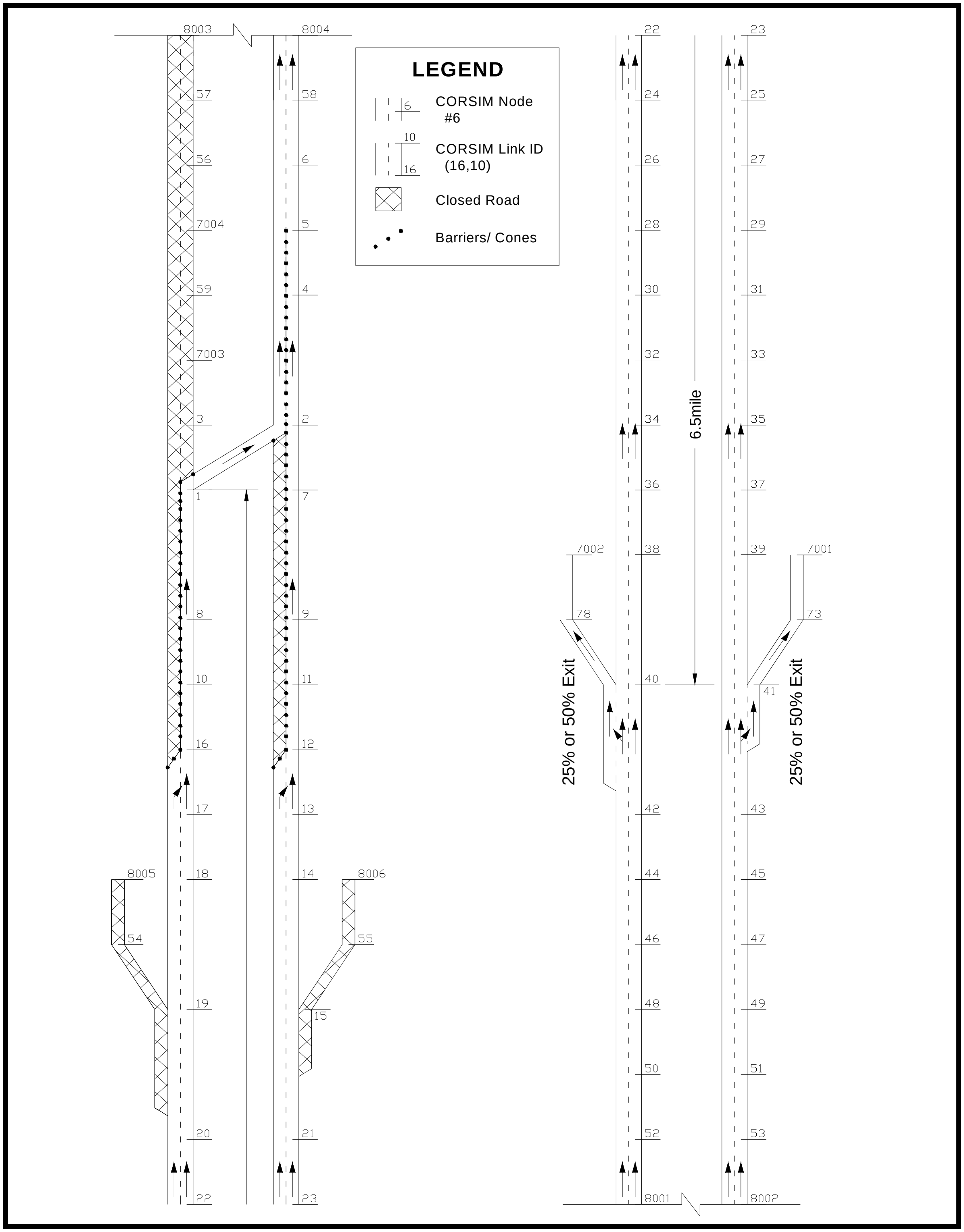


**Figure 32**
**Type D ($D_{25}$, $D_{50}$) model**

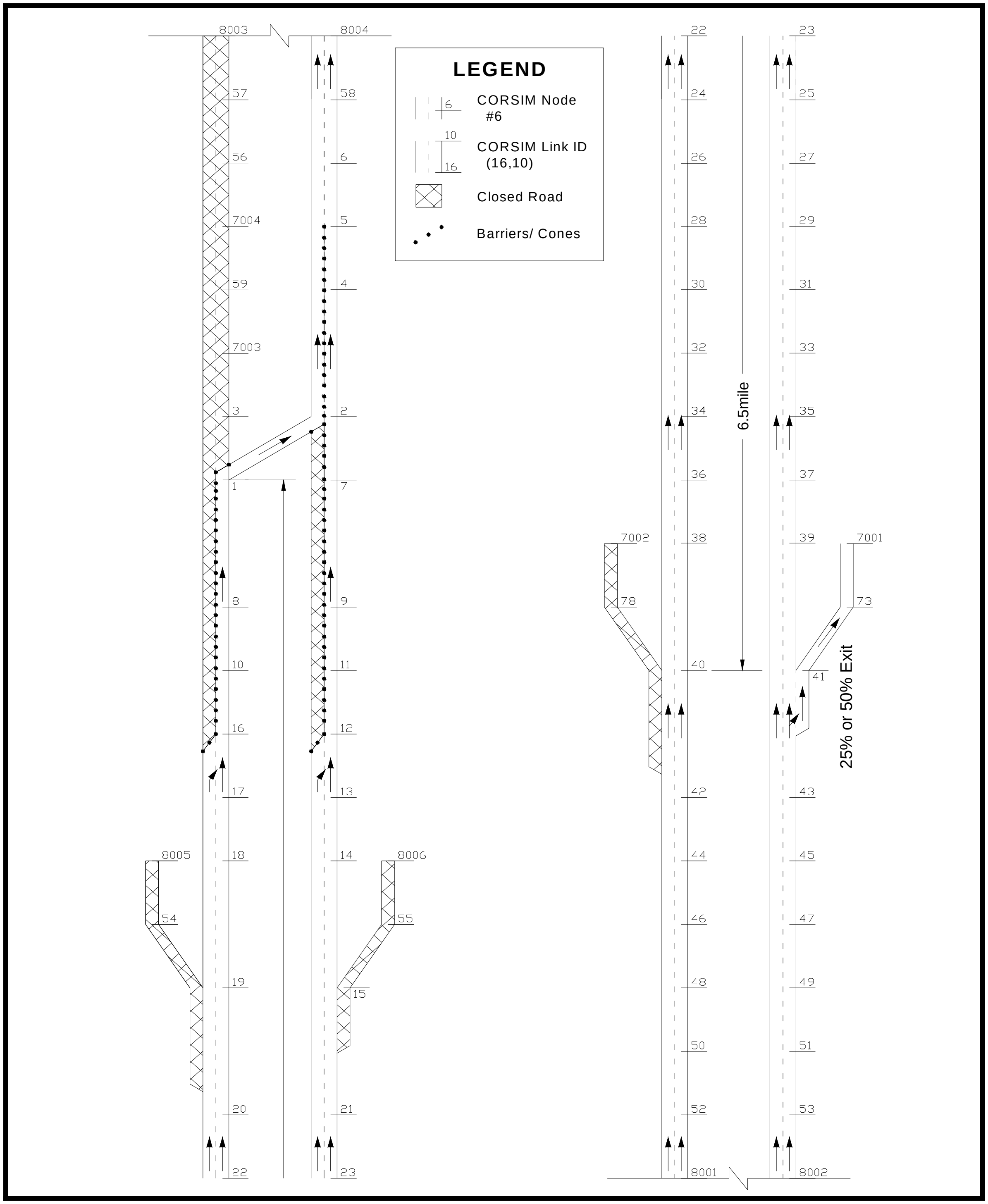


**Figure 33**
**Type E ($E_{25}$, $E_{50}$) model**

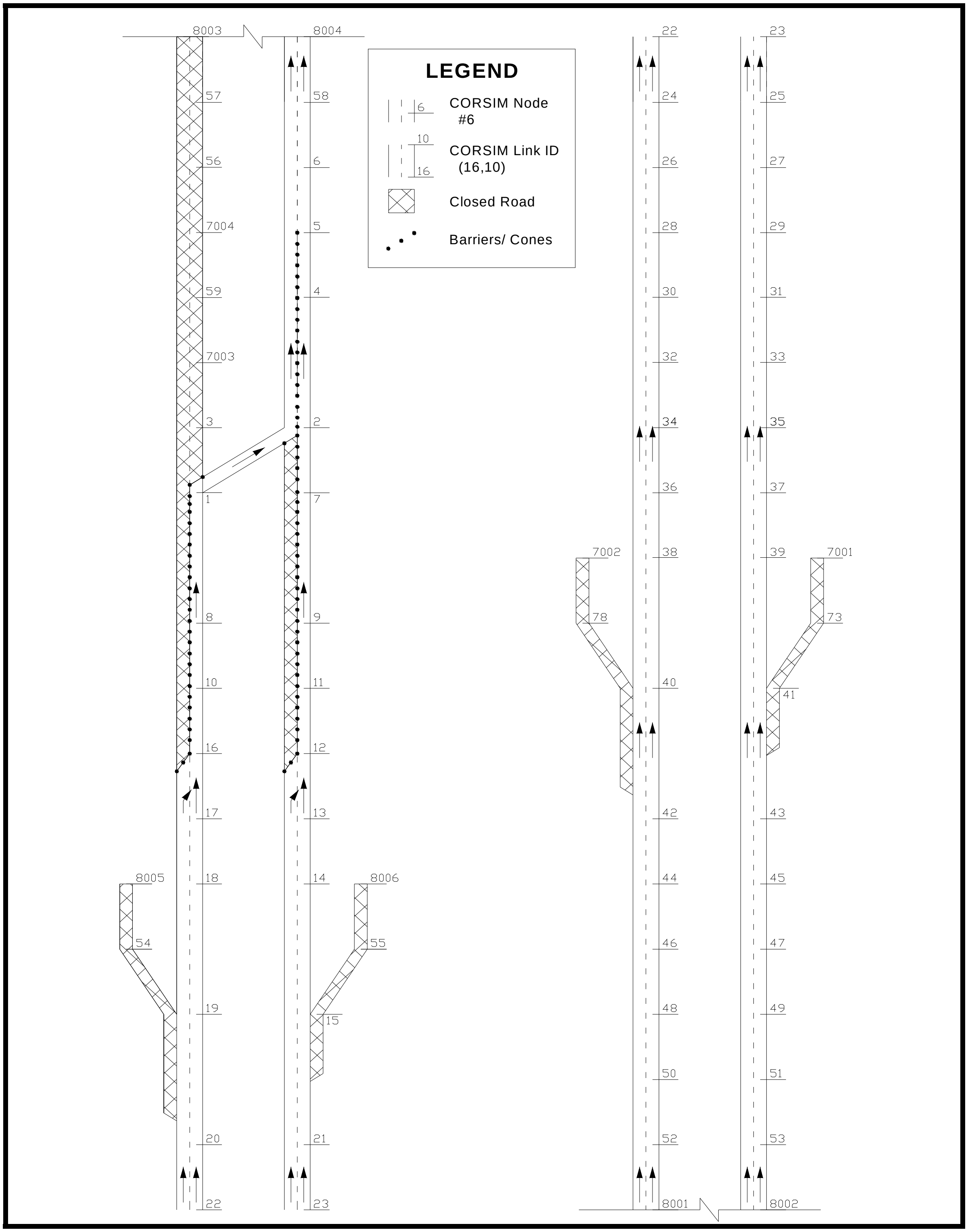


**Figure 34**
**Type F model**

### Selection of Traffic Flow Direction Percentage

In this research, a conservative traffic distribution of 45/55 was used on the reversed and normal lanes. This distribution ratio was the average value that based on the recent studies of contraflow for college sports events *[28]*, and the I-37 reverse-flow analysis *[16]*. The first study showed that there was not much difference between the reverse flow and normal traffic movements. In the latter study (I-37), a 40/60 distribution was used on the reversed and normal lanes.

### Selection of Traffic Turning Movement at Exit Ramp

As shown in Table 1, using different exiting percentages at the off-ramp, Types B, C, D and E models were subdivided into Type $B_{25}$, $B_{50}$, $C_{25}$, $C_{50}$, $D_{25}$, $D_{50}$, $E_{25}$, and $E_{50}$ models, where the subscript following by the model type indicates the different exiting traffic percentages of 25% and 50% turning movement at the off-ramps, respectively.

**Table 1**
**Exiting traffic percentage at the interchange for simulation models**

| Model Type | | Number of Lanes on Median Crossover | Exiting Traffic % at the Previous Interchange that within 1-mile ahead of Median Crossover | | Exiting Traffic % at the Previous Interchange that 6-mile ahead of Median Crossover | |
|---|---|---|---|---|---|---|
| | | | Reverse Direction | Normal Direction | Reverse Direction | Normal Direction |
| **Type A** | | 2 | - | 100% | - | - |
| **Type B** | **Type $B_{25}$** | 1 | 50% | 25% | - | - |
| | **Type $B_{50}$** | 1 | 50% | 50% | - | - |
| **Type C** | **Type $C_{25}$** | 1 | 25% | 50% | - | - |
| | **Type $C_{50}$** | 1 | 50% | 50% | - | - |
| **Type D** | **Type $D_{25}$** | 1 | - | - | 25% | 25% |
| | **Type $D_{50}$** | 1 | - | - | 50% | 50% |
| **Type E** | **Type $E_{25}$** | 1 | - | - | - | 25% |
| | **Type $E_{50}$** | 1 | - | - | - | 50% |
| **Type F** | | 1 | - | - | - | - |

Traffic turning movement at the exit ramp was assumed to be controlled either by a barrier divider or with on-site police enforcement. In this study, 25 percent and 50 percent of traffic was assumed to exit at the exit ramps. In some cases, due to each specific configuration design, 100 percent, 50 percent, or 0 percent of traffic turning movement might occur at particular off-ramp. Barrier dividers can be configured to direct all traffic to make a mandatory exit, force a particular single lane of traffic to exit, or close the off-ramp. For the Type A model, all traffic was directed to exit with the 2-lane off-ramp at the termination point of normal flow direction. In this study, the barrier dividers for the Type B and C models were assumed to achieve 50 percent exiting traffic at the off-ramp using advance warning signs to notify drivers who are traveling on the restricted lane to make a mandatory exit. A barrier divider was set up before the contraflow off-ramp to direct all traffic using the left lane to exit for the Type B model. In the same manner, a barrier divider was set up before the normal flow off-ramp to direct all traffic using the right lane to exit for the Type C model. In Figure 35, “white lines” on the freeway show the setup of barrier dividers in the simulation network models.

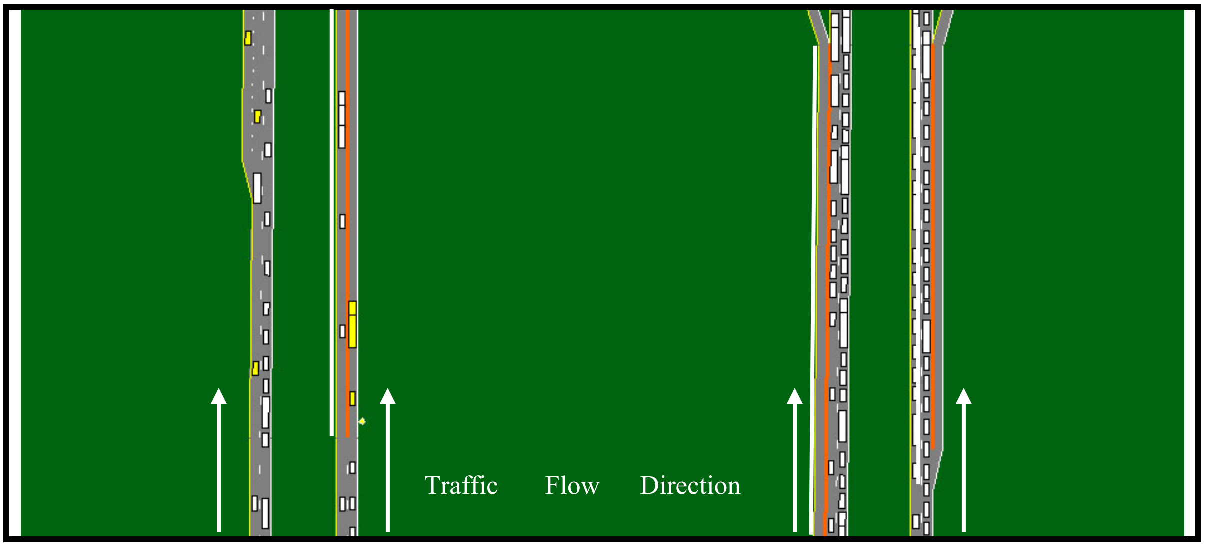


**Figure 35**
**Barrier divider setup in CORSIM**

### Selection of Truck Percentage

In this study, a truck percentage of 15 percent was used on all the simulation models. The simulation study conducted by TTI (Ford et. al, 2000), used a truck percentage of 30 percent to analyze I-37 reverse-flow traffic operations in the CORSIM traffic simulation.

**Figure 36**
**Hurricane Evacuation Aerial Photos**
**(Photo Source: The Corpus Christi Caller Times)**

However, as shown in Figure 36, the aerial photos taken on the previous evacuations showed that a truck percentage of 30 percent could be considered a high value. The 2001 FHWA *Highway Statistics Annual Report* showed that the heavy vehicle percentage on interstate system was around 7 percent to 8 percent, which is the total percentage of 3-axle or more combination trucks *[29]*. Prior studies showed that evacuees tend to bring all of their belongings that they can carry during an evacuation *[3 and 4]*. Hence, in this study a double amount of heavy vehicles was assumed to occur during an emergency evacuation; that is 15 percent of the total amount of traffic would be heavy vehicles such as trucks, recreational vehicles, vehicles with trailers or boats, etc.

**Selection of Geometric Design and Speed Limit**

A generic 13-mile segment of 2-lane freeway prior to the contraflow termination point was coded for each configuration. Based on the design speed from AASHTO, the free-flow speeds of 65 mph and 35 mph were assumed for the freeways and off-ramps, respectively. In this study, the speed limit on the median crossover was assumed to be 45 mph. This was based on the designs of *I-4 Emergency Crossover Design Plan* and *I-65 Northbound*

*Crossover Design Plan* from Florida Department of Transportation *[30]* and Alabama Department of Transportation *[18]*.  Figure 37 and Figure 38 show these design plans.

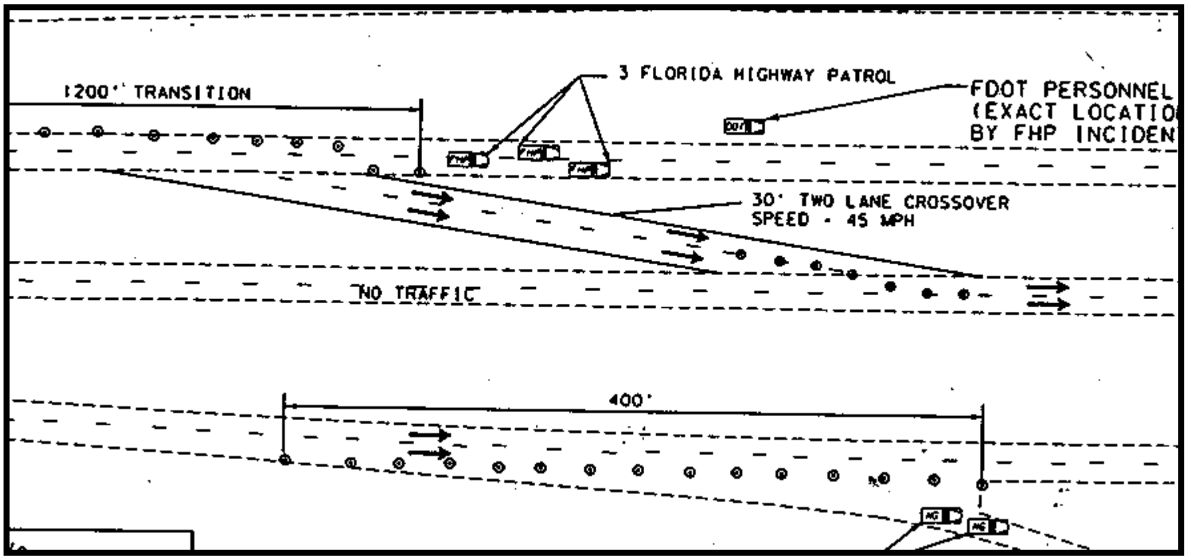


**Figure 37**
**I-4 emergency crossover design plan**
**(Source: Florida Department of Transportation *[30]*)**

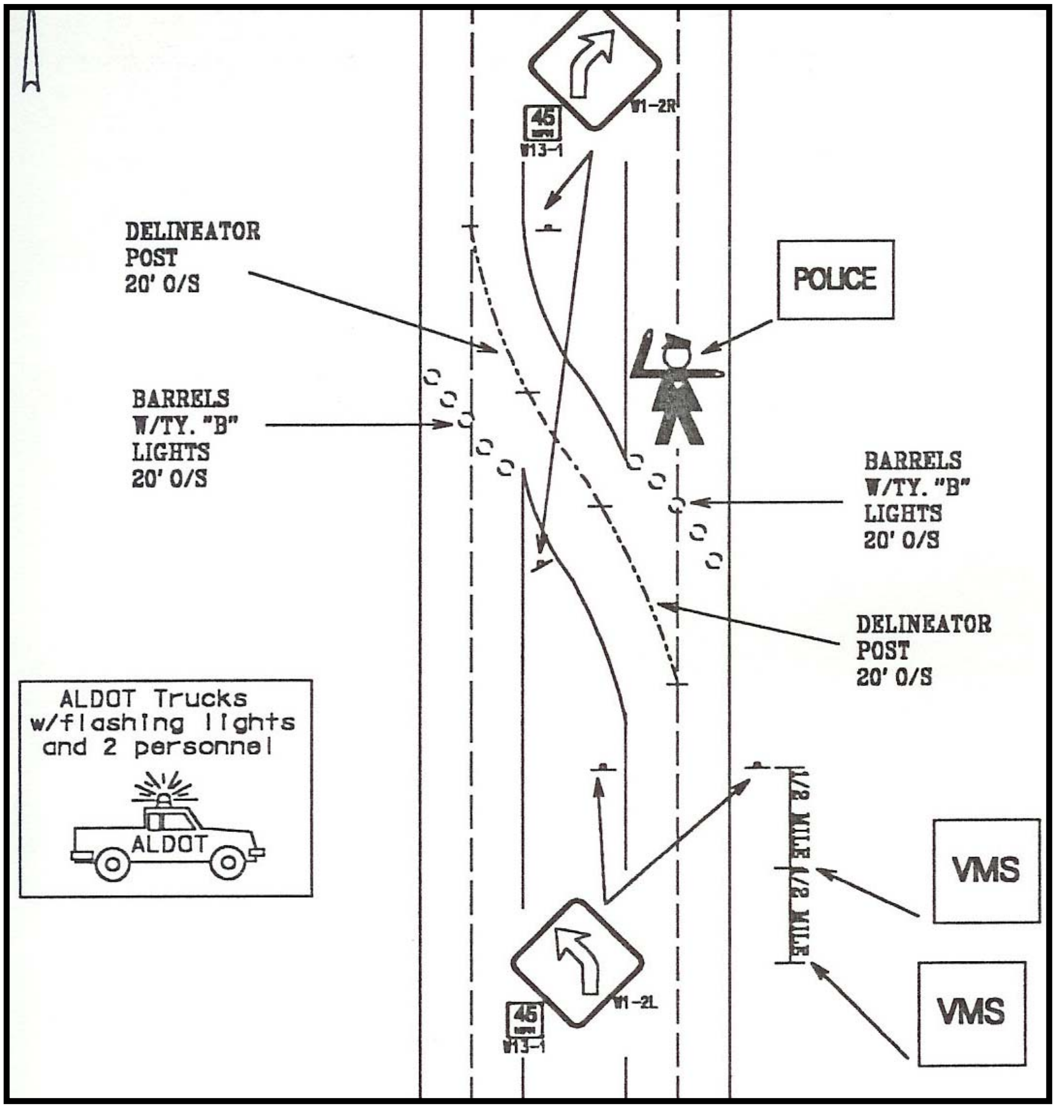


**Figure 38**
**I-65 northbound crossover design plan**
**(Source: Alabama Department of Transportation *[18]*)**

### Incidents/Blockages Setup on Network Model

CORSIM can be customized to simulate lane closure traffic operation using the incident function. In this research, incident events were created on certain segments of the network models to enable CORSIM to represent two lanes reduced to one lane at those lane closure segments. Lane blockages were setup on the freeway and assigned a warning sign one mile away from the incident location. The “white band” in figure 39 shows the lane blockage setup on the left lane of the freeway.  The location of the first incident warning sign is usually setup one mile ahead of the incident location with "One-Way Ends 1 Mile."

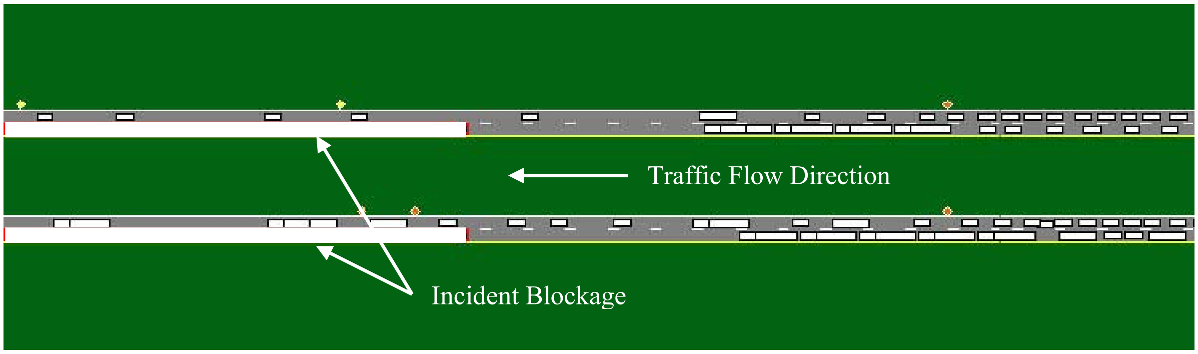


**Figure 39**
**Incident blockage setup**

### Model Revising and Evaluation

TRAFVU was used to display animations of the 10 preliminary models.  Each model was checked and revised until more realistic traffic conditions were achieved.  Although CORSIM provides a large number of parameters for fine tuning the simulation models to achieve imitated real traffic condition, no available actual data of contraflow operation can be used for validation in this study.  A calibration of the simulation models should be done for relative accuracy using the on-screen animation and model outputs.

### Parameters Adjustment in CORSIM

In this study, most of the parameters in CORSIM used the given default values.  The only parameter adjusted was the *Minimum separation for generation of vehicles*.  This parameter controls the maximum flow rate of vehicles entering the entry nodes in CORSIM.  Under ideal traffic operation and geometric conditions, the capacity of a freeway can reach 2,400 passenger car per hour per lane (pcphpl) *[31]*.  To create a heavily congested condition on the simulation model, 1.4 seconds was used in all simulations that allowed a flow of a 2,500 vphpl to be achieved on entering the entrance links on the network simulation models (see figure 40).  As the default value of *Minimum separation for generation of vehicles* in CORSIM was set at 1.6 seconds, the traffic flow entering the freeway was limited to 2,250 vphpl.

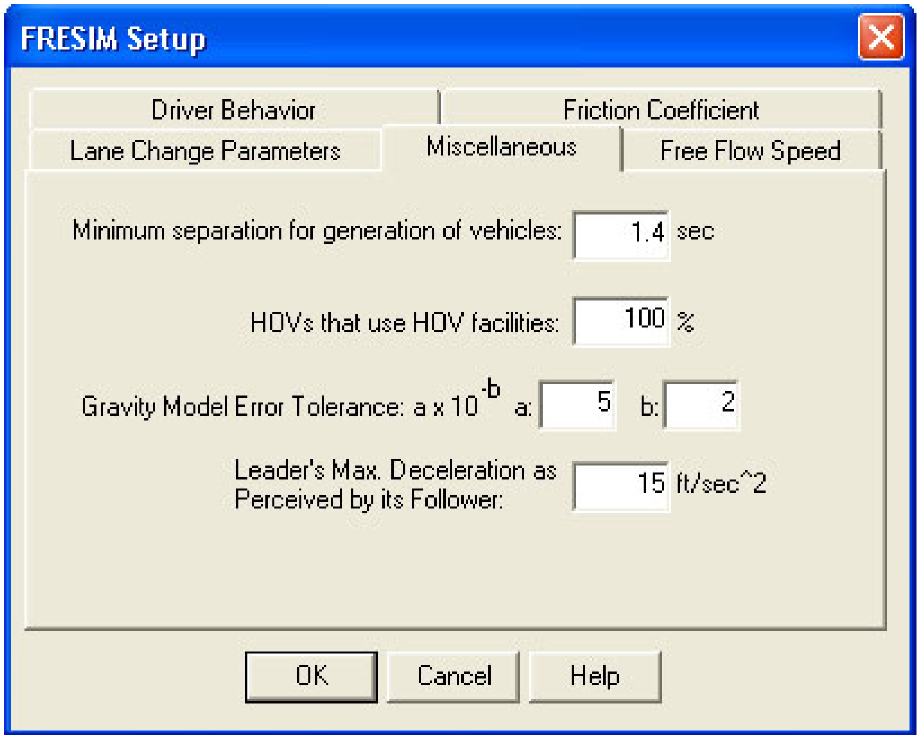


**Figure 40**
**FRESIM setup**

#### Selection of Traffic Volume for Final Simulation Models

First the model development process, a traffic volume of 5,000vph was used to code and develop the ten preliminary testing simulation models. This assumption was based on a prior study *[32]*. The prior study showed that all lanes in reversed contraflow operation (2 reversed inbound lanes plus 2 normal outbound lanes) can provide an outbound traffic volume of 5,000vph. After creating the 10 preliminary testing simulation models, these models were conducted using different traffic flows of 4,000 vph, 5,000 vph, 6,000 vph, 7,000 vph, and 8,000 vph. A total of 50 runs were executed using a simulation time of 4 hours, representing the cumulative network-wide average statistical results of the 5 preliminary test simulation groups.

The overall cumulative network-wide average speed appeared to drop below the free flow speed for the 6,000 vph simulation group. Figure 41 shows that the average speeds for this simulation group were around 8mph to 45mph because all models appeared to have congestion. Figure 42 illustrates the comparison of number of queued vehicles among the preliminary test simulations, where 6,000 vph simulation group models appeared to start having backed-up vehicles before entering the entry nodes of the contraflow and normal flow directions. Figure 43 indicates that the ratios of move time vehicle-hours over the total time vehicle-hours for the 6,000 vph simulation group ranged from 0.69 to 0.12, and the ratios dropped dramatically compared to the 4,000 vph and 5,000 vph simulation groups. Therefore, the 6,000 vph preliminary test simulation group was selected to run a complete simulation model.

### Preliminary Test Simulation

Since this study focused on the changes of merging congestion and performance of the freeway contraflow operations, the local traffic network was assumed to accommodate all traffic diverted from the freeway. Although this may or may not actually be true, the local traffic network would not be studied here.

To achieve a wide range of variation of CORSIM output results from the models, the built-in multi-run function in CORSIM was used to assign varying random number seeds and a maximum of thirty runs were simulated on each network configuration. A total of 300 CORSIM simulation runs were executed in this study, including 30 runs for each simulation model (Type A, Type $B_{25}$, Type $B_{50}$, Type $C_{25}$, Type $C_{50}$, Type $D_{25}$, Type $D_{50}$, Type $E_{25}$, Type $E_{50}$, and Type F). The results presented in the following chapter were based on the mean for these 30 runs. A four-hour simulation run time was used in each network configuration. This simulation run time was long enough to generate adequate numerical output results for analysis. Each run consisted of 16 time-periods (TP), and each time-period was 15 minutes.

For the majority of the simulation runs, a Pentium 4, 1500-megahertz computer, with 256 megabytes of random access memory (RAM) was used. Each simulation run time took from eight minutes to twenty-two minutes of processing time depending on the complexity of the simulation model. Two types of output files, output data and output animation files, were generated from each simulation. All the output data files were used for analysis purposes.

### CORSIM Output Data Description

The CORSIM output consisted of four main sections: input data echo, initialization results, intermediate results, and end of time period results *[33]*. The input data echo consisted of a copy of the input file and tables stating the complete specification of the traffic environment, run options, and the entire user supplied inputs and default values for the purpose of checking the validity and acceptability of values and parameters.

The initialization statistics show how the vehicles filled the network at different time intervals prior to the network reaching equilibrium. The initialization statistics results were not included in the cumulative results. Intermediate results were generated at the end of user specified intervals. Following the input data review, tables of output statistics containing

## Table 2
## Cumulative network-wide average statistical comparison

| Model Type | Traffic Volume Loaded on Network (vph) | Total Vehicle-Miles | Ave. Speed | Move Time | Delay Time | Total Time | Move/ Total | Delay Time | Total Time | # of Queued Vehicles | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (mph) | (Vehicle-Hours) | | | | (Minutes/Mile) | | Reverse | Normal |
| Type A | 4,000 | 191,339 | 59.96 | 2,953 | 238 | 3,191 | 0.93 | 0.07 | 1.00 | - | - |
| Type $B_{25}$ | 4,000 | 184,982 | 24.00 | 2,846 | 4,863 | 7,709 | 0.37 | 1.58 | 2.50 | - | - |
| Type $B_{50}$ | 4,000 | 180,844 | 23.24 | 2,776 | 5,005 | 7,781 | 0.36 | 1.66 | 2.58 | - | - |
| Type $C_{25}$ | 4,000 | 196,019 | 60.90 | 3,041 | 178 | 3,219 | 0.94 | 0.05 | 0.99 | - | - |
| Type $C_{50}$ | 4,000 | 192,789 | 61.20 | 2,988 | 163 | 3,150 | 0.95 | 0.05 | 0.98 | - | - |
| Type $D_{25}$ | 4,000 | 178,155 | 60.08 | 2,785 | 181 | 2,965 | 0.94 | 0.06 | 1.00 | - | - |
| Type $D_{50}$ | 4,000 | 147,501 | 60.20 | 2,323 | 128 | 2,450 | 0.95 | 0.05 | 1.00 | - | - |
| Type $E_{25}$ | 4,000 | 191,833 | 59.27 | 2,991 | 245 | 3,237 | 0.92 | 0.08 | 1.01 | - | - |
| Type $E_{50}$ | 4,000 | 175,164 | 59.33 | 2,742 | 210 | 2,952 | 0.93 | 0.07 | 1.01 | - | - |
| Type F | 4,000 | 195,960 | 24.48 | 3,027 | 4,979 | 8,006 | 0.38 | 1.52 | 2.45 | - | - |
| Type A | 5,000 | 239,264 | 58.32 | 3,695 | 407 | 4,102 | 0.90 | 0.10 | 1.03 | - | - |
| Type $B_{25}$ | 5,000 | 204,392 | 16.24 | 3,072 | 9,511 | 12,583 | 0.24 | 2.79 | 3.69 | - | 1,650 |
| Type $B_{50}$ | 5,000 | 200,922 | 16.01 | 3,017 | 9,530 | 12,547 | 0.24 | 2.85 | 3.75 | - | 1,650 |
| Type $C_{25}$ | 5,000 | 245,155 | 59.35 | 3,805 | 325 | 4,131 | 0.92 | 0.08 | 1.01 | - | - |
| Type $C_{50}$ | 5,000 | 240,939 | 59.76 | 3,739 | 293 | 4,032 | 0.93 | 0.07 | 1.00 | - | - |
| Type $D_{25}$ | 5,000 | 217,250 | 35.19 | 3,401 | 2,773 | 6,174 | 0.55 | 0.77 | 1.71 | - | - |
| Type $D_{50}$ | 5,000 | 186,019 | 58.20 | 2,934 | 263 | 3,196 | 0.92 | 0.08 | 1.03 | - | - |
| Type $E_{25}$ | 5,000 | 220,195 | 19.72 | 3,425 | 7,741 | 11,166 | 0.31 | 2.11 | 3.04 | - | - |
| Type $E_{50}$ | 5,000 | 205,396 | 23.86 | 3,200 | 5,408 | 8,608 | 0.37 | 1.58 | 2.51 | - | - |
| Type F | 5,000 | 204,059 | 11.12 | 3,050 | 15,300 | 18,351 | 0.17 | 4.50 | 5.40 | - | 1,450 |
| Type A | 6,000 | 282,993 | 40.80 | 4,369 | 2,567 | 6,935 | 0.63 | 0.54 | 1.47 | - | - |
| Type $B_{25}$ | 6,000 | 223,311 | 15.35 | 3,286 | 11,263 | 14,549 | 0.23 | 3.03 | 3.91 | - | 4,150 |
| Type $B_{50}$ | 6,000 | 220,371 | 15.24 | 3,240 | 11,217 | 14,457 | 0.22 | 3.05 | 3.94 | - | 4,150 |
| Type $C_{25}$ | 6,000 | 284,230 | 31.94 | 4,431 | 4,468 | 8,898 | 0.50 | 0.94 | 1.88 | - | - |
| Type $C_{50}$ | 6,000 | 285,592 | 44.41 | 4,432 | 1,999 | 6,430 | 0.69 | 0.42 | 1.35 | - | - |
| Type $D_{25}$ | 6,000 | 232,368 | 16.43 | 3,582 | 10,561 | 14,144 | 0.25 | 2.73 | 3.65 | - | 1,000 |
| Type $D_{50}$ | 6,000 | 220,413 | 39.78 | 3,474 | 2,066 | 5,540 | 0.63 | 0.56 | 1.51 | - | 50 |
| Type $E_{25}$ | 6,000 | 218,158 | 10.71 | 3,270 | 17,092 | 20,361 | 0.16 | 4.70 | 5.60 | 1,150 | 1,100 |
| Type $E_{50}$ | 6,000 | 224,902 | 16.47 | 3,462 | 10,197 | 13,659 | 0.25 | 2.72 | 3.64 | 1,000 | - |
| Type F | 6,000 | 199,462 | 8.36 | 2,839 | 21,019 | 23,858 | 0.12 | 6.32 | 7.18 | 1,300 | 3,900 |
| Type A | 7,000 | 306,747 | 29.68 | 4,744 | 5,591 | 10,335 | 0.46 | 1.09 | 2.02 | - | 1,850 |
| Type $B_{25}$ | 7,000 | 243,428 | 15.46 | 3,558 | 12,184 | 15,743 | 0.23 | 3.00 | 3.88 | - | 6,650 |
| Type $B_{50}$ | 7,000 | 240,330 | 15.32 | 3,506 | 12,182 | 15,688 | 0.22 | 3.04 | 3.92 | - | 6,650 |
| Type $C_{25}$ | 7,000 | 284,796 | 17.05 | 4,408 | 12,293 | 16,700 | 0.26 | 2.59 | 3.52 | 1,350 | 1,350 |
| Type $C_{50}$ | 7,000 | 310,509 | 30.97 | 4,822 | 5,205 | 10,027 | 0.48 | 1.01 | 1.94 | - | 1,550 |
| Type $D_{25}$ | 7,000 | 238,795 | 12.87 | 3,657 | 14,894 | 18,551 | 0.20 | 3.74 | 4.66 | 200 | 3,200 |
| Type $D_{50}$ | 7,000 | 237,485 | 34.59 | 3,744 | 3,123 | 6,867 | 0.55 | 0.79 | 1.73 | - | 2,200 |
| Type $E_{25}$ | 7,000 | 214,140 | 8.84 | 3,090 | 21,127 | 24,217 | 0.13 | 5.92 | 6.79 | 3,300 | 3,550 |
| Type $E_{50}$ | 7,000 | 224,359 | 13.62 | 3,407 | 13,065 | 16,471 | 0.21 | 3.49 | 4.40 | 2,800 | 2,200 |
| Type F | 7,000 | 197,092 | 7.51 | 2,678 | 23,580 | 26,257 | 0.10 | 7.18 | 7.99 | 3,300 | 6,400 |
| Type A | 8,000 | 328,640 | 29.60 | 5,081 | 6,022 | 11,103 | 0.46 | 1.10 | 2.03 | - | 4,200 |
| Type $B_{25}$ | 8,000 | 252,479 | 12.90 | 3,700 | 15,868 | 19,568 | 0.19 | 3.77 | 4.65 | 350 | 8,800 |
| Type $B_{50}$ | 8,000 | 250,591 | 13.02 | 3,674 | 15,578 | 19,252 | 0.19 | 3.73 | 4.61 | 250 | 8,850 |
| Type $C_{25}$ | 8,000 | 280,406 | 15.24 | 4,298 | 14,097 | 18,394 | 0.23 | 3.02 | 3.94 | 3,450 | 3,700 |
| Type $C_{50}$ | 8,000 | 331,170 | 29.75 | 5,144 | 5,988 | 11,132 | 0.46 | 1.08 | 2.02 | - | 3,700 |
| Type $D_{25}$ | 8,000 | 229,259 | 10.17 | 3,433 | 19,106 | 22,539 | 0.15 | 5.00 | 5.90 | 2,550 | 5,900 |
| Type $D_{50}$ | 8,000 | 255,136 | 32.97 | 4,024 | 3,715 | 7,739 | 0.52 | 0.87 | 1.82 | - | 4,400 |
| Type $E_{25}$ | 8,000 | 212,314 | 8.57 | 3,025 | 21,758 | 24,783 | 0.12 | 6.15 | 7.00 | 5,350 | 5,750 |
| Type $E_{50}$ | 8,000 | 226,221 | 12.96 | 3,377 | 14,073 | 17,450 | 0.19 | 3.73 | 4.63 | 4,800 | 4,250 |
| Type F | 8,000 | 193,334 | 7.17 | 2,571 | 24,405 | 26,976 | 0.10 | 7.57 | 8.37 | 4,300 | 8,750 |

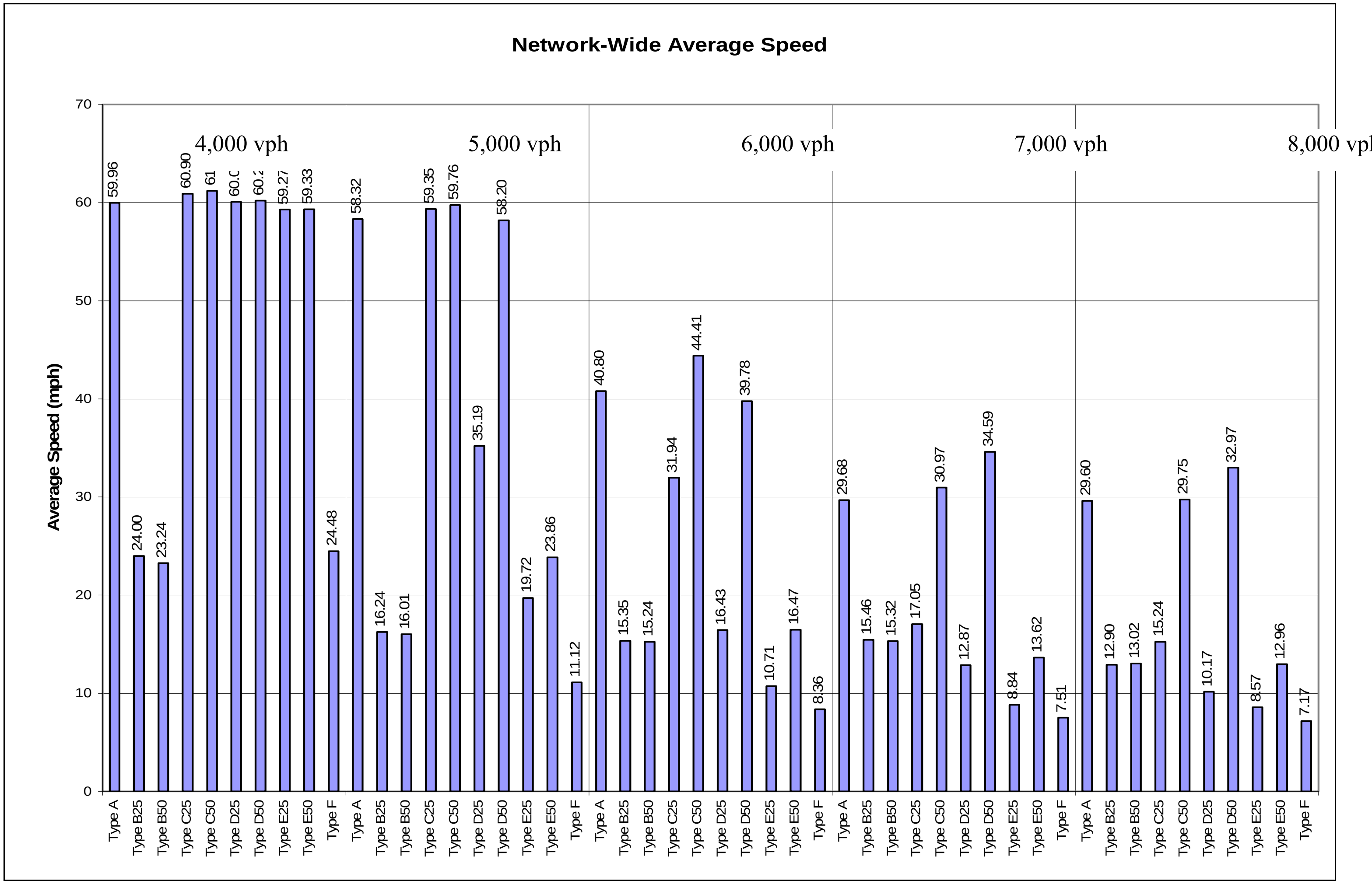


**Figure 41**
**Network-wide average speed**

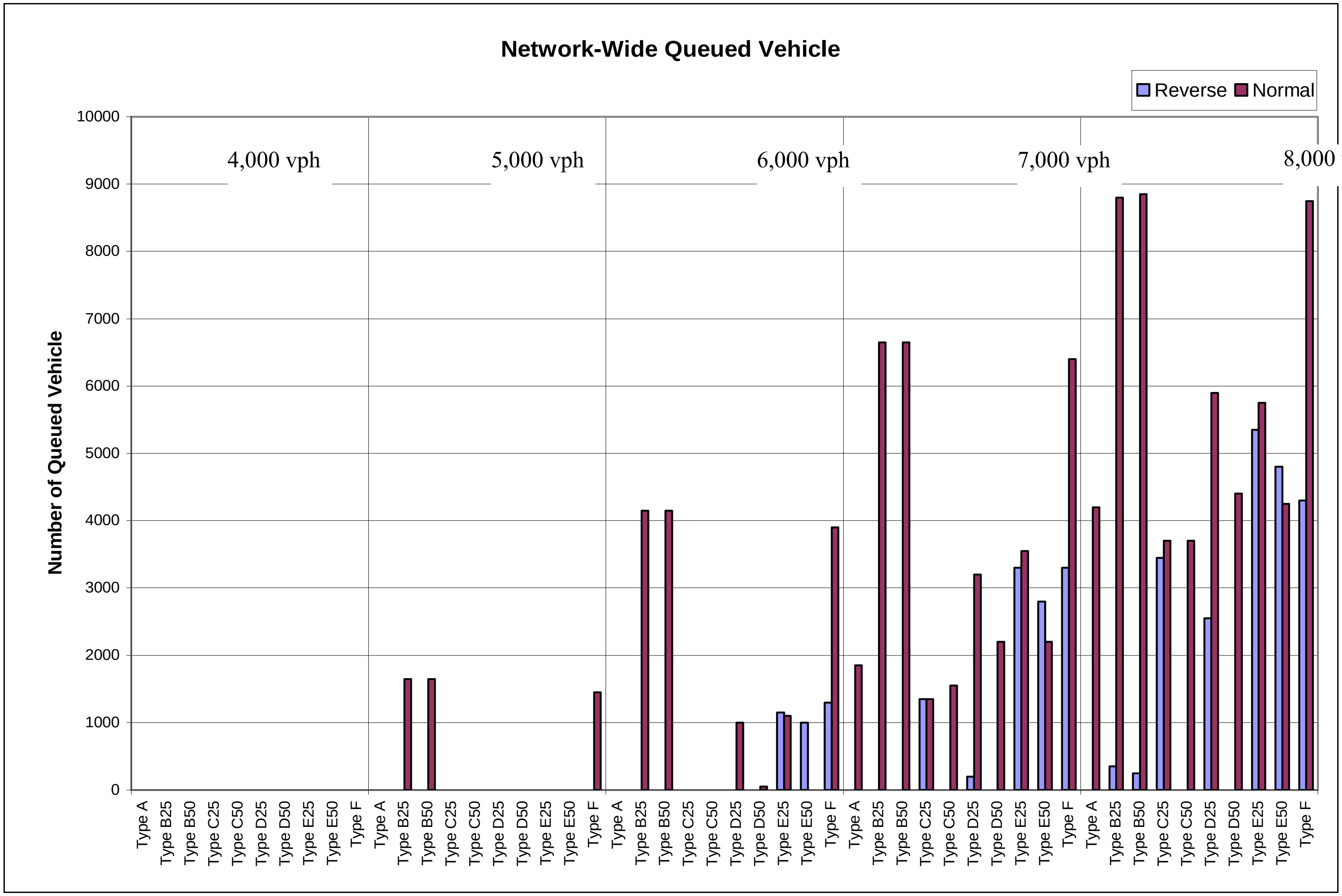


**Figure 42**
**Network-wide queued vehicle**

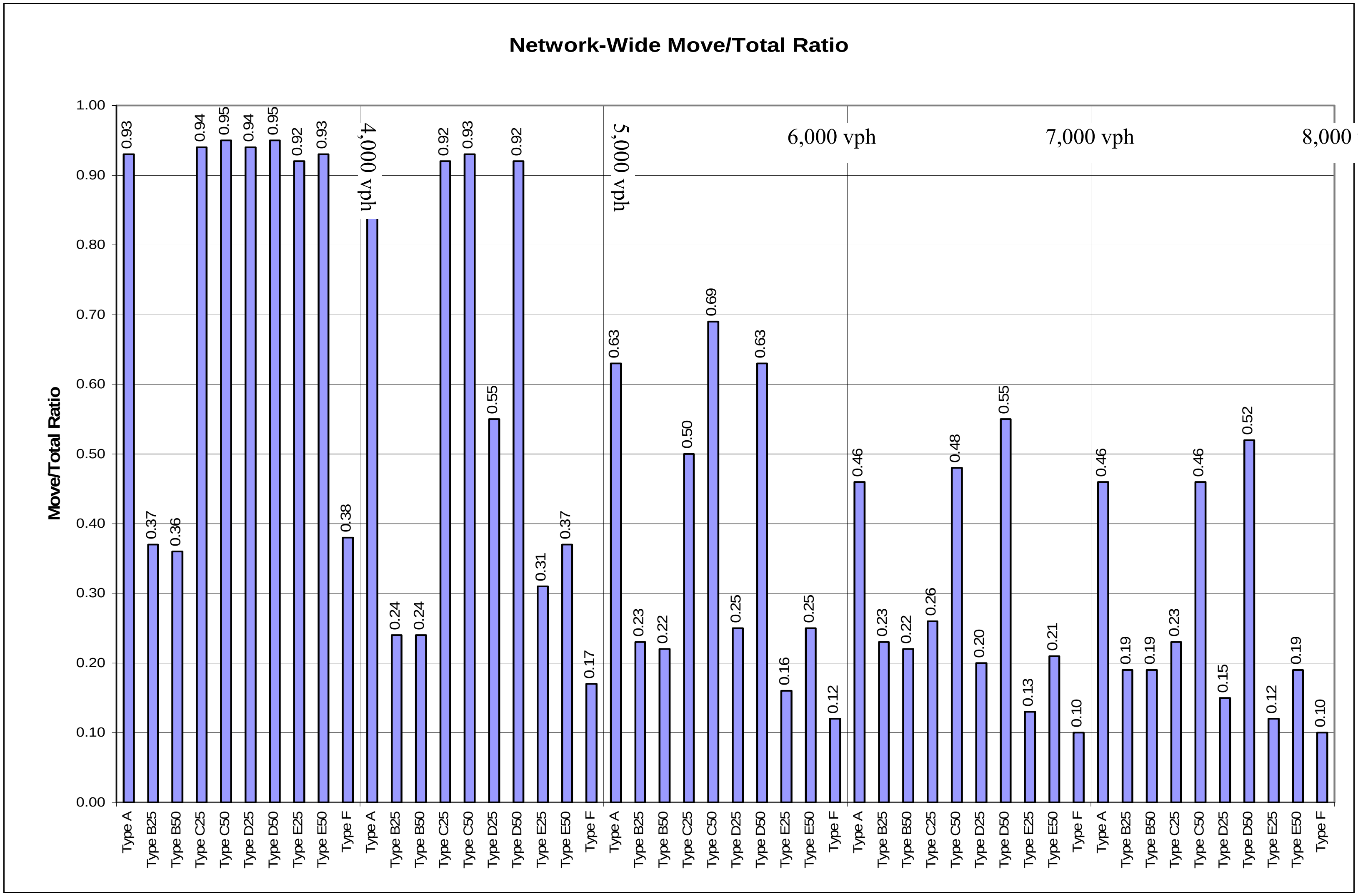


**Figure 43**
**Network-wide move/total ratio**

link statistics, link statistics by lane, cumulative FRESIM statistics, and network-wide statistics were generated. Table 3 and Table 4 provide a summary of the FRESIM cumulative link-specific statistics and network-wide average statistics that were used in this study.

**Table 3**
**Definitions of FRESIM cumulative link-specific statistics**
***[33]***

| **Link Statistics** | |
|---|---|
| Vehicles In | Number of vehicles that have entered the link since the beginning of the simulation. |
| Vehicles Out | Number of vehicles that have been discharged from the link since the beginning of the simulation. |
| Lane Change | Number of lane changes that have occurred on the link since the beginning of the simulation. |
| Current Content | Number of vehicles currently on the link. |
| Average Content | Total number of vehicle seconds accumulated on the link since the beginning of the simulation divided by the number of seconds since the beginning of the simulation. |
| Vehicle Miles | Total distance traveled on the link by all vehicles on the link since the beginning of the simulation. |
| Vehicle Minutes | Total time on the link for all vehicles on the link since the beginning of the simulation. |
| Total Time (Seconds/ vehicle) | Link length divided by the average speed (in feet/second) of all vehicles on the link since the beginning of the simulation. |
| Move Time (Seconds/ vehicle) | Total Time per vehicle multiplied by the Ratio of Move Time to Total Time. |
| Delay Time (Seconds/ vehicle) | Total Time per vehicle minus Move Time per vehicle. |
| M/ T | Total Vehicle Minutes minus the total accumulated number of vehicle delay (in seconds), divided by Total Vehicle Minutes. Delay is the difference between the time it would take a vehicle to travel the length of the link if it traveled at the link freeflow speed and the actual time that it takes the vehicle to travel that distance. |
| Total (Veh-Min/Veh-Mile) | Total Vehicle Minutes divided by Vehicle Miles. |
| Delay (Veh-Min/Veh-Mile) | Vehicle Minutes divided by Vehicle Miles multiplied by (1 minus Ratio of Move Time to Total Time). This represents average delay time for a single vehicle. |
| Volume (Veh/Ln/Hr) | Density multiplied by Speed. |
| Density (Veh/Ln-Mile) | Average Content divided by the link length divided by the average number of lanes on the link. |
| Speed (Miles/Hr) | Vehicle Miles divided by (Vehicle Minutes divided by 60). |

**Table 4**
**Definitions network-wide average statistics**
***[33]***

| **Network Statistics** | |
|---|---|
| Vehicle Miles | Summation of link Vehicle Miles for all links. |
| Vehicle Minutes | Summation of Total Time for each link. |
| Moving/Total Trip Time | Network Moving Time divided by Network Total Time. |
| Speed (MI/H) | Network Vehicle Miles divided by Network Total Time. |
| Total Delay (Veh-Min) | Total Delay per Vehicle Trip, representing the Average Delay per Vehicle in seconds. |
| Travel Time (Min/Veh-Mile) | Network Total Time divided by Network Vehicle Miles. |
| Delay Time (Min/Veh-Mile) | Network Delay Time divided by Network Vehicle Miles. |

### Time-Period Output Data

CORSIM computed the intermediate output link statistics by accumulating the preceding time-period statistics into the current time-period statistics. Hence, to find the intermediate output link statistic for each time-period, the generated cumulative statistics data were separated and recalculated correspondingly. The following equations were used to compute time-period statistics based on CORSIM's output results, where $TP_n$ is current time-period *n* and $TP_{n-1}$ is the previous time-period *n-1*.

- $TP_n$ Vehicles In = ($TP_n$ Vehicles In) – ($TP_{n-1}$ Vehicles In)
- $TP_n$ Vehicles Out = ($TP_n$ Vehicles Out) – ($TP_{n-1}$ Vehicles Out)
- $TP_n$ Veh-Miles = ($TP_n$ Veh-Miles) – ($TP_{n-1}$ Veh-Miles)
- $TP_n$ Veh-Min = ($TP_n$ Veh-Min) – ($TP_{n-1}$ Veh-Min)
- $TP_n$ Total Time (sec/veh) = $\frac{TP_n \text{Veh - Min}}{TP_n \text{Veh - Miles}} \times \frac{\text{Link Length}}{5280} \times 60$
- 
- $TP_n$ Move Time (sec/veh) = $\frac{\text{Link Length}}{\text{Speed Limit}} \times \frac{3600}{5280}$, the current $TP_n$ Move Time is assumed to be the default travel time required to complete the specific link with the posted speed limit
- $TP_n$ Delay Time (sec/veh) = $TP_n$ Total Time (sec/veh)- $TP_n$ Move Time (sec/veh)
- $TP_n$ M/T = $\frac{TP_n \text{Move Time (sec/veh)}}{TP_n \text{Total Time (sec/veh)}}$

- $TP_n$ Total (Veh-Min/Veh-Miles) = $\dfrac{TP_n \text{Veh - Min}}{TP_n \text{Veh - Miles}}$
- $TP_n$ Delay (Veh-Min/Veh-Miles) = $\dfrac{TP_n \text{Veh - Min}}{TP_n \text{Veh - Miles}} \times (1 - TP_n \text{ M/T})$
- $TP_n$ Volume (veh/ln/hr) = $\dfrac{TP_n \text{Veh - Miles}}{\dfrac{\text{Link Length}}{5280} \times \text{Lane \#}} \times 4$
- $TP_n$ Density (veh/ln-mile) = $\dfrac{TP_n \text{Volume (veh/ln/hr)}}{TP_n \text{Speed (mph)}}$
- $TP_n$ Speed (mph) = $\dfrac{TP_n \text{Veh - Miles}}{TP_n \text{Veh - Min}} \times 60$
- $TP_n$ Total Vehicle-Miles = ($TP_n$ Vehicle-Miles) – ($TP_{n-1}$ Vehicle-Miles)
- $TP_n$ Move Time (Vehicle-Hours) = ($TP_n$ Move Time) – ($TP_{n-1}$ Move Time)
- $TP_n$ Delay Time (Vehicle-Hours) = ($TP_n$ Delay Time) – ($TP_{n-1}$ Delay Time)
- $TP_n$ Total Time (Vehicle-Hours) = ($TP_n$ Total Time) – ($TP_{n-1}$ Total Time)
- $TP_n$ Average Speed (mph) = $\dfrac{TP_n \text{Total Vehicle - Miles}}{TP_n \text{Total Time (Vehicle - Hours)}}$
- $TP_n$ Move/Total = $\dfrac{TP_n \text{Move Time}}{TP_n \text{Total Time}}$
- $TP_n$ Delay Time (Minutes/Mile) = $\dfrac{TP_n \text{Delay Time (Vehicle - Hours)}}{TP_n \text{Total Vehicle - Mile}} \times 60$
- $TP_n$ Total Time (Minutes/Mile) = $\dfrac{TP_n \text{Total Time (Vehicle - Hours)}}{TP_n \text{Total Vechile - Miles}} \times 60$

Table 5 and Table 6 show the original cumulative FRESIM link statistics, the calculated time-period FRESIM link statistics, original network-wide statistics, and the calculated time-period network-wide statistics. Calculated time-period FRESIM link statistics and calculated time-period network-wide statistics for 30 runs of each simulation model were computed for the mean, minimum, maximum, standard deviation, as well as the 95 percent confidence interval statistics.

Table 5 through Table 8 also reflect time-period intermediate output link statistics. These means for each model that were used for statistical comparison in the following chapter were computed by averaging the results of the 30 runs.

## Table 5
## Original cumulative and calculated time-period FRESIM link statistics

| ORIGINAL CUMULATIVE FRESIM LINK STATISTICS | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LINK ID | TP | LINK | VEHICLES IN | VEHICLES OUT | LANE CHNG | CURR CONT | AVG CONT | VEH-MILES | VEH-MIN | TOTAL TIME (SEC/VEH) | MOVE TIME (SEC/VEH) | DELAY TIME (SEC/VEH) | M/T | TOTAL (VEH-MIN/VEH-MILE) | DELAY (VEH-MIN/VEH-MILE) | VOLUME (VEH/LN/HR) | DENSITY (VEH/LN-MILE) | SPEED (MPH) |
| Aa30_0001 | 1 | ( 10, 8 ) | 665 | 665 | 32 | 2 | 5.3 | 56.7 | 80.2 | 7.2 | 6.8 | 0.4 | 0.94 | 1.41 | 0.09 | 1,329.9 | 31.40 | 42.41 |
| Aa30_0063 | 2 | ( 10, 8 ) | 1,348 | 1,340 | 49 | 10 | 5.4 | 114.5 | 162.0 | 7.2 | 6.8 | 0.4 | 0.94 | 1.42 | 0.09 | 1,343.6 | 31.70 | 42.40 |
| Aa30_0125 | 3 | ( 10, 8 ) | 2,011 | 2,005 | 85 | 8 | 5.5 | 171.2 | 245.6 | 7.3 | 6.8 | 0.5 | 0.93 | 1.43 | 0.11 | 1,339.2 | 32.00 | 41.83 |
| Aa30_0187 | 4 | ( 10, 8 ) | 2,695 | 2,692 | 105 | 5 | 5.5 | 229.5 | 329.0 | 7.3 | 6.8 | 0.5 | 0.93 | 1.43 | 0.11 | 1,346.1 | 32.20 | 41.84 |
| Aa30_0249 | 5 | ( 10, 8 ) | 3,354 | 3,351 | 131 | 5 | 5.5 | 285.8 | 409.4 | 7.3 | 6.8 | 0.5 | 0.93 | 1.43 | 0.1 | 1,341.2 | 32.00 | 41.88 |
| Aa30_0311 | 6 | ( 10, 8 ) | 4,042 | 4,041 | 174 | 3 | 5.5 | 344.4 | 493.6 | 7.3 | 6.8 | 0.5 | 0.93 | 1.43 | 0.11 | 1,346.8 | 32.20 | 41.86 |
| Aa30_0373 | 7 | ( 10, 8 ) | 4,717 | 4,709 | 207 | 10 | 5.5 | 401.6 | 575.7 | 7.3 | 6.8 | 0.5 | 0.93 | 1.43 | 0.1 | 1,346.3 | 32.20 | 41.85 |
| Aa30_0435 | 8 | ( 10, 8 ) | 5,390 | 5,384 | 241 | 8 | 5.5 | 459.1 | 657.3 | 7.3 | 6.8 | 0.5 | 0.93 | 1.43 | 0.1 | 1,346.6 | 32.10 | 41.90 |
| Aa30_0497 | 9 | ( 10, 8 ) | 6,068 | 6,060 | 271 | 10 | 5.5 | 516.7 | 740.9 | 7.3 | 6.8 | 0.5 | 0.93 | 1.43 | 0.11 | 1,347.4 | 32.20 | 41.85 |
| Aa30_0559 | 10 | ( 10, 8 ) | 6,734 | 6,730 | 298 | 6 | 5.5 | 573.8 | 823.8 | 7.3 | 6.8 | 0.6 | 0.92 | 1.44 | 0.11 | 1,346.5 | 32.20 | 41.79 |
| Aa30_0621 | 11 | ( 10, 8 ) | 7,415 | 7,406 | 330 | 11 | 5.5 | 631.5 | 906.4 | 7.3 | 6.8 | 0.5 | 0.93 | 1.44 | 0.11 | 1,347.2 | 32.20 | 41.80 |
| Aa30_0683 | 12 | ( 10, 8 ) | 8,072 | 8,068 | 358 | 6 | 5.5 | 687.8 | 987.0 | 7.3 | 6.8 | 0.5 | 0.93 | 1.43 | 0.11 | 1,345.0 | 32.20 | 41.81 |
| Aa30_0745 | 13 | ( 10, 8 ) | 8,766 | 8,763 | 381 | 5 | 5.5 | 747.0 | 1,073.6 | 7.3 | 6.8 | 0.6 | 0.92 | 1.44 | 0.11 | 1,348.4 | 32.30 | 41.75 |
| Aa30_0807 | 14 | ( 10, 8 ) | 9,428 | 9,427 | 405 | 3 | 5.5 | 803.4 | 1,154.4 | 7.3 | 6.8 | 0.6 | 0.92 | 1.44 | 0.11 | 1,346.7 | 32.20 | 41.76 |
| Aa30_0869 | 15 | ( 10, 8 ) | 10,113 | 10,111 | 440 | 4 | 5.5 | 861.7 | 1,235.9 | 7.3 | 6.8 | 0.5 | 0.93 | 1.43 | 0.11 | 1,348.1 | 32.20 | 41.83 |
| Aa30_0931 | 16 | ( 10, 8 ) | 10,796 | 10,795 | 472 | 3 | 5.5 | 920.0 | 1,319.1 | 7.3 | 6.8 | 0.5 | 0.93 | 1.43 | 0.11 | 1,349.3 | 32.20 | 41.85 |

| CALCULATED TIME-PERIOD FRESIM LINK STATISTICS | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LINK ID | TP | LINK | VEHICLES IN | VEHICLES OUT | LANE CHNG | CURR CONT | AVG CONT | TP VEH-MILES | TP VEH-MIN | TP TOTAL TIME (SEC/VEH) | TP MOVE TIME (SEC/VEH) | TP DELAY TIME (SEC/VEH) | TP M/T | TP TOTAL (VEH-MIN/VEH-MILE) | TP DELAY (VEH-MIN/VEH-MILE) | TP VOLUME (VEH/LN/HR) | TP DENSITY (VEH/LN-MILE) | TP SPEED (MPH) |
| Aa30_T0001 | 1 | ( 10, 8 ) | 665 | 665 | 32 | - | - | 56.7 | 80.2 | 7.23 | 6.82 | 0.41 | 0.94 | 1.41 | 0.08 | 1,330.6 | 31.37 | 42.42 |
| Aa30_T0063 | 2 | ( 10, 8 ) | 683 | 675 | 17 | - | - | 57.8 | 81.8 | 7.24 | 6.82 | 0.42 | 0.94 | 1.42 | 0.08 | 1,356.4 | 31.99 | 42.40 |
| Aa30_T0125 | 3 | ( 10, 8 ) | 663 | 665 | 36 | - | - | 56.7 | 83.6 | 7.54 | 6.82 | 0.72 | 0.90 | 1.47 | 0.14 | 1,330.6 | 32.70 | 40.69 |
| Aa30_T0187 | 4 | ( 10, 8 ) | 684 | 687 | 20 | - | - | 58.3 | 83.4 | 7.32 | 6.82 | 0.50 | 0.93 | 1.43 | 0.10 | 1,368.1 | 32.62 | 41.94 |
| Aa30_T0249 | 5 | ( 10, 8 ) | 659 | 659 | 26 | - | - | 56.3 | 80.4 | 7.30 | 6.82 | 0.48 | 0.93 | 1.43 | 0.09 | 1,321.2 | 31.45 | 42.01 |
| Aa30_T0311 | 6 | ( 10, 8 ) | 688 | 690 | 43 | - | - | 58.6 | 84.2 | 7.35 | 6.82 | 0.53 | 0.93 | 1.44 | 0.10 | 1,375.1 | 32.93 | 41.76 |
| Aa30_T0373 | 7 | ( 10, 8 ) | 675 | 668 | 33 | - | - | 57.2 | 82.1 | 7.34 | 6.82 | 0.52 | 0.93 | 1.44 | 0.10 | 1,342.3 | 32.11 | 41.80 |
| Aa30_T0435 | 8 | ( 10, 8 ) | 673 | 675 | 34 | - | - | 57.5 | 81.6 | 7.26 | 6.82 | 0.44 | 0.94 | 1.42 | 0.09 | 1,349.3 | 31.91 | 42.28 |
| Aa30_T0497 | 9 | ( 10, 8 ) | 678 | 676 | 30 | - | - | 57.6 | 83.6 | 7.42 | 6.82 | 0.60 | 0.92 | 1.45 | 0.12 | 1,351.7 | 32.70 | 41.34 |
| Aa30_T0559 | 10 | ( 10, 8 ) | 666 | 670 | 27 | - | - | 57.1 | 82.9 | 7.42 | 6.82 | 0.61 | 0.92 | 1.45 | 0.12 | 1,339.9 | 32.42 | 41.33 |
| Aa30_T0621 | 11 | ( 10, 8 ) | 681 | 676 | 32 | - | - | 57.7 | 82.6 | 7.32 | 6.82 | 0.50 | 0.93 | 1.43 | 0.10 | 1,354.0 | 32.31 | 41.91 |
| Aa30_T0683 | 12 | ( 10, 8 ) | 657 | 662 | 28 | - | - | 56.3 | 80.6 | 7.32 | 6.82 | 0.50 | 0.93 | 1.43 | 0.10 | 1,321.2 | 31.52 | 41.91 |
| Aa30_T0745 | 13 | ( 10, 8 ) | 694 | 695 | 23 | - | - | 59.2 | 86.6 | 7.48 | 6.82 | 0.66 | 0.91 | 1.46 | 0.13 | 1,389.2 | 33.87 | 41.02 |
| Aa30_T0807 | 14 | ( 10, 8 ) | 662 | 664 | 24 | - | - | 56.4 | 80.8 | 7.33 | 6.82 | 0.51 | 0.93 | 1.43 | 0.10 | 1,323.5 | 31.60 | 41.88 |
| Aa30_T0869 | 15 | ( 10, 8 ) | 685 | 684 | 35 | - | - | 58.3 | 81.5 | 7.15 | 6.82 | 0.33 | 0.95 | 1.40 | 0.06 | 1,368.1 | 31.88 | 42.92 |
| Aa30_T0931 | 16 | ( 10, 8 ) | 683 | 684 | 32 | - | - | 58.3 | 83.2 | 7.30 | 6.82 | 0.48 | 0.93 | 1.43 | 0.09 | 1,368.1 | 32.54 | 42.04 |

**Table 6**
**Original and calculated time-period network-wide average statistics**

| ORIGINAL NETWORK-WIDE AVERAGE STATISTICS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| LINK ID | TP | TOTAL VEHICLE-MILE | MOVE TIME (VEHICLE-HOURS) | DELAY TIME (VEHICLE-HOURS) | TOTAL TIME (VEHICLE-HOURS) | AVERAGE SPEED (MPH) | MOVE/TOTAL | DELAY TIME (MINUTES/MILE) | TOTAL TIME (MINUTES/MILE) |
| Aa_465 | 1 | 17,753.48 | 273.81 | 70.25 | 344.06 | 51.60 | 0.80 | 0.24 | 1.16 |
| Aa_466 | 2 | 35,504.21 | 547.39 | 156.68 | 704.08 | 50.43 | 0.78 | 0.26 | 1.19 |
| Aa_467 | 3 | 53,353.28 | 823.09 | 257.22 | 1,080.31 | 49.39 | 0.76 | 0.29 | 1.21 |
| Aa_468 | 4 | 71,185.74 | 1,098.32 | 367.15 | 1,465.47 | 48.58 | 0.75 | 0.31 | 1.24 |
| Aa_469 | 5 | 88,869.68 | 1,371.92 | 491.07 | 1,862.99 | 47.70 | 0.74 | 0.33 | 1.26 |
| Aa_470 | 6 | 106,589.60 | 1,646.02 | 631.05 | 2,277.07 | 46.81 | 0.72 | 0.36 | 1.28 |
| Aa_471 | 7 | 124,227.00 | 1,918.50 | 792.16 | 2,710.66 | 45.83 | 0.71 | 0.38 | 1.31 |
| Aa_472 | 8 | 141,870.60 | 2,189.88 | 964.64 | 3,154.52 | 44.97 | 0.69 | 0.41 | 1.33 |
| Aa_473 | 9 | 159,534.80 | 2,462.62 | 1,151.89 | 3,614.52 | 44.14 | 0.68 | 0.43 | 1.36 |
| Aa_474 | 10 | 177,252.40 | 2,736.47 | 1,347.81 | 4,084.28 | 43.40 | 0.67 | 0.46 | 1.38 |
| Aa_475 | 11 | 194,972.70 | 3,010.51 | 1,555.82 | 4,566.33 | 42.70 | 0.66 | 0.48 | 1.41 |
| Aa_476 | 12 | 212,632.20 | 3,283.21 | 1,773.82 | 5,057.03 | 42.05 | 0.65 | 0.5 | 1.43 |
| Aa_477 | 13 | 230,420.30 | 3,557.83 | 2,001.82 | 5,559.65 | 41.45 | 0.64 | 0.52 | 1.45 |
| Aa_478 | 14 | 247,954.10 | 3,827.94 | 2,243.15 | 6,071.08 | 40.84 | 0.63 | 0.54 | 1.47 |
| Aa_479 | 15 | 265,505.50 | 4,098.71 | 2,499.35 | 6,598.06 | 40.24 | 0.62 | 0.56 | 1.49 |
| Aa_480 | 16 | 283,035.80 | 4,369.40 | 2,770.50 | 7,139.90 | 39.64 | 0.61 | 0.59 | 1.51 |

| CALCULATED TIME-PERIOD NETWORK-WIDE AVERAGE STATISTICS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| LINK ID | TP | TP TOTAL VEHICLE-MILE | TP MOVE TIME (VEHICLE-HOURS) | TP DELAY TIME (VEHICLE-HOURS) | TP TOTAL TIME (VEHICLE-HOURS) | TP AVERAGE SPEED (MPH) | TP MOVE/TOTAL | TP DELAY TIME (MINUTES/MILE) | TP TOTAL TIME (MINUTES/MILE) |
| Aa_T465 | 1 | 17,753.48 | 273.81 | 70.25 | 344.06 | 51.60 | 0.80 | 0.24 | 1.16 |
| Aa_T466 | 2 | 17,750.73 | 273.58 | 86.43 | 360.02 | 49.30 | 0.76 | 0.29 | 1.22 |
| Aa_T467 | 3 | 17,849.07 | 275.70 | 100.54 | 376.23 | 47.44 | 0.73 | 0.34 | 1.26 |
| Aa_T468 | 4 | 17,832.46 | 275.23 | 109.93 | 385.16 | 46.30 | 0.71 | 0.37 | 1.30 |
| Aa_T469 | 5 | 17,683.94 | 273.60 | 123.92 | 397.52 | 44.49 | 0.69 | 0.42 | 1.35 |
| Aa_T470 | 6 | 17,719.92 | 274.10 | 139.98 | 414.08 | 42.79 | 0.66 | 0.47 | 1.40 |
| Aa_T471 | 7 | 17,637.40 | 272.48 | 161.11 | 433.59 | 40.68 | 0.63 | 0.55 | 1.48 |
| Aa_T472 | 8 | 17,643.60 | 271.38 | 172.48 | 443.86 | 39.75 | 0.61 | 0.59 | 1.51 |
| Aa_T473 | 9 | 17,664.20 | 272.74 | 187.25 | 460.00 | 38.40 | 0.59 | 0.64 | 1.56 |
| Aa_T474 | 10 | 17,717.60 | 273.85 | 195.92 | 469.76 | 37.72 | 0.58 | 0.66 | 1.59 |
| Aa_T475 | 11 | 17,720.30 | 274.04 | 208.01 | 482.05 | 36.76 | 0.57 | 0.70 | 1.63 |
| Aa_T476 | 12 | 17,659.50 | 272.70 | 218.00 | 490.70 | 35.99 | 0.56 | 0.74 | 1.67 |
| Aa_T477 | 13 | 17,788.10 | 274.62 | 228.00 | 502.62 | 35.39 | 0.55 | 0.77 | 1.70 |
| Aa_T478 | 14 | 17,533.80 | 270.11 | 241.33 | 511.43 | 34.28 | 0.53 | 0.83 | 1.75 |
| Aa_T479 | 15 | 17,551.40 | 270.77 | 256.20 | 526.98 | 33.31 | 0.51 | 0.88 | 1.80 |
| Aa_T480 | 16 | 17,530.30 | 270.69 | 271.15 | 541.84 | 32.35 | 0.50 | 0.93 | 1.85 |

## Table 7
## Time-period intermediate output link statistics

**TIME-PERIOD FRESIM LINK MIN, MAX, AVERAGE, STANDARD DEVIATION, AND 95%CI STATISTICS FOR 30 RUNS**

| LINK ID | TP | LINK | VEHICLES IN | | | | | | VEHICLES OUT | | | | | | VEH-MILES | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | MIN | MAX | AVE | STDEV | MIN 95%CI | MAX 95%CI | MIN | MAX | AVE | STDEV | MIN 95%CI | MAX 95%CI | MIN | MAX | AVE | STDEV | MIN 95%CI |
| Aa25_0001 | 1 | ( 10, 8 ) | 652 | 693 | 671.13 | 10.30 | 667.45 | 674.82 | 646 | 693 | 670.90 | 10.67 | 667.08 | 674.72 | 55.3 | 58.9 | 57.18 | 0.88 | 56.86 |
| Aa25_0063 | 2 | ( 10, 8 ) | 647 | 703 | 676.10 | 12.82 | 671.51 | 680.69 | 645 | 706 | 677.40 | 12.51 | 672.92 | 681.88 | 55.2 | 60 | 57.69 | 1.05 | 57.32 |
| Aa25_0125 | 3 | ( 10, 8 ) | 643 | 713 | 674.03 | 12.40 | 669.60 | 678.47 | 648 | 715 | 673.40 | 13.21 | 668.67 | 678.13 | 54.9 | 60.8 | 57.40 | 1.09 | 57.01 |
| Aa25_0187 | 4 | ( 10, 8 ) | 653 | 696 | 676.60 | 10.48 | 672.85 | 680.35 | 652 | 696 | 676.63 | 11.59 | 672.49 | 680.78 | 55.8 | 59.4 | 57.67 | 0.93 | 57.34 |
| Aa25_0249 | 5 | ( 10, 8 ) | 648 | 713 | 674.67 | 13.76 | 669.74 | 679.59 | 644 | 709 | 674.13 | 13.63 | 669.25 | 679.01 | 55.2 | 60.6 | 57.50 | 1.15 | 57.09 |
| Aa25_0311 | 6 | ( 10, 8 ) | 653 | 701 | 671.77 | 11.86 | 667.52 | 676.01 | 650 | 702 | 672.93 | 12.82 | 668.35 | 677.52 | 55.6 | 59.7 | 57.27 | 1.05 | 56.89 |
| Aa25_0373 | 7 | ( 10, 8 ) | 645 | 703 | 674.27 | 13.68 | 669.37 | 679.16 | 648 | 703 | 675.03 | 13.67 | 670.14 | 679.93 | 55 | 60 | 57.50 | 1.18 | 57.07 |
| Aa25_0435 | 8 | ( 10, 8 ) | 648 | 697 | 678.80 | 10.51 | 675.04 | 682.56 | 646 | 696 | 676.80 | 10.33 | 673.10 | 680.50 | 55.1 | 59.3 | 57.77 | 0.89 | 57.45 |
| Aa25_0497 | 9 | ( 10, 8 ) | 635 | 705 | 674.60 | 14.70 | 669.34 | 679.86 | 632 | 703 | 675.63 | 15.35 | 670.14 | 681.13 | 53.9 | 60.1 | 57.54 | 1.27 | 57.08 |
| Aa25_0559 | 10 | ( 10, 8 ) | 643 | 704 | 675.37 | 13.67 | 670.47 | 680.26 | 639 | 711 | 674.53 | 13.38 | 669.74 | 679.32 | 54.6 | 60.4 | 57.53 | 1.13 | 57.12 |
| Aa25_0621 | 11 | ( 10, 8 ) | 646 | 698 | 674.23 | 10.60 | 670.44 | 678.03 | 642 | 702 | 674.57 | 11.64 | 670.40 | 678.73 | 54.8 | 59.7 | 57.46 | 0.94 | 57.12 |
| Aa25_0683 | 12 | ( 10, 8 ) | 655 | 702 | 675.63 | 13.06 | 670.96 | 680.31 | 651 | 699 | 674.53 | 12.65 | 670.01 | 679.06 | 55.6 | 59.8 | 57.52 | 1.09 | 57.13 |
| Aa25_0745 | 13 | ( 10, 8 ) | 640 | 694 | 671.80 | 12.06 | 667.48 | 676.12 | 646 | 695 | 672.33 | 12.51 | 667.86 | 676.81 | 54.7 | 59.2 | 57.28 | 1.05 | 56.90 |
| Aa25_0807 | 14 | ( 10, 8 ) | 649 | 708 | 678.23 | 14.43 | 673.07 | 683.40 | 657 | 710 | 678.90 | 13.47 | 674.08 | 683.72 | 55.8 | 60.3 | 57.82 | 1.17 | 57.40 |
| Aa25_0869 | 15 | ( 10, 8 ) | 645 | 711 | 676.50 | 15.30 | 671.02 | 681.98 | 643 | 715 | 675.97 | 15.46 | 670.43 | 681.50 | 54.8 | 60.8 | 57.63 | 1.32 | 57.15 |
| Aa25_0931 | 16 | ( 10, 8 ) | 644 | 712 | 672.53 | 14.95 | 667.18 | 677.88 | 644 | 711 | 672.53 | 14.43 | 667.37 | 677.70 | 54.9 | 60.6 | 57.31 | 1.25 | 56.87 |

| LINK ID | TP | LINK | VEH-MIN | | | | | | TOTAL TIME (SEC/VEH) | | | | | | MOVE TIME (SEC/VEH) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | MIN | MAX | AVE | STDEV | MIN 95%CI | MAX 95%CI | MIN | MAX | AVE | STDEV | MIN 95%CI | MAX 95%CI | MIN | MAX | AVE | STDEV | MIN 95%CI |
| Aa25_0001 | 1 | ( 10, 8 ) | 79.7 | 84.6 | 81.79 | 1.32 | 81.32 | 82.27 | 7.18 | 7.52 | 7.32 | 0.08 | 7.29 | 7.34 | 6.818 | 6.818 | 6.82 | 2E-07 | 6.82 |
| Aa25_0063 | 2 | ( 10, 8 ) | 79.5 | 90.0 | 83.25 | 2.49 | 82.36 | 84.14 | 7.15 | 7.854 | 7.38 | 0.15 | 7.33 | 7.43 | 6.818 | 6.818 | 6.82 | 2E-07 | 6.82 |
| Aa25_0125 | 3 | ( 10, 8 ) | 76.8 | 87.2 | 82.08 | 1.87 | 81.41 | 82.75 | 7.15 | 7.54 | 7.31 | 0.09 | 7.28 | 7.34 | 6.818 | 6.818 | 6.82 | 2E-07 | 6.82 |
| Aa25_0187 | 4 | ( 10, 8 ) | 78.7 | 88.1 | 82.93 | 2.31 | 82.10 | 83.76 | 7.18 | 7.794 | 7.35 | 0.14 | 7.30 | 7.40 | 6.818 | 6.818 | 6.82 | 2E-07 | 6.82 |
| Aa25_0249 | 5 | ( 10, 8 ) | 78.4 | 86.1 | 82.32 | 2.01 | 81.60 | 83.04 | 7.16 | 7.468 | 7.32 | 0.08 | 7.29 | 7.35 | 6.818 | 6.818 | 6.82 | 2E-07 | 6.82 |
| Aa25_0311 | 6 | ( 10, 8 ) | 78.3 | 85.7 | 82.21 | 1.98 | 81.51 | 82.92 | 7.16 | 7.63 | 7.34 | 0.12 | 7.30 | 7.38 | 6.818 | 6.818 | 6.82 | 2E-07 | 6.82 |
| Aa25_0373 | 7 | ( 10, 8 ) | 78.6 | 87.9 | 82.34 | 2.34 | 81.51 | 83.18 | 7.13 | 7.777 | 7.32 | 0.14 | 7.27 | 7.37 | 6.818 | 6.818 | 6.82 | 2E-07 | 6.82 |
| Aa25_0435 | 8 | ( 10, 8 ) | 78.0 | 88.6 | 82.94 | 1.88 | 82.27 | 83.62 | 7.19 | 7.718 | 7.34 | 0.11 | 7.30 | 7.38 | 6.818 | 6.818 | 6.82 | 2E-07 | 6.82 |
| Aa25_0497 | 9 | ( 10, 8 ) | 76.6 | 88.9 | 82.32 | 2.35 | 81.48 | 83.16 | 7.16 | 7.564 | 7.32 | 0.10 | 7.28 | 7.35 | 6.818 | 6.818 | 6.82 | 2E-07 | 6.82 |
| Aa25_0559 | 10 | ( 10, 8 ) | 79.1 | 91.2 | 82.80 | 2.70 | 81.83 | 83.76 | 7.18 | 7.958 | 7.36 | 0.18 | 7.30 | 7.42 | 6.818 | 6.818 | 6.82 | 2E-07 | 6.82 |
| Aa25_0621 | 11 | ( 10, 8 ) | 78.7 | 88.3 | 82.64 | 2.04 | 81.91 | 83.37 | 7.18 | 7.64 | 7.35 | 0.11 | 7.32 | 7.39 | 6.818 | 6.818 | 6.82 | 2E-07 | 6.82 |
| Aa25_0683 | 12 | ( 10, 8 ) | 79.6 | 89.2 | 82.97 | 2.29 | 82.15 | 83.79 | 7.2 | 7.653 | 7.38 | 0.11 | 7.34 | 7.42 | 6.818 | 6.818 | 6.82 | 2E-07 | 6.82 |
| Aa25_0745 | 13 | ( 10, 8 ) | 78.7 | 86.6 | 82.16 | 1.86 | 81.50 | 82.83 | 7.19 | 7.599 | 7.34 | 0.11 | 7.30 | 7.38 | 6.818 | 6.818 | 6.82 | 2E-07 | 6.82 |
| Aa25_0807 | 14 | ( 10, 8 ) | 79.9 | 87.7 | 83.00 | 1.93 | 82.31 | 83.69 | 7.19 | 7.525 | 7.34 | 0.09 | 7.31 | 7.37 | 6.818 | 6.818 | 6.82 | 2E-07 | 6.82 |
| Aa25_0869 | 15 | ( 10, 8 ) | 78.5 | 87.1 | 82.53 | 2.12 | 81.77 | 83.29 | 7.15 | 7.558 | 7.32 | 0.10 | 7.29 | 7.36 | 6.818 | 6.818 | 6.82 | 2E-07 | 6.82 |
| Aa25_0931 | 16 | ( 10, 8 ) | 78.4 | 90.6 | 82.19 | 2.42 | 81.32 | 83.05 | 7.22 | 7.734 | 7.33 | 0.12 | 7.29 | 7.37 | 6.818 | 6.818 | 6.82 | 2E-07 | 6.82 |

**Table 8**
**Time-period intermediate output link statistics (continued)**

| TIME-PERIOD FRESIM LINK MIN, MAX, AVERAGE, STANDARD DEVIATION, AND 95%CI STATISTICS FOR 30 RUNS, con't | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LINK ID | TP | LINK | DELAY TIME (SEC/VEH) | | | | | | TOTAL TIME (VEH-MIN/VEH-MILE) | | | | | | DELAY TIME (VEH-MIN/VEH-MI | | | | |
| | | | MIN | MAX | AVE | STDEV | MIN 95%CI | MAX 95%CI | MIN | MAX | AVE | STDEV | MIN 95%CI | MAX 95%CI | MIN | MAX | AVE | STDEV | MIN 95%CI |
| Aa25_0001 | 1 | ( 10, 8 ) | 0.37 | 0.70 | 0.50 | 0.08 | 0.47 | 0.53 | 1.40 | 1.47 | 1.43 | 0.02 | 1.42 | 1.44 | 0.07 | 0.14 | 0.10 | 0.02 | 0.09 |
| Aa25_0063 | 2 | ( 10, 8 ) | 0.33 | 1.04 | 0.56 | 0.15 | 0.51 | 0.61 | 1.40 | 1.54 | 1.44 | 0.03 | 1.43 | 1.45 | 0.06 | 0.20 | 0.11 | 0.03 | 0.10 |
| Aa25_0125 | 3 | ( 10, 8 ) | 0.34 | 0.72 | 0.49 | 0.09 | 0.46 | 0.53 | 1.40 | 1.47 | 1.43 | 0.02 | 1.42 | 1.44 | 0.07 | 0.14 | 0.10 | 0.02 | 0.09 |
| Aa25_0187 | 4 | ( 10, 8 ) | 0.36 | 0.98 | 0.53 | 0.14 | 0.49 | 0.58 | 1.40 | 1.52 | 1.44 | 0.03 | 1.43 | 1.45 | 0.07 | 0.19 | 0.10 | 0.03 | 0.09 |
| Aa25_0249 | 5 | ( 10, 8 ) | 0.34 | 0.65 | 0.50 | 0.08 | 0.47 | 0.53 | 1.40 | 1.46 | 1.43 | 0.02 | 1.43 | 1.44 | 0.07 | 0.13 | 0.10 | 0.02 | 0.09 |
| Aa25_0311 | 6 | ( 10, 8 ) | 0.34 | 0.81 | 0.52 | 0.12 | 0.48 | 0.57 | 1.40 | 1.49 | 1.44 | 0.02 | 1.43 | 1.44 | 0.07 | 0.16 | 0.10 | 0.02 | 0.09 |
| Aa25_0373 | 7 | ( 10, 8 ) | 0.32 | 0.96 | 0.51 | 0.14 | 0.46 | 0.55 | 1.40 | 1.52 | 1.43 | 0.03 | 1.42 | 1.44 | 0.06 | 0.19 | 0.10 | 0.03 | 0.09 |
| Aa25_0435 | 8 | ( 10, 8 ) | 0.37 | 0.90 | 0.52 | 0.11 | 0.48 | 0.56 | 1.41 | 1.51 | 1.44 | 0.02 | 1.43 | 1.44 | 0.07 | 0.18 | 0.10 | 0.02 | 0.09 |
| Aa25_0497 | 9 | ( 10, 8 ) | 0.34 | 0.75 | 0.50 | 0.10 | 0.46 | 0.53 | 1.40 | 1.48 | 1.43 | 0.02 | 1.42 | 1.44 | 0.07 | 0.15 | 0.10 | 0.02 | 0.09 |
| Aa25_0559 | 10 | ( 10, 8 ) | 0.36 | 1.14 | 0.54 | 0.18 | 0.48 | 0.61 | 1.40 | 1.56 | 1.44 | 0.04 | 1.43 | 1.45 | 0.07 | 0.22 | 0.11 | 0.04 | 0.09 |
| Aa25_0621 | 11 | ( 10, 8 ) | 0.36 | 0.82 | 0.54 | 0.11 | 0.50 | 0.57 | 1.40 | 1.49 | 1.44 | 0.02 | 1.43 | 1.45 | 0.07 | 0.16 | 0.10 | 0.02 | 0.10 |
| Aa25_0683 | 12 | ( 10, 8 ) | 0.38 | 0.84 | 0.56 | 0.11 | 0.52 | 0.60 | 1.41 | 1.50 | 1.44 | 0.02 | 1.43 | 1.45 | 0.08 | 0.16 | 0.11 | 0.02 | 0.10 |
| Aa25_0745 | 13 | ( 10, 8 ) | 0.37 | 0.78 | 0.52 | 0.11 | 0.48 | 0.56 | 1.41 | 1.49 | 1.43 | 0.02 | 1.43 | 1.44 | 0.07 | 0.15 | 0.10 | 0.02 | 0.09 |
| Aa25_0807 | 14 | ( 10, 8 ) | 0.37 | 0.71 | 0.52 | 0.09 | 0.49 | 0.55 | 1.41 | 1.47 | 1.44 | 0.02 | 1.43 | 1.44 | 0.07 | 0.14 | 0.10 | 0.02 | 0.10 |
| Aa25_0869 | 15 | ( 10, 8 ) | 0.33 | 0.74 | 0.51 | 0.10 | 0.47 | 0.54 | 1.40 | 1.48 | 1.43 | 0.02 | 1.42 | 1.44 | 0.06 | 0.14 | 0.10 | 0.02 | 0.09 |
| Aa25_0931 | 16 | ( 10, 8 ) | 0.40 | 0.92 | 0.51 | 0.12 | 0.47 | 0.56 | 1.41 | 1.51 | 1.43 | 0.02 | 1.43 | 1.44 | 0.08 | 0.18 | 0.10 | 0.02 | 0.09 |

| LINK ID | TP | LINK | VOLUME (VEH/LN/HR) | | | | | | DENSITY (VEH/LN-MILE) | | | | | | SPEED (MILE/HR) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | MIN | MAX | AVE | STDEV | MIN 95%CI | MAX 95%CI | MIN | MAX | AVE | STDEV | MIN 95%CI | MAX 95%CI | MIN | MAX | AVE | STDEV | MIN 95%CI |
| Aa25_0001 | 1 | ( 10, 8 ) | 1,298 | 1,382 | 1,341.82 | 20.69 | 1,334.42 | 1,349.23 | 31.17 | 33.09 | 31.99 | 0.52 | 31.81 | 32.18 | 40.80 | 42.71 | 41.95 | 0.46 | 41.78 |
| Aa25_0063 | 2 | ( 10, 8 ) | 1,295 | 1,408 | 1,353.87 | 24.63 | 1,345.06 | 1,362.68 | 31.09 | 35.20 | 32.56 | 0.97 | 32.21 | 32.91 | 39.07 | 42.91 | 41.60 | 0.80 | 41.31 |
| Aa25_0125 | 3 | ( 10, 8 ) | 1,288 | 1,427 | 1,347.06 | 25.63 | 1,337.89 | 1,356.24 | 30.04 | 34.10 | 32.10 | 0.73 | 31.84 | 32.36 | 40.69 | 42.89 | 41.97 | 0.51 | 41.79 |
| Aa25_0187 | 4 | ( 10, 8 ) | 1,309 | 1,394 | 1,353.32 | 21.71 | 1,345.55 | 1,361.09 | 30.78 | 34.46 | 32.43 | 0.90 | 32.11 | 32.76 | 39.36 | 42.74 | 41.74 | 0.75 | 41.47 |
| Aa25_0249 | 5 | ( 10, 8 ) | 1,295 | 1,422 | 1,349.41 | 26.99 | 1,339.75 | 1,359.07 | 30.66 | 33.67 | 32.20 | 0.79 | 31.92 | 32.48 | 41.09 | 42.86 | 41.92 | 0.44 | 41.76 |
| Aa25_0311 | 6 | ( 10, 8 ) | 1,305 | 1,401 | 1,343.86 | 24.66 | 1,335.03 | 1,352.68 | 30.62 | 33.52 | 32.15 | 0.77 | 31.88 | 32.43 | 40.21 | 42.87 | 41.80 | 0.68 | 41.56 |
| Aa25_0373 | 7 | ( 10, 8 ) | 1,291 | 1,408 | 1,349.26 | 27.75 | 1,339.33 | 1,359.18 | 30.74 | 34.38 | 32.21 | 0.92 | 31.88 | 32.53 | 39.45 | 43.01 | 41.91 | 0.76 | 41.64 |
| Aa25_0435 | 8 | ( 10, 8 ) | 1,293 | 1,392 | 1,355.75 | 20.92 | 1,348.26 | 1,363.23 | 30.51 | 34.65 | 32.44 | 0.73 | 32.18 | 32.70 | 39.75 | 42.67 | 41.80 | 0.62 | 41.58 |
| Aa25_0497 | 9 | ( 10, 8 ) | 1,265 | 1,410 | 1,350.19 | 29.78 | 1,339.54 | 1,360.85 | 29.96 | 34.77 | 32.19 | 0.92 | 31.87 | 32.52 | 40.56 | 42.88 | 41.95 | 0.55 | 41.75 |
| Aa25_0559 | 10 | ( 10, 8 ) | 1,281 | 1,417 | 1,349.96 | 26.49 | 1,340.48 | 1,359.44 | 30.94 | 35.67 | 32.38 | 1.06 | 32.00 | 32.76 | 38.55 | 42.72 | 41.71 | 0.98 | 41.36 |
| Aa25_0621 | 11 | ( 10, 8 ) | 1,286 | 1,401 | 1,348.32 | 22.00 | 1,340.44 | 1,356.19 | 30.78 | 34.54 | 32.32 | 0.80 | 32.04 | 32.61 | 40.16 | 42.75 | 41.73 | 0.60 | 41.51 |
| Aa25_0683 | 12 | ( 10, 8 ) | 1,305 | 1,403 | 1,349.80 | 25.54 | 1,340.66 | 1,358.94 | 31.13 | 34.89 | 32.45 | 0.90 | 32.13 | 32.77 | 40.09 | 42.60 | 41.61 | 0.62 | 41.38 |
| Aa25_0745 | 13 | ( 10, 8 ) | 1,284 | 1,389 | 1,344.17 | 24.61 | 1,335.37 | 1,352.98 | 30.78 | 33.87 | 32.13 | 0.73 | 31.88 | 32.39 | 40.38 | 42.70 | 41.84 | 0.63 | 41.61 |
| Aa25_0807 | 14 | ( 10, 8 ) | 1,309 | 1,415 | 1,356.92 | 27.57 | 1,347.05 | 1,366.79 | 31.25 | 34.30 | 32.46 | 0.75 | 32.19 | 32.73 | 40.78 | 42.70 | 41.81 | 0.51 | 41.63 |
| Aa25_0869 | 15 | ( 10, 8 ) | 1,286 | 1,427 | 1,352.31 | 30.98 | 1,341.22 | 1,363.39 | 30.70 | 34.07 | 32.28 | 0.83 | 31.98 | 32.57 | 40.59 | 42.92 | 41.90 | 0.59 | 41.69 |
| Aa25_0931 | 16 | ( 10, 8 ) | 1,288 | 1,422 | 1,344.95 | 29.31 | 1,334.46 | 1,355.44 | 30.66 | 35.43 | 32.14 | 0.95 | 31.81 | 32.48 | 39.67 | 42.50 | 41.85 | 0.65 | 41.62 |

## ANALYSIS

A total of 30 runs were executed for this project in CORSIM. Each run consisted of 19 one-hour periods. A 19-hour period of simulation took about 2 hours to execute on a Pentium IV-1700 MHz PC; therefore approximately 60 hours of processing time was required. In this research, Measures of Effectiveness (MOE) of traffic flow and speed per link were used. Data such as number of vehicles, vehicles-miles and vehicles-minute per link were used to estimate traffic flow, average speed, and time to discharge the segment before a hurricane landfall. Since the MOE's of this study were analyzed per link, figure 44 shows the CORSIM link node diagram that was used for the evaluation of the contraflow operation. The CORSIM network shown in this figure was divided into three sections to provide a more clear view of the link node diagram.

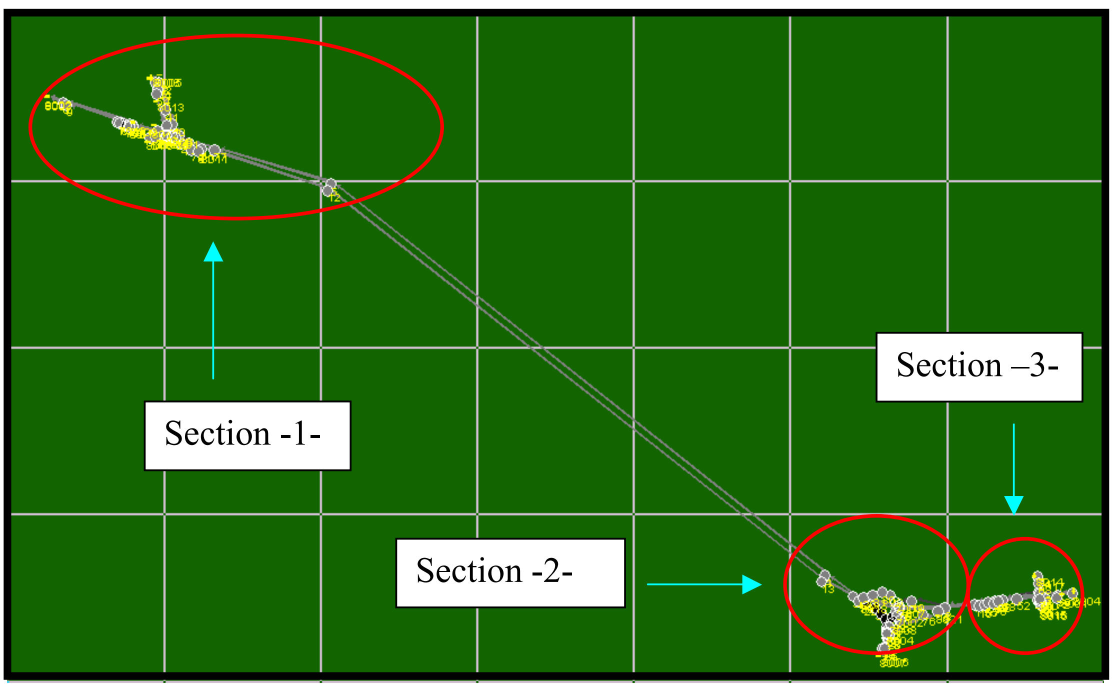


**Figure 44**
**Link node diagram of the contraflow segment**

Section one represents the initiation point of the segment as shown in figure 45. Section two represents the link node diagram on I-10/I310 Interchange as shown in figure 46, and finally, section three represents the termination point of the segment as shown in figure 47. For Figure 45 to Figure 47, plans from LSP were used. The numbers in the circles in Figure 45 to Figure 47 represent node numbers of the CORSIM network.

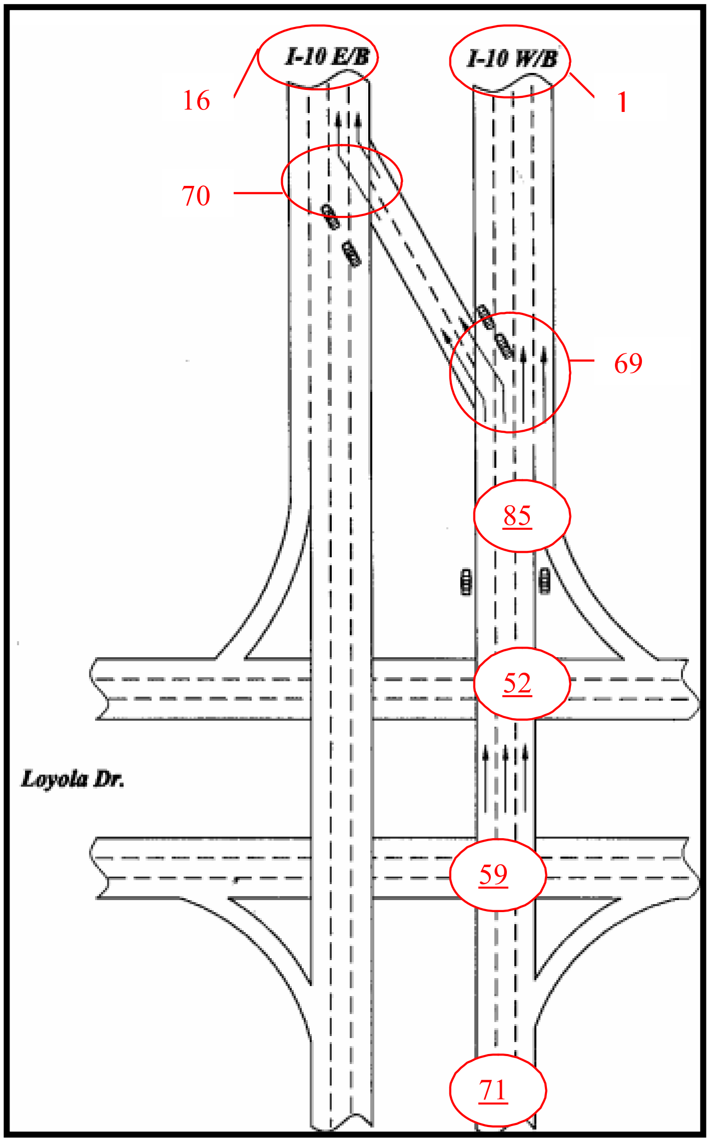


**Figure 45**
**Link node diagram in Section 1**

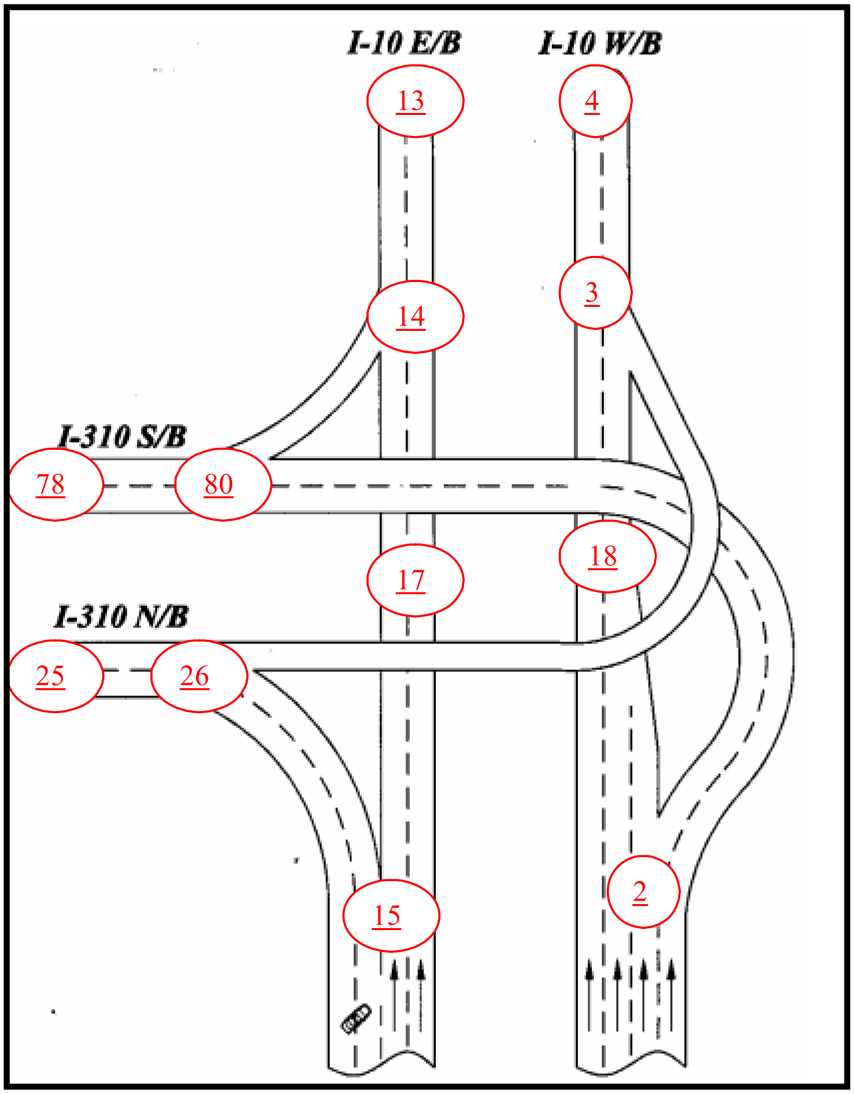


**Figure 46**
**Link node diagram in Section 2**

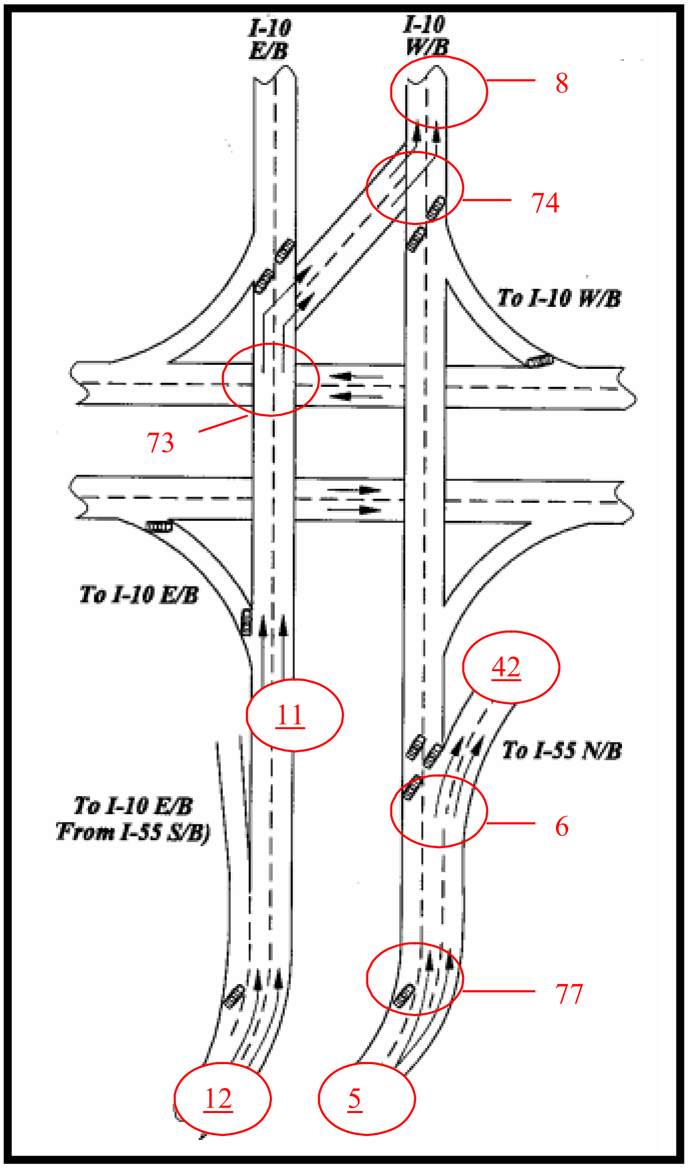


**Figure 47**
**Link node diagram in Section 3**

**CORSIM Output**
The CORSIM model produced a lot of unnecessary data for this study. Data such as vehicles emission and fuel consumption made it hard to estimate the objectives of this study. To address this problem, with the use of a macro-function in Excel, only the data based on volume and speed were imported into a spreadsheet.

These data were cumulative since CORSIM can provide only cumulative data for each period. For example, instead of having the volume at period 10, CORSIM provides the sum of volumes of period one through period 10 and all divided by 10. To estimate the volume and speed during a period, the following procedures were used. The volume of a period was the cumulative number of vehicles getting into the system until that particular period minus the cumulative number of vehicles from the previous period as shown in Equation 1. The space-mean speed of a period as shown in Equation 2 was the cumulative number of vehicles-miles until that particular period minus the cumulative numbers of vehicles-miles from the previous period. This total was then divided by the sum of the cumulative vehicles-minutes until that period minus the cumulative vehicles-minutes from the previous period. Since each period is 1 hour, the calculated speed was multiplied by 60 to have the speed in miles per hour.

**Volume (10:00am) = Number of vehicles at 10am - Number of vehicles at 9:00 am (Equation 1)**

$$\textbf{Speed (10:00am)} = \frac{(Vehicles - miles\_at10am) - (Vehicles - miles\_at9am)}{(Vehicles - \min\_at10am) - (Vehicles - \min\_at9am)} \times 60 \quad \textbf{(Equation 2)}$$

After the volume and speed for each hour were estimated, the following plots were developed to represent the volume and speed in the network for each period as shown in Figures 48 and 49.

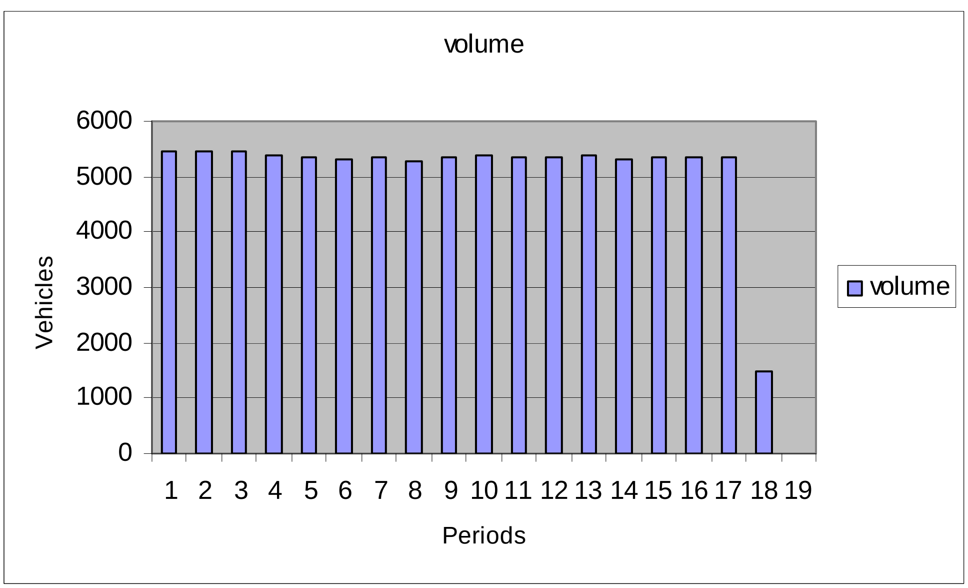


**Figure 48**
**Average volume in vehicles per hour for each period**

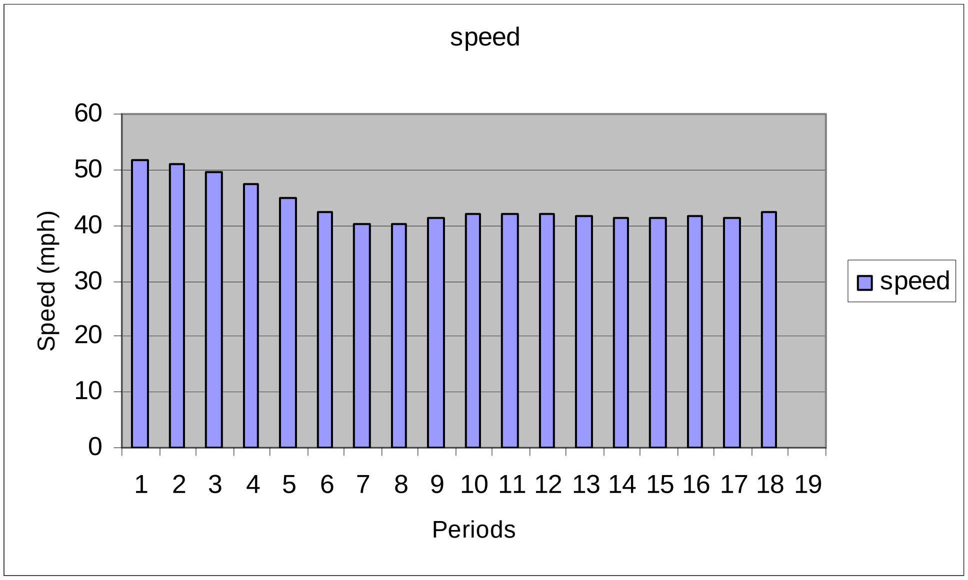


**Figure 49**
**Average speed in miles per hour for each period**

Based on the volume-graph shown in figure 48, the volume in the network was approximately the same for periods 1 through 17 since each of these periods used a constant evacuation response rate of 5,450 vehicles per hour. From the total amount of 92,650 evacuation vehicles, 91,182 vehicles left the system during the 17 periods from 8:00am to 1:00am of the following morning. The remaining 1,468 vehicles entered the network during period 18.

The speed-graph in figure 49 shows a decrease of average speed in the network until period six. This likely resulted from the adjustment of speed based on the traffic flow and capacity of the road. For example, if during the first period, 10 vehicles did not exit the network from an amount of vehicles that entered in the network, then these 10 vehicles would be an additional volume for the second period. Consequently, since more vehicles are in the segment during the second period than in the first, the speed of the segment will be reduced until it reaches the saturation conditions. At period 18, there was an increase in speed because the volume during period 18 was decreased.

However, the results from the above graphs were average volume and speed of the whole network. In this study, three routes were developed. The first route, Normal I-10, starts from I-10, before the Loyola entrance, and ends on I-55 after the I-10/I-55 Interchange. The second route, Normal Loyola, starts from Loyola Avenue continues on westbound I-10 through Loyola Avenue entrance ramp, and ends on I-55 after the I-10/I-55 Interchange. The third and last route, Reverse I-10, starts from I-10, before Loyola entrance, continues into the inbound lanes of the interstate through the Kenner median crossover and ends on I-10 after the median crossover in LaPlace. To estimate the volume and speed for each route, Equations 1 and 2 were used based on link data. For example, if a route included only link A, B, and C, then the volume of this route will be equal to the summation of vehicles in these three links.

**Volume**

The volume-graph in figure 48 showed that the volumes through period 17 were constant. Therefore, only the last three periods (17, 18, and 19) were used for analysis. Given that the model was simulated 30 times, 30 values of volume were analyzed for the last three periods. The average, minimum, maximum and 95 percent confident interval of the volume was estimated for each link in the network using Equation 1. Figure 50 shows the average volume per link in the first route (Normal I-10) for the last three periods. The numbers in the ellipses represent a specific link of the route, and the nodes dotted on the step lines illustrate the number of vehicles in the particular link. During period 17, the number of vehicles in link (58, 85), which represents the Loyola Avenue Interchange, increased because additional vehicles entered in the normal lanes of I-10 from the Loyola Avenue. The number of vehicles in link (69, 56), which represents the normal lanes after the Kenner crossover, decreased because some evacuees used the reverse lanes through the crossover. After the diversion point the volume in the normal lanes of I-10 was constant. Figure 48 illustrates that the average volume of the network during period 18 was much less than period 17. As a result, the number of vehicles per link during period 18, as shown in Figure 50, was less than period 17, except the last six links. The reason for the same number of vehicles during period 17 and 18 in the last six links, is because the vehicles that were in the previous links during period 17 travel into the last six links during period 18. The volume during period 19 was zero because there were no vehicles getting in the network.

Figure 51 shows the number of vehicles in each link for the second route (Normal Loyola) for the last three periods. During periods 17 and 18, there was an increase in the number of vehicles at link (58, 85), because vehicles from Loyola Avenue merged into the normal lanes of I-10. After that link, since vehicles merged on I-10, the volume characteristics were the same as in the normal lanes shown in figure 50.

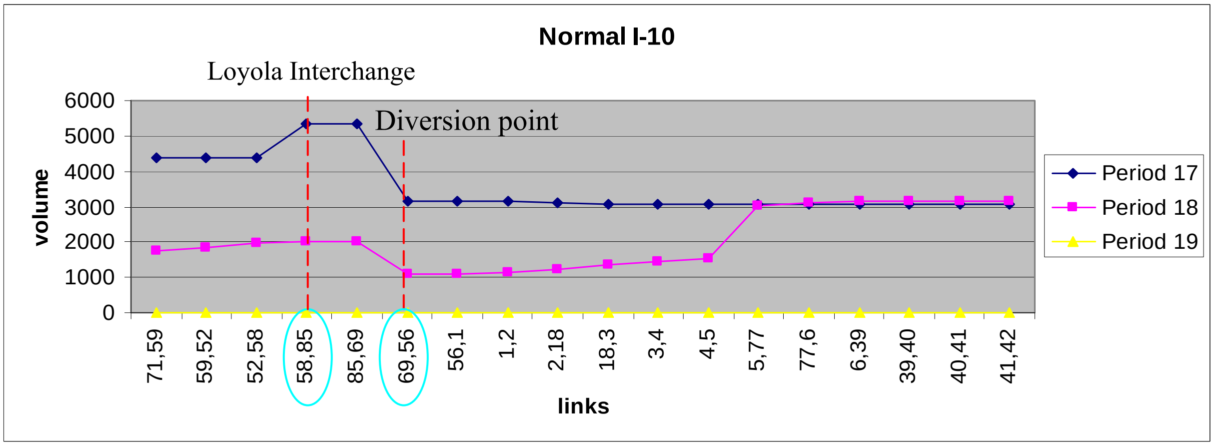


**Figure 50**
**Number of vehicles per hour using the normal I-10 to evacuate**

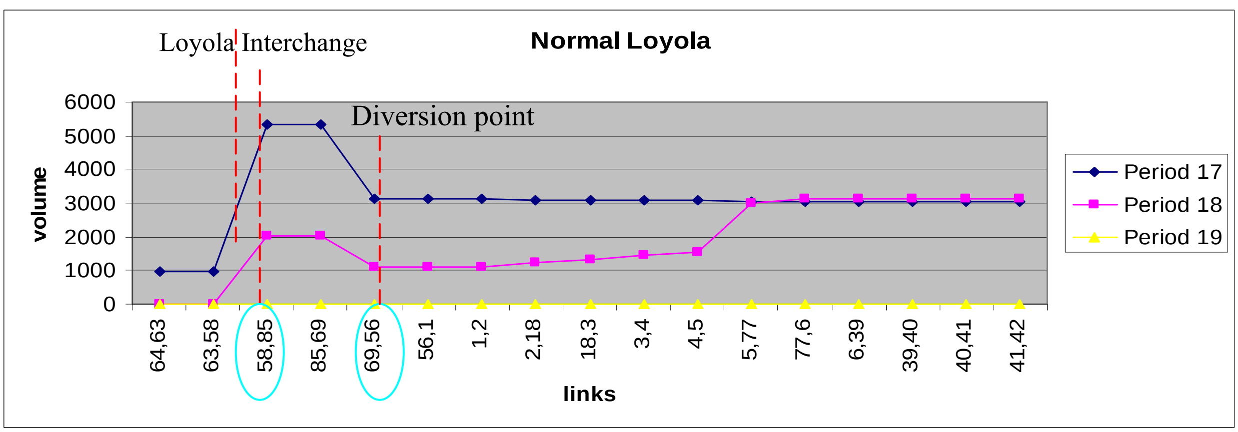


**Figure 51**
**Volume from Loyola Avenue and continuing in the normal I-10**

Finally, the volume in each link for the third route (Reverse I-10) is shown in figure 52. Until link (85, 69) the volume characteristics were the same as in the normal lanes of I-10. At link (69, 70), which represents the Kenner crossover, there was a decrease in the amount of vehicles because an amount of vehicles used the normal lanes. After the crossover, the volume in the reverse lanes during period 17 was constant. During period 18 the volume from link (69, 56) to link (13, 12) was also constant. However at link (12, 11), there was a slight increase of volume, and in the following links the volume was constant. The increase in link (12, 11) was because the vehicles that were in the previous links during period 17 traveled into this link during period 18. The volume during period 19 was zero since there were no vehicles entering in the network.

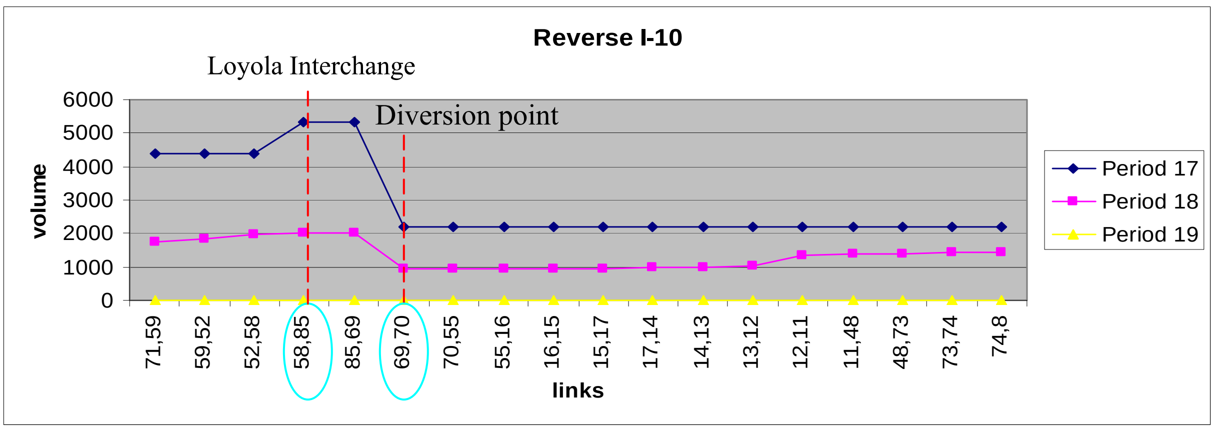


**Figure 52**
**Volume using the reverse lanes on I-10 to evacuate**

Since period 17 had the largest volume among the last three periods, it was chosen to develop Table 9. This table shows the number of vehicles entering and exiting from the network during period 17. The values for the two entry links, and the values for the two exit links, were estimated based on the minimum, maximum, average, and 95 percent confidence intervals. This table also shows the number of vehicles that used the normal and the reverse lanes. Link (69, 70) represents the median crossover were the vehicles start using the reverse lanes, and link (69, 56) represents the segment that vehicles continue on the normal lanes. From these amounts, the percentage of vehicles going through the normal lanes and through the reverse lanes were estimated. Based on the average values, approximately 60 percent of the evacuation vehicles used the normal lanes of I-10 and approximately a 40 percent used the reverse lanes. This volume was the sum of traffic coming from Loyola Avenue and approximately 50 percent coming from the right most lane of westbound I-10.

**Table 9**
**Volume data based on entry, crossover and termination links at period 17**

| Location | Link Segment | Minimum Volume (veh.) | Maximum Volume (veh.) | Average Volume (veh.) | C.I. Upper Bound Volume (veh.) | C.I. Lower Bound Volume (veh.) |
|---|---|---|---|---|---|---|
| | | | | | | |
| **Entry node on I-10** | (71,59) | 4,065 | 4,778 | 4,388 | 4,445 | 4,330 |
| **Entry node in Loyola** | (64,63) | 950 | 950 | 950 | 950 | 950 |
| | **IN** | **5,015** | **5,728** | **5,338** | **5,395** | **5,280** |
| | | | | | | |
| **Normal lanes after the crossover** | (69,56) | 2,946 | 3,372 | 3,144 | 3,179 | 3,108 |
| | **%Normal** | **59.74** | **58.87** | **58.90** | **58.93** | **58.87** |
| | | | | | | |
| **Kenner crossover** | (69,70) | 1,696 | 2,563 | 2,191 | 2,268 | 2,115 |
| | **%Reverse** | **33.82** | **44.75** | **41.06** | **42.03** | **40.06** |
| | | | | | | |
| **Termination point on I-55** | (41,42) | 2,559 | 3,366 | 3,051 | 3,131 | 2,971 |
| **Termination point on I-10** | (74,8) | 1,818 | 2,625 | 2,191 | 2,261.97 | 2,120 |
| | **OUT** | **4377** | **5991** | **5242** | **5393** | **5091** |

The percentage of vehicles that used the normal and the reverse lanes shown in Table 9 was about the same as the theoretical assumptions that 60 percent of the traffic entering the contraflow segment would continue in the normal flow lanes, since it has been hypothesized that evacuees tend to stay on the normal travel lanes *[13]*.

Table 10 was developed from cumulative volume data. This table shows how many vehicles entered and exited the network from period one through period 17. For example, based on the average data, approximately 90,884 vehicles entered in the network and 88,224 vehicles exited. That means that for 88,224 evacuation vehicles, approximately 17 hours were needed to evacuate them from the contraflow segment.

**Table 10**
**Cumulative volume data, based on entry and exit links until period 17**

| Location | Link Segment | Minimum Volume (veh.) | Maximum Volume (veh.) | Average Volume (veh.) | C.I. Upper Bound Volume (veh.) | C.I. Lower Bound Volume (veh.) |
|---|---|---|---|---|---|---|
| | | | | | | |
| **Entry node on I-10** | (71,59) | 74,337 | 75,032 | 74,736 | 74,797 | 74,674 |
| **Entry node in Loyola** | (64,63) | 16,148 | 16,148 | 16,148 | 16,148 | 16,148 |
| | **IN** | **90,485** | **91,180** | **90,884** | **90,945** | **90,822** |
| | | | | | | |
| **Termination point on I-55** | (41,42) | 51,146 | 51,792 | 51,500 | 51,555 | 51,445 |
| **Termination point on I-10** | (74,8) | 36,402 | 37,018 | 36,724 | 36,774 | 36,674 |
| | **OUT** | **87,548** | **88,810** | **88,224** | **88,328** | **88,119** |

### Speed

Data from time periods 17, 18, and 19 were also used to estimate the speed for each link. The average, minimum, maximum, and 95 percent confident intervals of the speed were estimated for each link on the network from the 30-run simulation for these periods. Equation 2 was used to estimate the speed for each link during the last three time periods. From the link data, the speed in each route for periods 17, 18, and 19 were estimated.

Figure 53 shows the average speed in each link for the first route (Normal I-10) during the last three periods. Since the barricades and the Kenner median crossover reduced the capacity in the initial links of the segment, the first links had the lowest speed. After that, the speed started increasing because of the discharge through the LaPlace crossover at node 69. At link (2, 18) the speed decreased because one lane was dropped based on the geometric layout of the contraflow segment. For the following links (18, 3) and (3, 4), there was still a small reduction of speed based on the high demand, created after a lane was dropped in link (2, 18). After a lane drops, vehicles need some space to adjust to the new capacity. Since links (18, 3) and (3, 4) are short in length, about one mile combined, there was a slight reduction of speed until vehicles adjust to the new capacity of the road. Therefore, in the following link (link 4, 5), which was about eight miles long, there was an increase in speed. The decrease of speed at link (5, 77) was caused from link (77, 6), where a transition area was used to represent the termination point in I-10/I-55 interchange. After the termination point, vehicles increased their speed. For period 18, the speed characteristics were similar to period 17, and for period 19 the speed was zero since there were no vehicles.

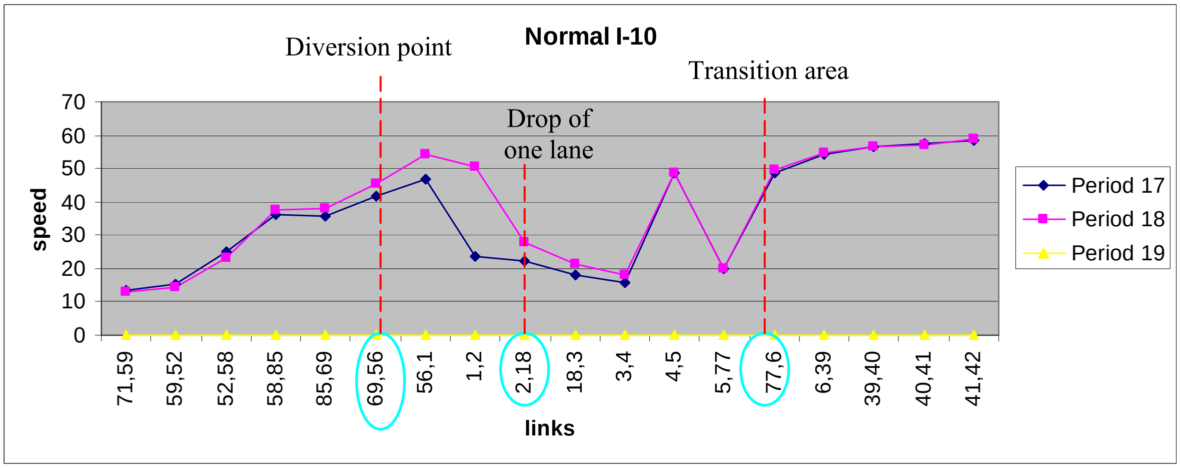


**Figure 53**
**Average speed using the normal I-10**

Figure 54 shows the speed in each link from the second route (Normal Loyola) during the last three periods. After link (63, 58), since vehicles merged into I-10, the speed characteristics were the same as in the normal lanes shown in figure 53.

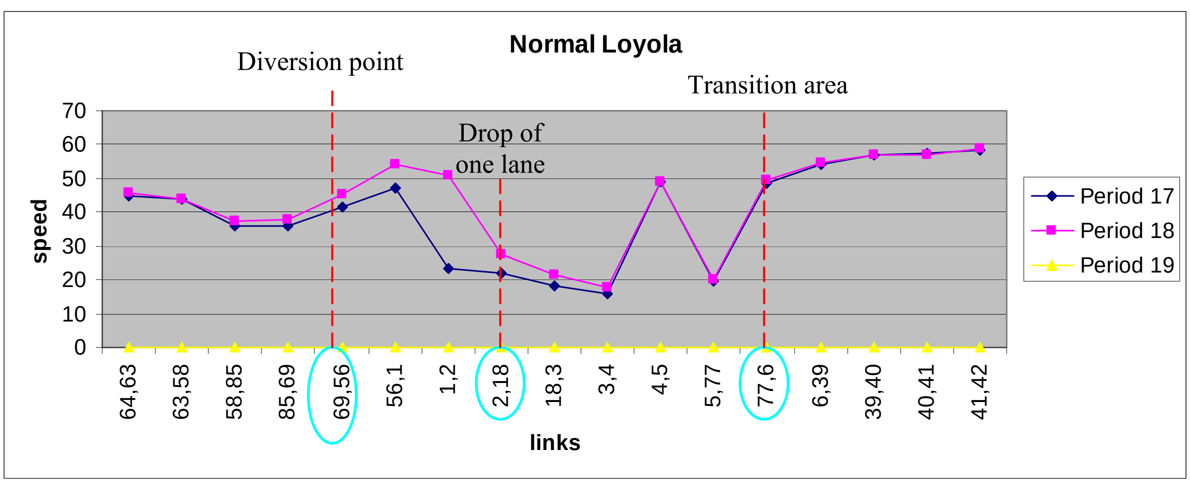


**Figure 54**
**Average speed from Loyola Avenue and continuing in the normal I-10**

Finally, the speed in each link for the third route (Reverse I-10) is shown in figure 55. From link (71, 59) until link (85, 69) the speed characteristics were the same as in the normal lanes of I-10 since they shared the same traveled way in that portion of the route. Link (69, 70) represents the median crossover. After the crossover, the speed increased to free-flow speed. The following links had a free-flow speed until the LaPlace crossover in link (73, 74). After the crossover, the speed increased to free-flow speed.

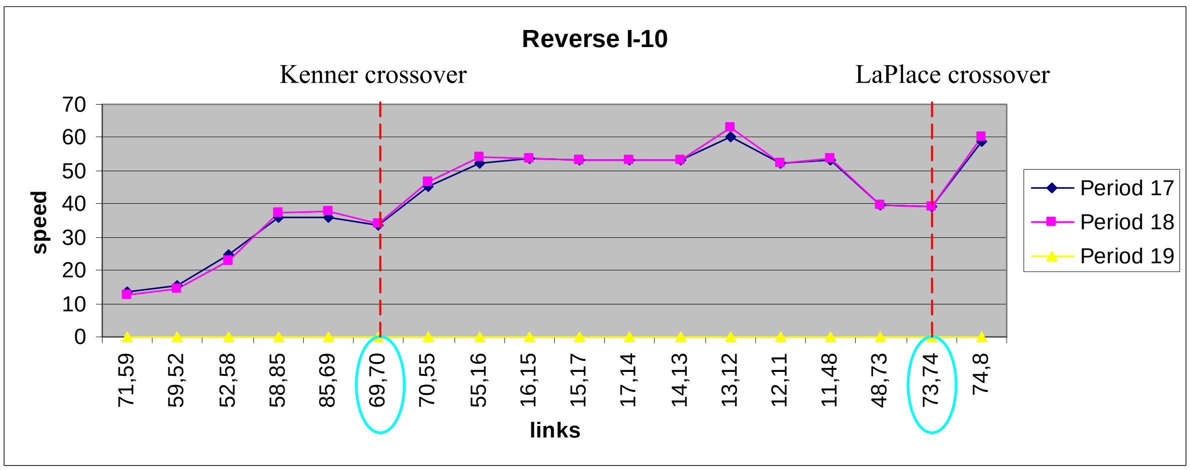


**Figure 55**
**Average speed using the reverse lanes**

Figure 55 shows that the traffic in the reverse lanes operates at higher speeds than in the normal lanes, probably because the volume decreased as fewer vehicles used the reverse lanes (around 40 percent of the total amount).

Table 11 illustrates the travel time and mean speed on the three routes based on average speed and length of each link during the last three periods. The time needed to travel a link was estimated by dividing the link's length by its speed. The time needed to travel a route was estimated from the summation of travel times of the links for that route. Based on this table, the longest time could be used as the amount of time needed to discharge this segment before a hurricane landfall. This research study found approximately 25 minutes would be required to clear this segment based on the first route (Normal I-10).

A mean velocity was calculated based on the travel time and length of each route during the last three time periods, as shown in
Table 11. The route that uses the normal I-10 trough I-55 had the lowest mean speed of approximately 33 mph. The route that uses the reverse lanes had the lowest travel time and

the highest mean speed.

**Table 11**
**Travel time and mean speed on the three routes for the three last periods**

| Simulation Periods | | Normal I-10 (First Route) | Normal Loyola (Second Route) | Reverse I-10 (Third Route) |
|---|---|---|---|---|
| **Period 17** | **Travel Time (minutes)** | 24.33 | 22.06 | 17.09 |
| | **Mean Speed (mph)** | 32.33 | 35.06 | 48.85 |
| **Period 18** | **Travel Time (minutes)** | 23.18 | 20.69 | 16.90 |
| | **Mean Speed (mph)** | 33.94 | 37.37 | 49.39 |
| **Period 19** | **Travel Time (minutes)** | 0.00 | 0.00 | 0.00 |
| | **Mean Speed (mph)** | 0.00 | 0.00 | 0.00 |

The density per link was determined from the number of vehicles in each link divided by the length of each link. Based on the density data, the following graphs were plotted representing the density in each link during periods 17 and 18. The density during period 19 was not estimated because the volume was zero during that time period. The first graph represents the density for the first route (Normal I-10), as shown in figure 56.

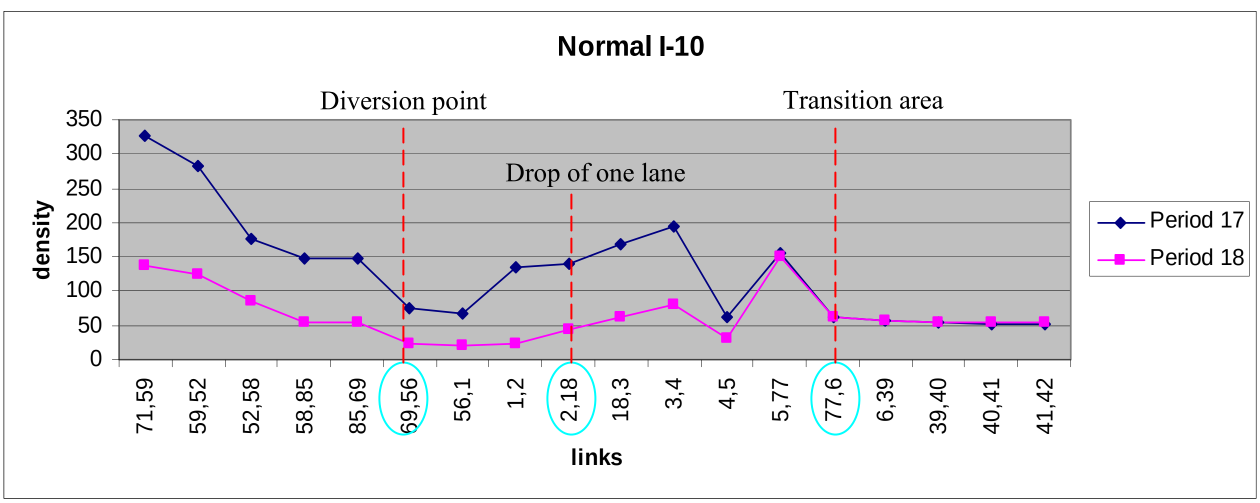

**Figure 56**
**Density for Normal I-10**

The second graph represents the density for the second route (Normal Loyola), as shown in Figure 57. After link (63, 58) vehicles merged on I-10, so the characteristics of density were the same as in the normal lanes of I-10 shown in figure 56.

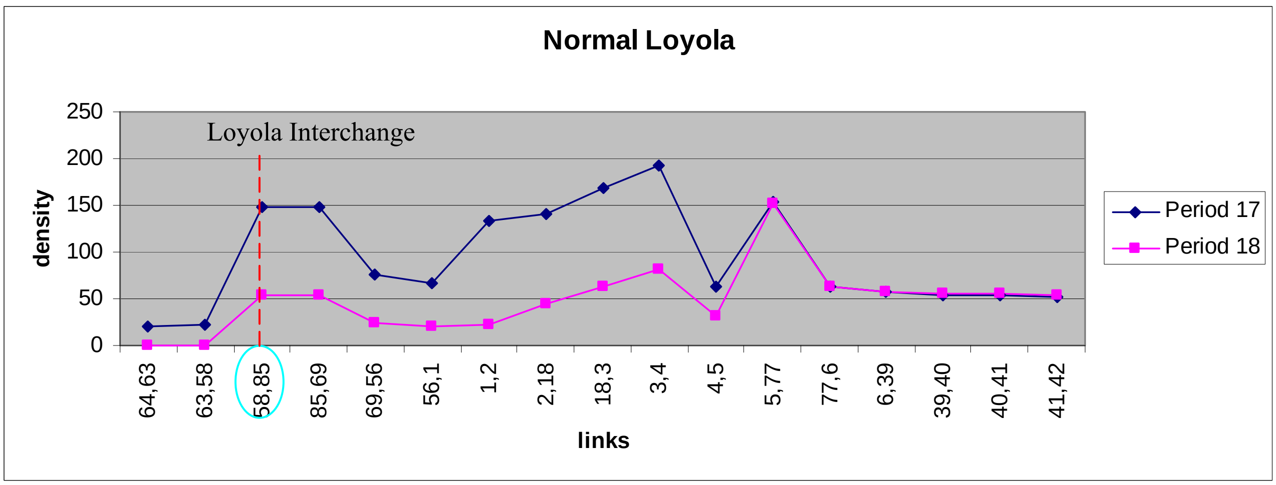


**Figure 57**
**Density for Loyola Dr.**

The third graph represents the density for the last route (Reverse I-10), as shown in figure 58. From this graph, it can be assumed that the level of service is not in the congestion level.

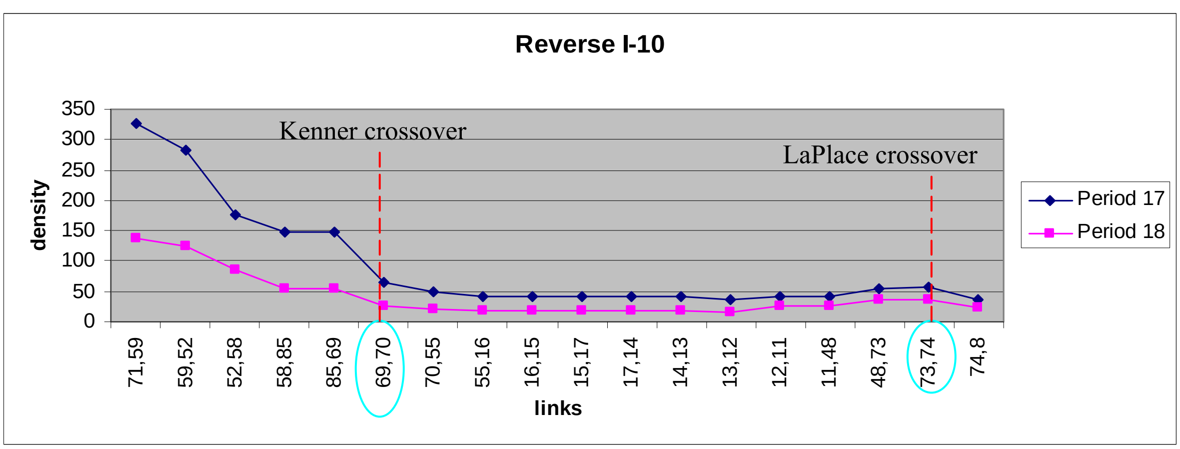

**Figure 58**
**Density for Reverse I-10**

The objectives of this research were reached. First, the traffic flow of the contraflow segment was estimated to be around 5,000 vehicles per hour. Therefore, for 17 hours, approximately 88,224 evacuation vehicles were able to travel through the contraflow segment.

Secondly, the average speed of the segment was estimated. Comparing the speed-graphs of the Normal I-10 and Reverse I-10 interestingly revealed that the speed on I-10/I-55 Interchange (around 20mph) was lower that the speed on the LaPlace crossover (around 39mph).

From the speed data and the length of the segment, the travel time was calculated. Based on the travel time, the third objective of this research was reached. The amount of time that will be required to discharge this segment before a hurricane landfall was estimated from the travel time data. The data analyses showed that 25 minutes were needed to clear the segment based on the average data. The mean speed of the segment was estimated to be about 33 miles per hour based on the total travel time and length of the segment.

The last two objectives of this study, estimating density and delay time, were also reached. From the amount of vehicles and length of each link, the density characteristics of the segment were estimated. The delay time was estimated from the total travel time and the actual travel time during normal operations. Based on the posted speed of 65mph and the length of the segment (69,216 ft.), 12 minutes was needed to travel the segment during normal operation. Since the maximum travel time during an evacuation was estimated to be around 25 minutes, the delay time was only 13 minutes for the contraflow segment.

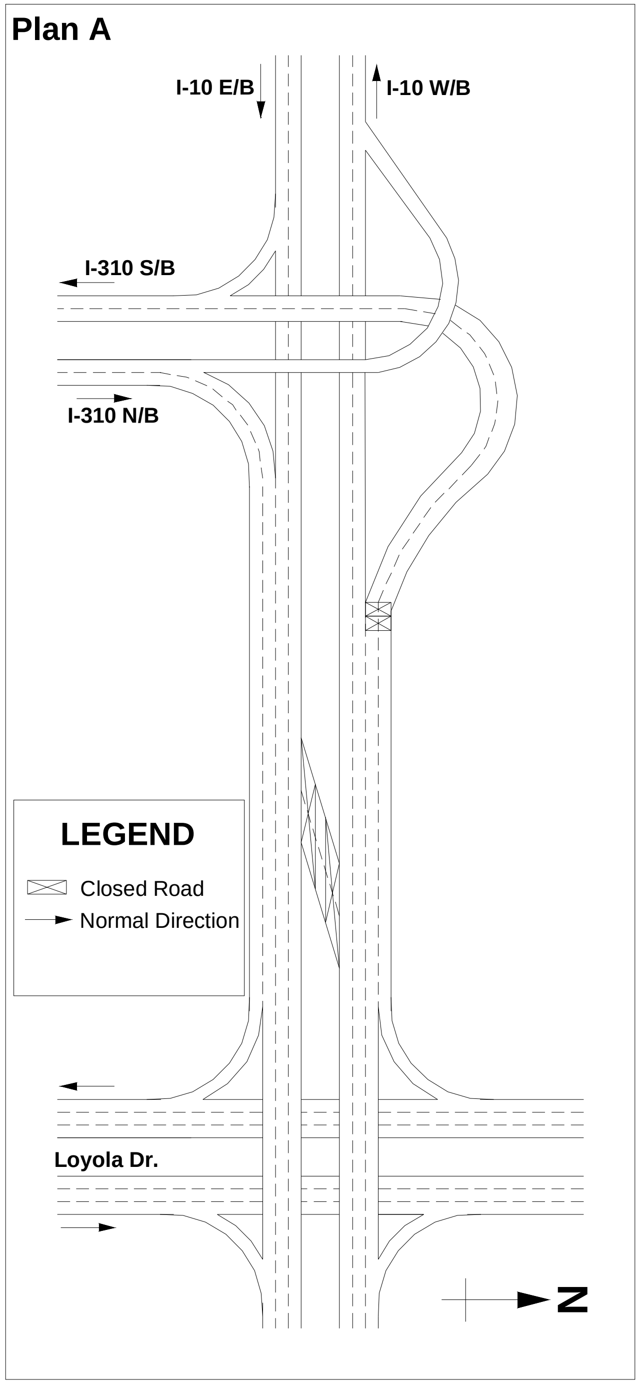


**Figure 59**
**PLAN A: Flow only from the normal outbound lanes on westbound I-10**

To evaluate the effectiveness of the contraflow operation, an experiment (Plan A), as shown in Figure 59, was conducted. Plan A used the same operational characteristics as the plan by LSP (Plan B) shown in Figure 60, except that only the two normal outbound lanes on westbound I-10 were used for the evacuation of that segment.

Furthermore, entering an additional volume on the segment did not seem inappropriate. Since the contraflow segment starts with three freeway lanes and ends with four, there are no indications of stopped queues during the 19 one-hour periods of the simulation. Two alternative experimental plans were conducted allowing an additional flow from I-310. The first experiment (Plan C), as shown in figure 61, had the same operational characteristics as the plan from LSP, while also allowing flow from the normal lanes of I-310 to enter in the normal lanes of I-10. The flow from the normal lanes of I-310 that continued into the normal lanes of I-10 through an entrance ramp had the same volume of 950 vehicles per hour as used in the Loyola Avenue entrance ramp.

The second experiment (Plan D), as shown in Figure 62, uses the same operational characteristics as Plan B, while also allowing flow from the normal and reverse lanes of I-310. The flow from the normal lanes of I-310 that continued into the normal lanes of I-10 had the same volume of 950 vehicles per hour as used in the Loyola Avenue entrance ramp. The flow from the reverse lanes of I-310 that continued into the reverse lanes of I-10 also had the same volume of 950 vehicles per hour as used in the Loyola Avenue entrance ramp.

These three experiments were compared with the Plan B based on Period 17. Period 17 was chosen because from Plan B, the previous periods had almost the same volume characteristics as shown in figure 48 and the last two periods (18 and 19) had a significant decrease of volume. Therefore, Period 17 was selected to evaluate the effectiveness of the contraflow operation based on the above experiments.

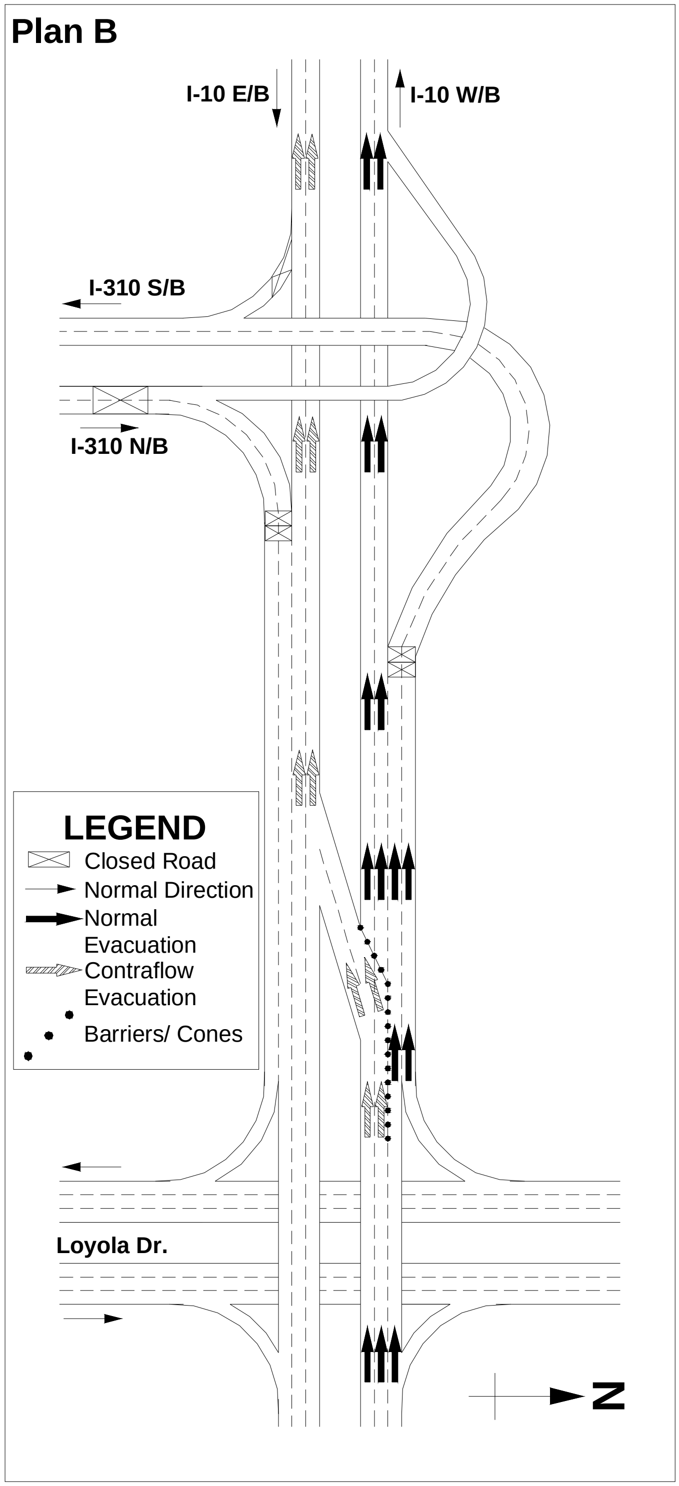


**Figure 60**
**PLAN B: Flow from the normal and contraflow lanes on westbound I-10**

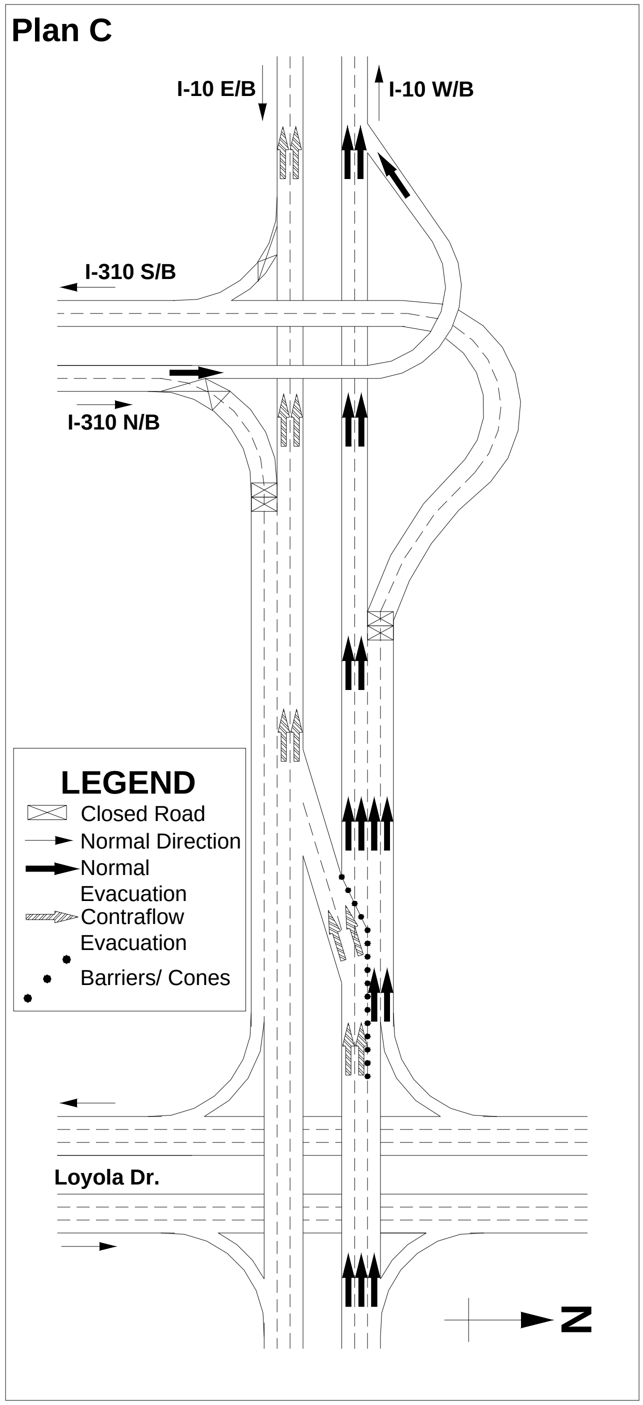


**Figure 61**
**PLAN C: Allowing additional flow from Northbound I-310**

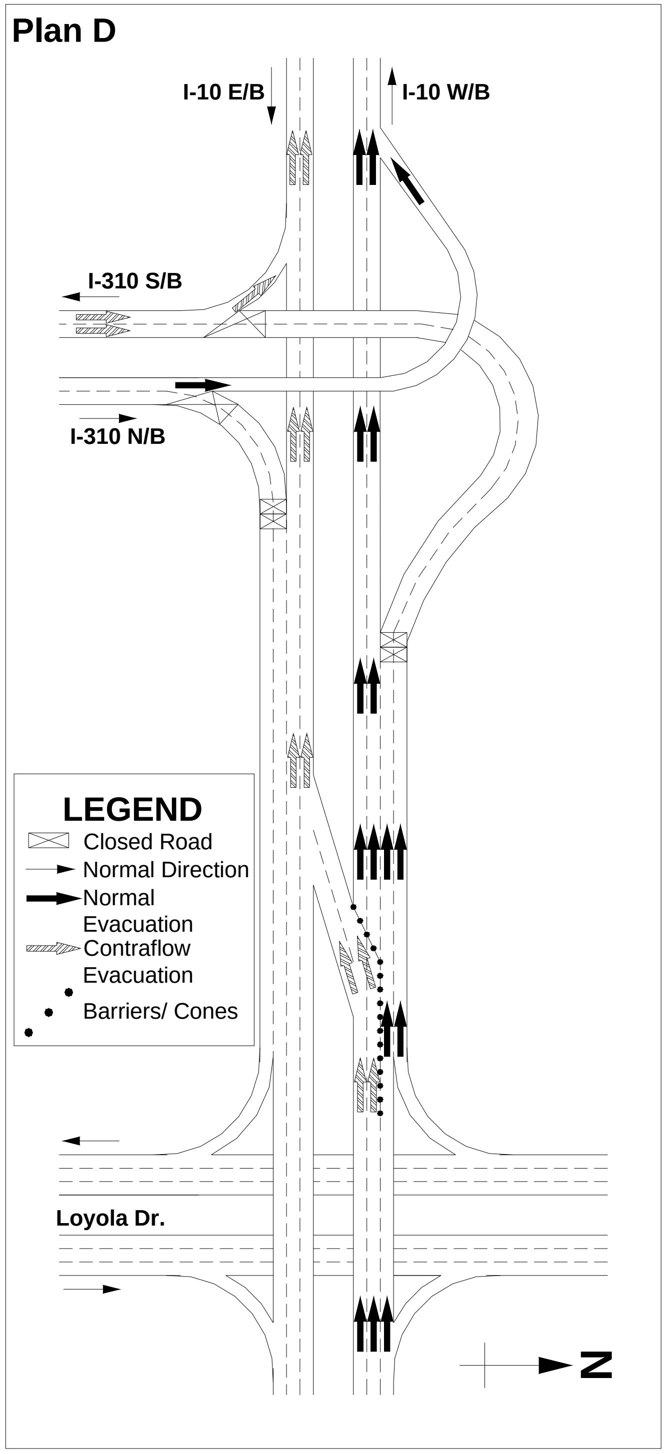


**Figure 62**
**PLAN D: Allowing additional flow from Southbound and Northbound I-310**

**Alternative Plans**

In this chapter, analysis based on the results from the four plans (Plans A to D) was estimated. For each plan, volume and speed tables were developed. The tables for each plan included the amount of vehicles through Period 17, and the travel time and mean speed for each route during Period 17. Graphs and tables were developed to compare the four plans based on the amount of vehicles and travel time. From the results of the comparisons, the four plans were evaluated and ranked to determine which plan was most effective for cases of mass evacuation. To verify the ranking, statistical testing was used to determine if the means of the four plans had any significant differences. Based on the results of the statistical testing, conclusions were drawn and recommendations were made.

**Plan A**

Plan A used the same flow volume as Plan B. However, since it did not include contraflow operation, only the two normal outbound lanes were used for the evacuation of the segment. Volume and speed tables were developed using the same procedure as in Plan B.

**Volume**

Based on the volume data during Period 17 and the total amount of vehicles that used the contraflow segment from 8:00am to 1:00 am of the next morning, Table 12 was developed to illustrate the amount of vehicles that entered and exited that segment. The second column in the table shows the number of vehicles that entered and exited the network during Period 17 based on the average volume data. The two entry links were on I-10 before Loyola Avenue entrance ramp at link (71, 59) and on Loyola Avenue at link (64, 63). The two exit links were on I-55 at link (41, 42) and on I-10 at link (74, 8). The third column shows the cumulative number of evacuation vehicles that entered and exited the network through Period 17.

**Table 12**
**Volume data based on entry, exit links at Period 17 and until Period 17**

| Location | Link Segment | Number of Vehicles During Period 17 | Number of Vehicles From Period 1 through Period 17 |
|---|---|---|---|
| | | | |
| **Entry node on I-10** | (71,59) | 2,487 | 42,800 |
| **Entry node in Loyola** | (64,63) | 950 | 16,148 |
| | **IN** | **3,437** | **58,948** |
| | | | |
| **Termination point on I-55** | (41,42) | 1,388 | 23,076 |
| **Termination point on I-10** | (74,8) | 2,053 | 3,4610 |
| | **OUT** | **3,441** | **57,686** |

**Speed**

Table 12 was listed based on the average speed and length of each link during Period 17. The table shows the time in minutes needed to travel the contraflow segment based on four routes. The first route, I-10 to I-55, starts from I-10, before Loyola Avenue Interchange, and ends on I-55 after the I-10/I-55 interchange. The second route, Loyola to I-55, starts from Loyola Avenue, continues through I-10, and ends on I-55 after the I-10/I-55 Interchange. The third route, I-10 to I-10, starts from I-10 before Loyola Avenue Interchange, and ends on I-10 after the I-10/I-55 Interchange. The last route, Loyola to I-10, starts from Loyola Avenue, and ends on I-10 after the I-10/I-55 Interchange.

The time needed to travel a link was estimated by dividing the link's length by its speed. The time needed to travel a route was estimated from the summation of travel time of the links for that route. From this table, the longest time can be used as the amount of time that will be required to clear this segment before hurricane landfall. In this research study, it was found that approximately 31 minutes was required to clear this segment based on the third route (I-10 to I-10).

A mean velocity was calculated during Period 17 for the four routes as shown in Table 13, based on the travel time and length of each route. The first route that starts from I-10 and ends on I-55 had the lowest mean speed of approximately 27 mph.

**Table 13**
**Travel time and mean speed on the four routes at Period 17 for Plan A**

| Period 17 of the Simulation | I-10 to I-55 (First Route) | Loyola to I-55 (Second Route) | I-10 to I-10 (Third Route) | Loyola to I-10 (Fourth Route) |
|---|---|---|---|---|
| **Travel Time (minutes)** | 29.53 | 20.30 | 30.34 | 21.10 |
| **Mean Speed (mph)** | 26.63 | 38.09 | 27.48 | 38.88 |

**Plan C**

From
Figure 61, it can be concluded that Plan C had the same operational characteristics as Plan B, except that Plan C also allows flow volume from the normal lanes of I-310 to enter in the normal lanes of I-10. Volume and speed calculations were conducted and listed in a table, using the same procedure as in Plan B.

Volume was developed to show the volume in the entry nodes, diversion points, and exit nodes, based on the volume data for each link during Period 17. The table shows the number of evacuation vehicles that entered and exited the network at Period 17 based on the minimum, maximum, average, and 95 percent confidence interval. The three entry links were, on I-10 before Loyola entrance ramp at link (71, 59), on Loyola Avenue at link (64,63), and on northbound I-310 entering to westbound I-10 at link (25,26). The two exit links were, on I-55 at link (41, 42) and on I-10 at link (74, 8).

**Table 14**
**Volume data based on entry, crossovers and exit links during Period 17**

| Location | Link Segment | Minimum Volume (veh.) | Maximum Volume (veh.) | Average Volume (veh.) | C.I. Upper Bound Volume (veh.) | C.I. Lower Bound Volume (veh.) |
|---|---|---|---|---|---|---|
| | | | | | | |
| **Entry node on I-10** | (71,59) | 3,577 | 4,830 | 4,030 | 4,109 | 3,950 |
| **Entry node in Loyola** | (64,63) | 950 | 950 | 950 | 950 | 950 |
| **Entry node on I-310** | (25,26) | 950 | 950 | 950 | 950 | 950 |
| | **IN** | **5,477** | **6,730** | **5,930** | **6,009** | **5,850** |
| | | | | | | |
| **Normal lanes after the crossover** | (69,56) | 1,723 | 2,645 | 2,184 | 2,276 | 2,093 |
| | **%Normal** | **38.06** | **45.76** | **43.87** | **44.98** | **42.71** |
| | | | | | | |
| **Kenner crossover** | (69,70) | 1,673 | 3,685 | 2,790 | 2,938 | 2,641 |
| | **%Reverse** | **36.96** | **63.75** | **56.13** | **58.09** | **53.90** |
| | | | | | | |
| **Termination point on I-55** | (41,42) | 1,298 | 5,133 | 3,129 | 3,336 | 2,922 |
| **Termination point on I-10** | (74,8) | 1,700 | 3,908 | 2,790 | 2,936 | 2,644 |
| | **OUT** | **2,998** | **9,041** | **5,919** | **6,272** | **5,566** |

Table 14 also shows the number of vehicles that used the normal and reverse lanes. Link (69, 70) represents the median crossover where the vehicles start using the reverse lanes, and link (69, 56) represents the segment where vehicles continue on the normal lanes. Using these volumes, the percentage of vehicles going through the normal and reverse lanes was estimated respectively. This table shows approximately 44 percent continued on the normal I-10 after the Kenner crossover and 56 percent continued on the reverse lanes. The 44 percent was the sum of traffic that came from Loyola Avenue and an about 30 percent came from the right most lane of I-10.

Cumulative volume data was composed in Table 15. This table shows how many vehicles entered and exited the network from 8:00AM through 1:00AM of the following day. For example, based on the average data, 101,736 vehicles entered the network and 98,486 vehicles exited.

**Table 15**
**Cumulative volume data, based on entry and exit links until period 17**

| **Location** | **Link Segment** | **Minimum Volume (veh.)** | **Maximum Volume (veh.)** | **Average Volume (veh.)** | **C.I. Upper Bound Volume (veh.)** | **C.I. Lower Bound Volume (veh.)** |
|---|---|---|---|---|---|---|
| | | | | | | |
| **Entry node on I-10** | (71,59) | 69,165 | 70,072 | 69,440 | 69,508 | 69,372 |
| **Entry node in Loyola** | (64,63) | 16,148 | 16,148 | 16,148 | 16,148 | 16,148 |
| **Entry node on I-310** | (25,26) | 16,148 | 16,148 | 16,148 | 16,148 | 16,148 |
| | **IN** | **101,461** | **102,368** | **101,736** | **101,804** | **101,668** |
| | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Termination point on I-55** | (41,42) | 52,457 | 54,470 | 52,855 | 52,981 | 52,730 |
| **Termination point on I-10** | (74,8) | 44,799 | 45,986 | 45,631 | 45,723 | 45,538 |
| | **OUT** | **97,256** | **100,456** | **98,486** | **98,704** | **98,268** |

Table 15 shows that for 98,486 evacuation vehicles, approximately 17 hours were needed to evacuate them from the contraflow segment.

**Speed**

Table 16 was developed based on the average speed and length of each link during Period 17. This table shows the time in minutes needed to travel the contraflow segment based on four routes. The first route, Normal I-10, starts from I-10 before Loyola Avenue Interchange, and ends on I-55 after the I-10/I-55 Interchange. The second route, Normal Loyola, starts from Loyola Avenue, continues through I-10, and ends on I-55 after the I-10/I-55 Interchange. The third route, Normal I-310, starts from the normal lanes of I-310, continues in the normal lanes of I-10, and ends on I-55 after the I-10/I-55 Interchange. The last route, Reverse I-10, starts from I-10 before Loyola Avenue Interchange, continues in the reverse lanes of I-10 through the Kenner crossover, and ends on westbound I-10 after the LaPlace crossover.

The time to travel a link was estimated, using the length of a link divided by the speed of that link. The time needed to travel a route, was estimated from the summation of travel time of the links for that route. From this table, the longest time can be used as the amount of time that will be required to clear this segment before a hurricane landfall. This research study found that approximately 40 minutes was required to clear this segment based on the first route (Normal I-10).

A mean velocity was calculated during Period 17 for the four routes as shown in Table 16, based on the travel time and length of each route. The first route that starts from I-10 and ends on I-55 had the lowest mean speed of approximately 20 mph. The route that uses the reverse lanes had the lowest travel time and the highest mean speed.

**Table 16**
**Travel time and mean speed on the four routes at Period 17 for Plan C**

| Period 17 of the Simulation | Normal I-10 (First Route) | Normal Loyola (Second Route) | Normal I-310 (Third Route) | Reverse I-10 (Fourth Route) |
|---|---|---|---|---|
| **Travel Time (minutes)** | 39.51 | 37.02 | 19.23 | 19.46 |
| **Mean Speed (mph)** | 19.91 | 20.89 | 36.03 | 42.91 |

As shown in Figure 62, Plan D had the same operational characteristics as Plan B, except that Plan D allows an additional flow volume from the normal lanes of I-310 to I-10, and from the reverse lanes of I-310 into the reverse lanes of I-10.  The flow from the normal and reverse lanes of I-310 had the same volume of 950 vehicles per hour as used in the Loyola Avenue entrance ramp. Volume and speed tables were developed using the same procedure as in Plan B.

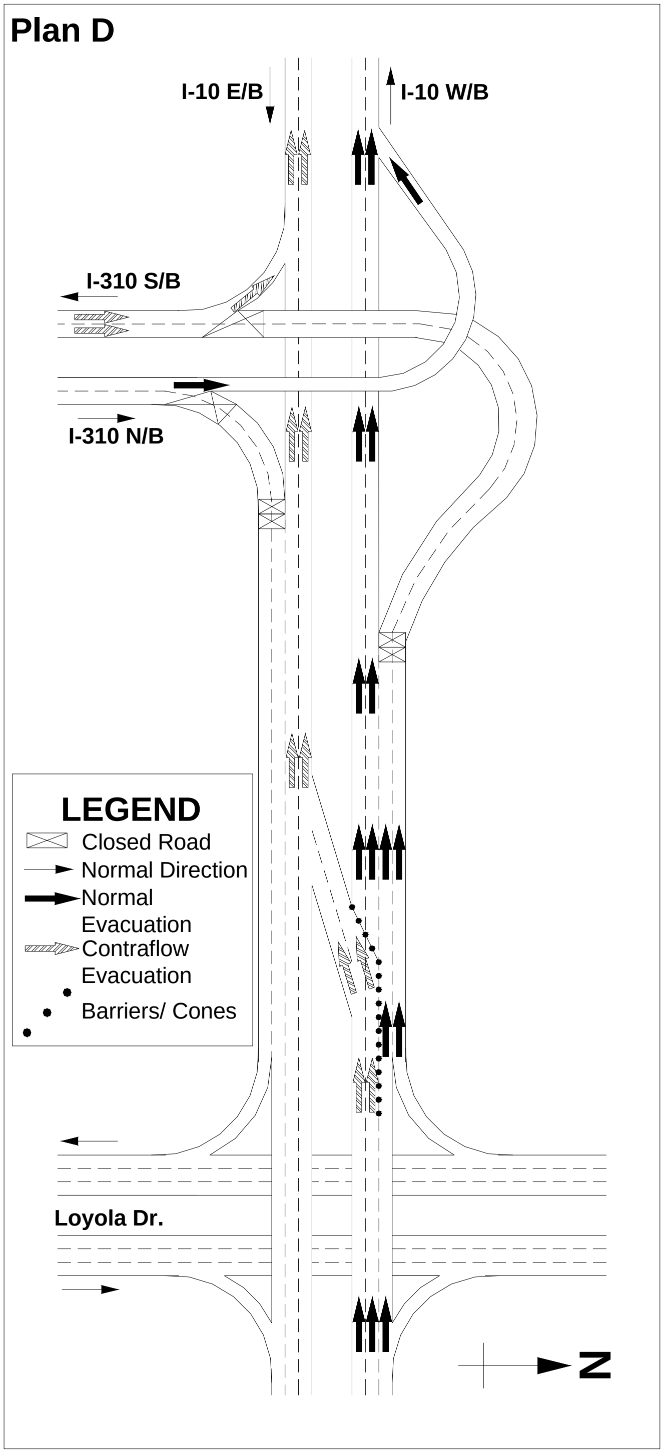


**Figure 62**
**PLAN D: Allowing additional flow from Southbound and Northbound I-310**

### Volume

Table 17 was developed to illustrate the number of vehicles per link that entered and exited the network during Period 17 according to the minimum, maximum, average, and 95 percent confidence intervals. The four entry links were as follows: one from I-10, before Loyola entrance ramp at link (71,59), the second from Loyola Avenue at link (64,63), the other one from the northbound I-310 entering to I-10 West at link (25,26) through an entrance ramp, and the last one from the reverse lanes of I-310 entering the contraflow lanes of I-10 using the "normal" exit ramp to (from) I-310 at link (78,80). The values for the two exit links were, on I-55 at link (41, 42) and on I-10 at link (74, 8).

Table 17 also shows the number of vehicles that used the normal and the reverse lanes. Link (69, 70) represents the media crossover where the vehicles start using the reverse lanes, and link (69, 56) represents the segment where vehicles continue on the normal lanes. From these amounts the percentage of vehicles going through the normal lanes and through the reverse lanes are illustrated in Table 17.

**Table 17**
**Volume data based on entry, exit and splitting links at period 17**

| Location | Link Segment | Minimum Volume (veh.) | Maximum Volume (veh.) | Average Volume (veh.) | C.I. Upper Bound Volume (veh.) | C.I. Lower Bound Volume (veh.) |
|---|---|---|---|---|---|---|
| | | | | | | |
| **Entry node on I-10** | (71,59) | 0 | 4,630 | 4,043 | 4,115 | 3,970 |
| **Entry node in Loyola** | (64,63) | 950 | 950 | 950 | 950 | 950 |
| **Entry node on I-310** | (25,26) | 950 | 950 | 950 | 950 | 950 |
| **Entry node on Reverse I-310** | (78,80) | 950 | 950 | 950 | 950 | 950 |
| | **IN** | **2,850** | **7,480** | **6,893** | **6,965** | **6,820** |
| | | | | | | |
| **Normal lanes after the crossover** | (69,56) | 1,797 | 3,095 | 2,235 | 2,339 | 2,132 |
| | **%Normal** | **189** | **55.47** | **44.77** | **46.19** | **43.32** |
| | | | | | | |
| **Kenner crossover** | (69,70) | 0 | 9,264 | 2,760 | 3,418 | 2,102 |
| | **%Reverse** | **0** | **166** | **55.28** | **67.48** | **42.72** |
| | | | | | | |
| **Termination point on I-55** | (41,42) | 1,112 | 5,016 | 3,120 | 3,323 | 2,917 |
| **Termination point on I-10** | (74,8) | 0 | 9,633 | 3,711 | 4,337 | 3,084 |
| | **OUT** | **1,112** | **14,649** | **6,831** | **7,660** | **6,001** |

Based on the average volume values of Table 18, approximately 45 percent continued on the normal I-10 just after the Kenner crossover and 55 percent continued on the reverse lanes. The 45 percent was from 100 percent traffic coming from Loyola Drive and an about 32 percent coming from the right most lane of I-10.

Using this cumulative data, Table 18 was developed. This table illustrates how many vehicles got into and out of the network from 8:00AM until 1:00am of the next day. For example, based on the average data, approximately 117,983 vehicles entered in the network and 114,150 vehicles exited the network. That means that for an amount of 114,150 evacuation vehicles, approximately 17 hours were needed to evacuate them from the contraflow segment.

**Table 18**
**Cumulative volume data, based on entry and exit links until period 17**

| Location | Link Segment | Minimum Volume (veh.) | Maximum Volume (veh.) | Average Volume (veh.) | C.I. Upper Bound Volume (veh.) | C.I. Lower Bound Volume (veh.) |
|---|---|---|---|---|---|---|
| | | | | | | |
| **Entry node on I-10** | (71,59) | 69,105 | 73,317 | 69,538 | 69,804 | 69,272 |
| **Entry node in Loyola** | (64,63) | 16,148 | 16,148 | 16,148 | 16,148 | 16,148 |
| **Entry node on I-310** | (25,26) | 16,148 | 16,148 | 16,148 | 16,148 | 16,148 |
| **Entry node on Reverse I-310** | (78,80) | 16,148 | 16,148 | 16,148 | 16,148 | 16,148 |
| | **IN** | **117,548** | **121,761** | **117,982** | **118,248** | **117,716** |
| | | | | | | |
| **Termination point on I-55** | (41,42) | 52,233 | 54,425 | 52,804 | 52,932 | 52,677 |
| **Termination point on I-10** | (74,8) | 55,060 | 61,975 | 61,346 | 61,782 | 60,909 |
| | **OUT** | **107,293** | **116,400** | **114,150** | **114,714** | **113,586** |

**Speed**

Table 19 was developed based on the average speed and length of each link during Period 17. This table shows the time in minutes needed to travel the contraflow segment based on five routes. The first four routes were the same as in Plan C. The fifth route, Reverse I-310, starts from the reverse lanes of I-310, continues in the reverse lanes of I-10, and ends on westbound I-10 after the LaPlace crossover.

The time to travel a link and a route was estimated using the same procedure as in Plan C. From this table, it was determined that approximately 38 minutes were required to clear this segment based on the first route (Normal I-10).

A mean velocity was calculated during Period 17 for the five routes based on the travel time and length of each route, as shown in Table 19. The route that starts from I-10 and ends on I-55 had the lowest mean speed of approximately 21 mph. The routes that used the reverse lanes had the lowest travel time and the highest mean speed.

**Table 19**
**Travel time and mean speed on the five routes at Period 17 for Plan D**

| Period 17 of the Simulation | Normal I-10 (First Route) | Normal Loyola (Second Route) | Normal I-310 (Third Route) | Reverse I-10 (Fourth Route) | Reverse I-310 (Fifth Route) |
|---|---|---|---|---|---|
| **Travel Time (minutes)** | 38.08 | 35.80 | 19.03 | 20.43 | 15.13 |
| **Mean Speed (mph)** | 20.66 | 21.60 | 36.41 | 40.85 | 47.74 |

## Comparison

From the four plans (Plans A to D), tables and graphs were developed, and the plans were compared based on volume and speed data. The amount of evacuation vehicles leaving the segment through Period 17 was compared among the four plans. The time to discharge the segment during Period 17 was also compared among the plans. The purpose of the comparison between the four plans was to evaluate the traffic characteristics of contraflow operation and determine which plan might be more effective for evacuating New Orleans on the westbound I-10. In addition, statistical testing was used to verify the results from the tables and graphs, based on the significant differences of the means of the four plans.

### Volume

Table 20 represents the average number of evacuation vehicles that exited the segment

through Period 17 for the four plans. The results in the table show that Plan D was the most effective, followed by Plan C, Plan B, and Plan A. During the 17 hours of evacuation, 25,926 more vehicles passed through the segment using Plan D than Plan B.
Table 21 shows how many more vehicles exited using the three types of contraflow operation (Plans B to D) than using only the normal outbound lanes based on the data in Table 21. The first column of Table 21 compares Plan B minus Plan A, and it calculates how many more vehicles got in and out of the network during Period 17. The next column represents the difference between these two plans in percentage increase. The same procedure was conducted for the difference between Plan C and A, and for the difference between Plan D and A. This table illustrates that Plan D, with an increase of about 98 percent, was the most effective among the four plans.

Furthermore, Tables 21 and 22 show the differences between the three-contraflow plans with the normal outbound lanes during Period 17. From the last two tables it can be concluded that the values of the percentage increase in Table 22 were similar to the percentage values in Table 21.

**Table 20**
**Amount of vehicles that exited the segment until Period 17**

| **Cumulative volume through Period 17** | **Plan A** | **Plan B** | **Plan C** | **Plan D** |
|---|---|---|---|---|
| **Exited Volume (veh)** | 57,686 | 88,224 | 98,486 | 114,150 |

**Table 21**
**Differences between the three contraflow plans and plan A until Period 17**

| **Volume through Period 17** | **Plan B-Plan A** | **% INCREASE** | **Plan C-Plan A** | **% INCREASE** | **Plan D-Plan A** | **% INCREASE** |
|---|---|---|---|---|---|---|
| **Vehicles Entered (veh)** | 31,935 | 54.18 | 42,788 | 72.59 | 59,034 | 100.15 |
| **Vehicles Exited (veh)** | 30,538 | 52.94 | 40,800 | 70.73 | 56,464 | 97.88 |

**Table 22**
**Differences between the three contraflow plans and plan A at Period 17**

| Volume during Period 17 | Plan B-Plan A | % INCREASE | Plan C-Plan A | % INCREASE | Plan D-Plan A | % INCREASE |
|---|---|---|---|---|---|---|
| **Vehicles Entered (veh)** | 1,901.37 | 55.33 | 2,492.83 | 72.54 | 3,455.73 | 100.55 |
| **Vehicles Exited (veh)** | 1,801.43 | 52.35 | 2,477.93 | 72.01 | 3,389.40 | 98.50 |

These tables show that Plan A was the least effective among the other three in terms of volume. It was very logical to determine that Plan A was the worst of the four plans, since it uses only the two normal outbound lanes. However, to evaluate the reasons why Plan D was better than Plan C, and Plan C was better than Plan B, an additional table and graph were constructed. Table 22 was developed from the cumulative volume data during Period 17. The number of vehicles in the diversion and exit points of the three-contraflow plans (Plans B to D) is shown in Figure 62. The two exit nodes were on I-55 after the I-10/I-55 interchange and on I-10 after the LaPlace crossover. The exit node on I-55 used Route 1, which is the route on the normal outbound lanes. The exit node on I-10 used Route 2, which is the route on the reverse lanes. The two diversion points illustrate the amount of vehicles that continued in the normal lanes (Route 1) and the amount of vehicles that diverted in the reverse lanes (Route 2). For Plan C an additional flow came from the normal lanes of northbound I-310 and merged in the normal lanes of westbound I-10 (
Figure 61). For Plan D, an additional flow came from the normal lanes of northbound I-310 and also from the reverse lanes of I-310 that merged on the reverse lanes of I-10.

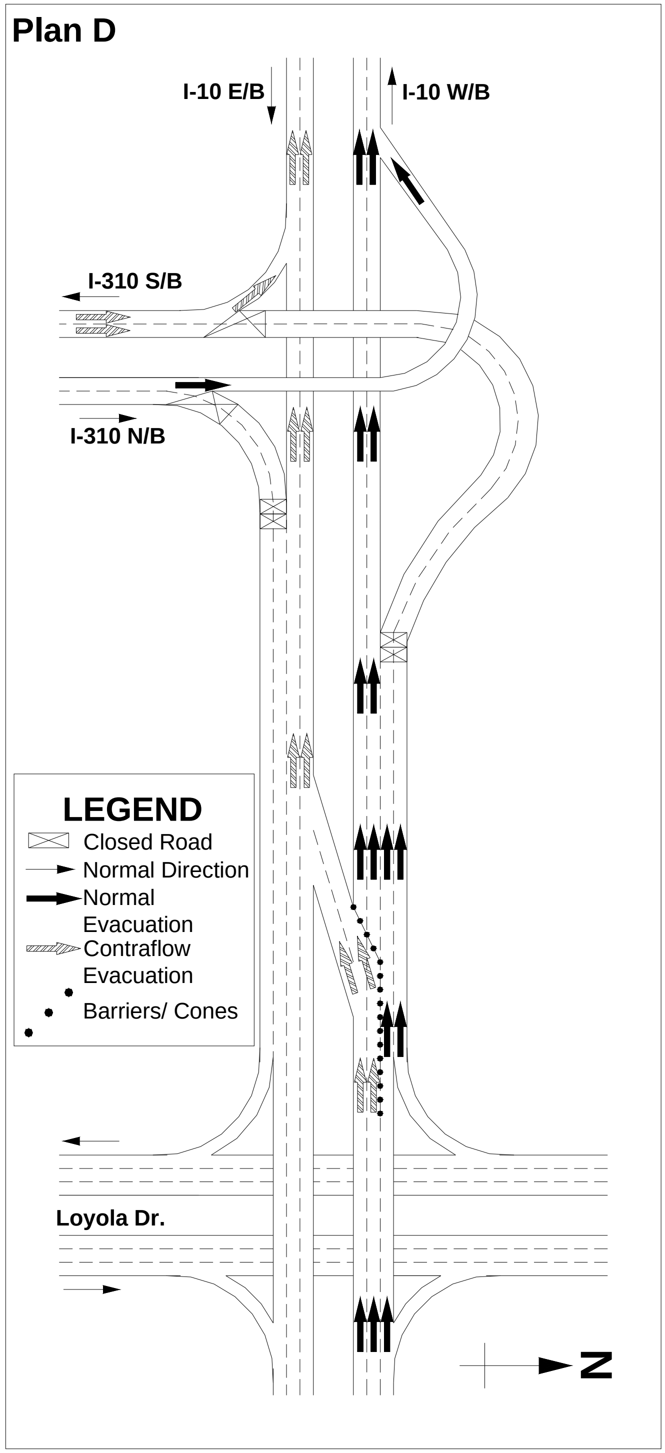


**Figure 62**
**PLAN D: Allowing additional flow from Southbound and Northbound I-310**

Comparing Plan C with Plan B reveals that the additional flow of 16,148 vehicles added in Route 1 increased the exited amount by only 1,355 vehicles. However, the additional flow from I-310 made more efficient use of the available roadway. The percentage of diverting vehicles on the reversal lanes was increased from 41 percent in Plan B to 54 percent in Plan C. Since the traffic in the reverse lanes was much less congested than the normal lanes, based on Figure 58, there was an increase of 8,907 exiting vehicles from Route 2.

Comparing Plan D with the other two plans reveals that the additional flow from both normal and reverse lanes of I-310 made much more efficient use of the available roadway. The additional flow of 16,148 vehicles on Route 2 and the diversion of 54 percent of the total amount of vehicles in the reverse lanes increased the exiting amount from Route 2 to 61,346 vehicles.

**Table 23**
**Amount of vehicles that entered and exited in the three plans until period 17**

| Location | | Plan B | Plan C | Plan D |
|---|---|---|---|---|
| % Volume Entered in the Diversion Point Diversion | Route 1 | 59 | 46 | 46 |
| | Route2 | 41 | 54 | 54 |
| Volume Entered in the Diversion Point | Route 1 | 53,561 | 39,071 | 39,405 |
| | Route2 | 37,185 | 46,242 | 45,978 |
| Additional flow volume | N. I-310/Route 1 | | 16,148 | 16,148 |
| | R. I-310/Route2 | | | 16,148 |
| Exited Volume | Route 1 | 51,500 | 52,855 | 52,804 |
| | Route2 | 36,724 | 45,631 | 61,346 |
| Total Exited Volume from both Routes | | 88,224 | 98,486 | 114,150 |

Figure 63 shows the number of evacuation vehicles between the three contraflow plans (Plans B to D) per link for the first route (Normal I-10). From the graph, it can be concluded that the volume through link (85, 69) was quite the same for each plan. From link (69, 56), which represents the normal lanes after the Kenner crossover, through link (18, 3), Plan C and D had the lowest volume. This was the result of the reduction in the percentage of vehicles that used the normal lanes, as shown in Table 23. From link (3, 4), which represents the I-10/I-310 Interchange, through the end of the segment, the volume for the three plans was quite similar. The increased of volume at link (3, 4) for plan C and D, had to do with the additional flow of 950 vehicles per hour that came from the normal lanes of I-310 and merged in the normal lanes of I-10 through an entrance ramp.

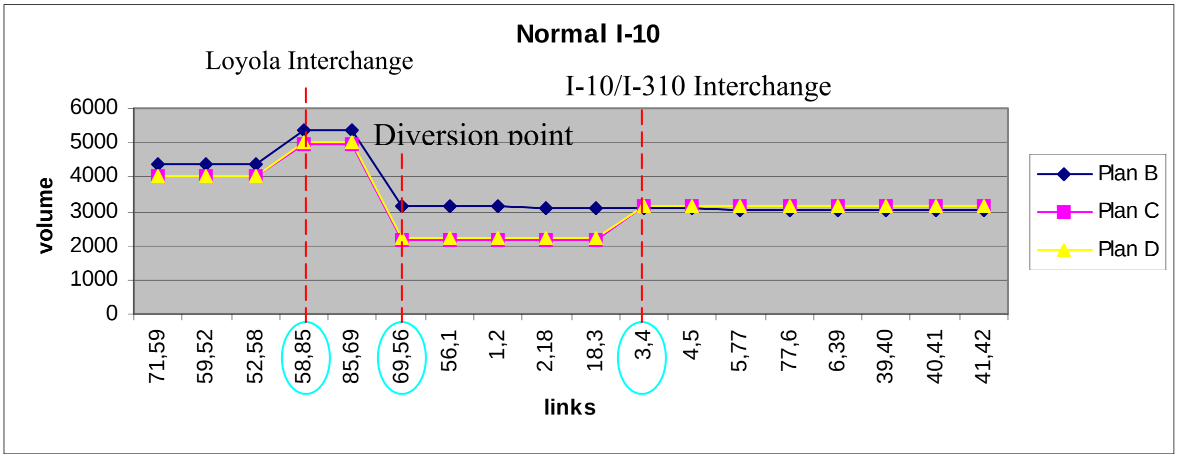


**Figure 63**
**Number of vehicles per hour using the normal I-10 to evacuate for the three plans at period 17**

Figure 64 illustrates the number of evacuation vehicles between the three contraflow plans (Plans B to D) per link for the reverse route (Reverse I-10). The graph illustrates that the volume through link (85, 69) was quiet the same for each plan. From link (69, 70), which represents the Kenner crossover, through link (17, 14), Plan C and D had more volume than Plan A. This was the result of the increase in the percentage of vehicles that used the reverse lanes as shown in Figure 64. From link (14, 13), which represents the merging point of the reversal lanes of I-310 in the reverse lanes of I-10, through the end of the segment, the volume in Plan D was higher than in Plan C. The increase of volume for plan D at link (14, 13) had to do with the additional flow of 950 vehicles per hour that came from the reverse lanes of I-310 and merged to the reverse lanes of I-10 through an exit "entrance" ramp.

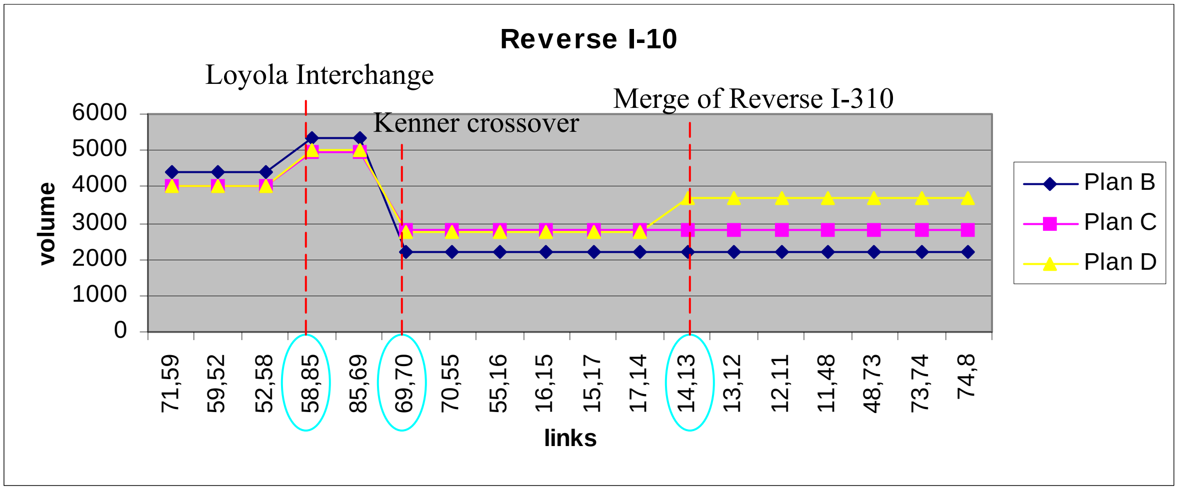


**Figure 64**
**Number of vehicles per hour using the reverse I-10 to evacuate for the three plans at period 17**

Based on the analysis it can be concluded that the best plan among the four for an evacuation of New Orleans using westbound I-10 was plan D. Plan C comes second followed by plan B. After considering all plans, Plan A was the least effective. To verify these conclusions, a statistical testing was used. With the help of MINITAB (statistical package) the significance of differences in the means of the four plans were estimated. First, the total amount of evacuation vehicles exiting the network through Period 17 was input into four columns. These four columns represented the four evacuation plans. Since Plans B, C, and D were simulated 30 times, 30 values were input into these columns. Plan A was run 10 times. Therefore 10 values were input into the column for Plan A. After the values were inserted into columns, a two-sample t-test (one side/one tail) was conducted for each pair of plans, to test whether or not there is a significant difference between their means. The t-value was estimated in MINITAB using the following equation:

$$\boxed{\frac{(\overline{X}_n - \overline{Y}_m) - (\mu_1 - \mu_2)}{\hat{\sigma}\sqrt{\frac{1}{n} + \frac{1}{m}}}}$$

(Equation 3)

$\overline{X}_n$ is the mean value of the 30 samples in the first plan. $\overline{Y}_m$ is the mean value of the 30 samples in the second plan. $\mu 1$ and $\mu 2$ are the real means of the two plans. $\hat{\sigma}$ is the Pooled estimation that is also called sample standard deviation. The letters *n* and *m* are the numbers of observation of the first and second plan respectively.

In this research study the null hypothesis (Ho) was that the populations' means are equal or smaller ($\mu 1 \leq \mu 2$), against an alternative hypothesis (H1) saying that the mean of the first plan is greater than the mean of the second plan. The volume data that were used to test the means of the four plans were plotted in the following figure. Figure 65 shows the cumulative volume data in dots for each run of the four plans. The numbers on the horizontal axes represent the amount of evacuation vehicles. From Figure 65, it can be easily concluded that the four means differ because even the outlier values of each plan do not overlap with the range of values of the other plans.

**Testing the Difference Between the Means of the Four Plans**

First, the difference between the means of plan D and plan C, assuming equal variances, was tested. The null hypothesis was that the mean value from Plan D minus the mean value from Plan C was less than or equal to zero. If it was zero, there was no significant difference between the two plans. The alternative hypothesis was that the mean value from Plan D was larger than the mean value from Plan C.

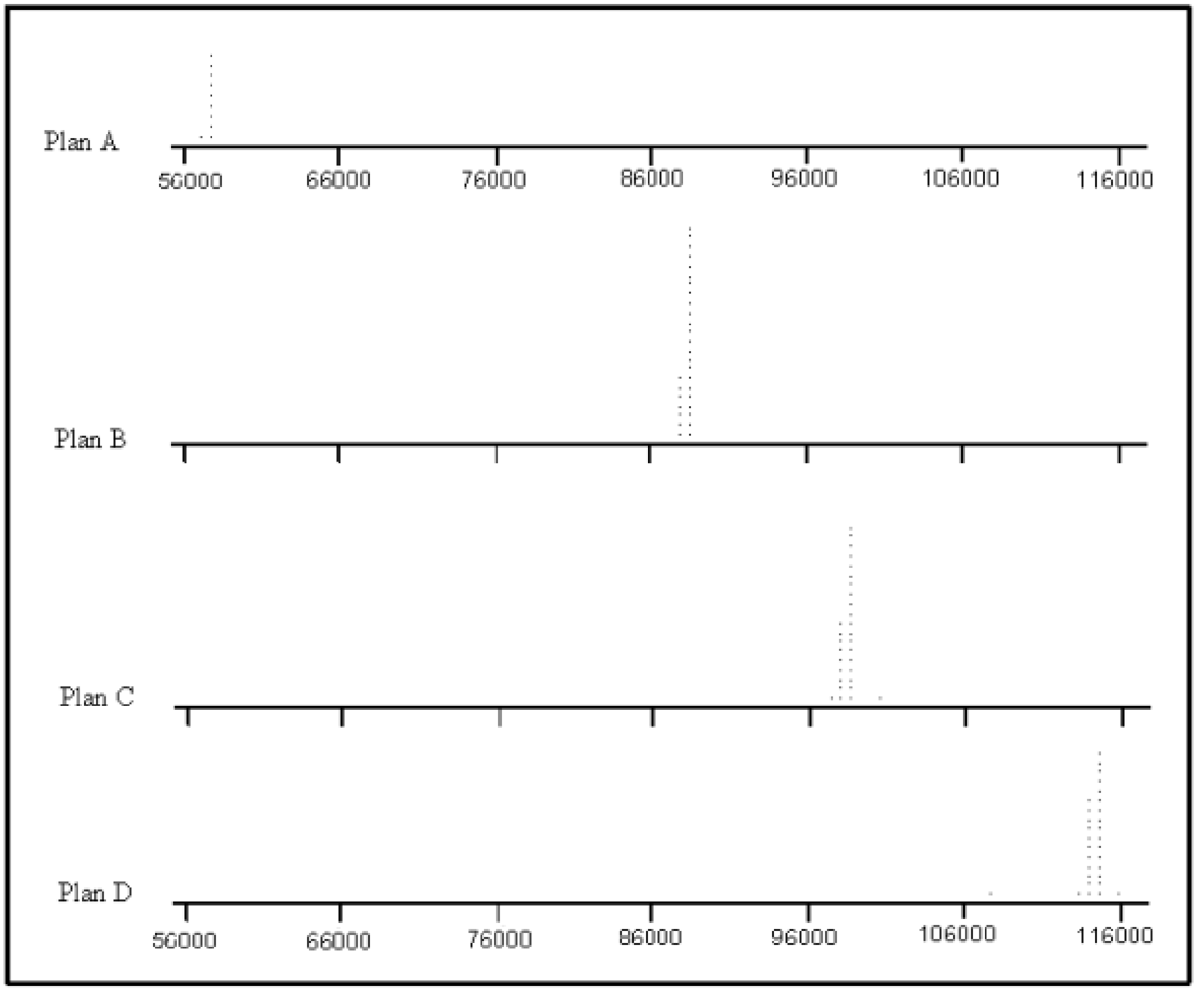


**Figure 65**
**Range of number of vehicles evacuated using the four plans until period 17**

Figure 66 shows the results from MINITAB output. Plan C and D had a range of 30 values each and their mean value was 114,075 vehicles and 98,431 vehicles respectively. The mean difference from these two plans was estimated to be 15,644 vehicles, and the Pooled value was 991.

Therefore, using the Equation 3 researchers found the T-value that was equal to 61.17. The Degrees of Freedom were equal to 58 (Number of observation of plan D plus the number of observation of plan C minus two). From the Degrees of Freedom and T-value, the P-value was calculated using MINITAB. To reject the null hypothesis the p-value must be less than the value of a. In this study, since the experiments constructed a 95 percent confidence, the value of a was equal to 0.05. This means that this interval will contain the true parameter, with 95 percent confidence. Only 0.05 (five percent) of all values will exceed this interval. Therefore, since the p-value was almost zero and consequently less than the value of a, the null hypothesis was rejected. That means that the mean amount of vehicles exiting the segment in plan D was larger than the mean amount in plan C. Therefore, it can be concluded that Plan D was more efficient than plan C in terms of flow volume exiting the network.

**1. Ho: $\mu D-\mu C \leq 0$ Vs Ha: $\mu D-\mu C > 0$**
Two-sample T for Plan D Vs Plan C

| | N | Mean |
|---|---|---|
| Plan: D | 30 | 114075 |
| Plan: C | 30 | 98431 |

Difference = mu Plan D - mu Plan C
Estimate for difference: 15644
T-Test of difference = 0 (vs >): T-Value = 61.17, P-Value = 0.000 DF = 58
Both use Pooled StDev = 991

**Figure 66**
**Significant mean difference of Plan D and Plan C**

The same procedure was used to verify the difference between Plan C and B, and the output from the statistical package is shown in Figure 67 below.

**2. Ho: $\mu C-\mu B \leq 0$ vs Ha: $\mu C-\mu B > 0$**
Two-sample T for Plan_C vs Plan_B

| | N | Mean |
|---|---|---|
| Plan: C | 30 | 98431 |
| Plan: B | 30 | 88184 |

Difference = mu Plan_C - mu Plan_B
Estimate for difference: 10246.5
T-Test of difference = 0 (vs >): T-Value = 108.92 P-Value = 0.000 DF = 58
Both use Pooled StDev = 364

**Figure 67**
**Significant mean difference of Plan C and Plan B**

Since p-value was very small, close to zero, the null hypothesis (Ho) was rejected. That means that the amount of vehicles evacuating the segment in plan C was larger than the amount in plan B. Therefore, it can be concluded that plan C is more efficient than plan B.

**3. Ho: µA-µB ≤ 0 vs Ha: µA-µB > 0**

Two-sample T for Plan A vs Plan B

| | N | Mean |
|---|---|---|
| Plan: A | 10 | 57652 |
| Plan: B | 30 | 88184 |

Difference = mu Plan_A - mu Plan_B
Estimate for difference: -30531.9
T-Test of difference = 0 (vs >): T-Value = -405.23 P-Value = 1.000 DF = 38
Both use Pooled StDev = 206

**Figure 68**
**Significant mean difference of Plan A and Plan B**

From the comparison between Plan A and B (Figure 68), the null hypothesis was not rejected. The p-value, which was equal to one, was larger than the a value. Therefore the null hypothesis was accepted since there was no strong evidence to conclude that Plan A was larger than Plan B. That means that the amount of vehicles exiting the segment in Plan B was larger than the amount in Plan A.

From the three statistical tests, researchers found in terms of exiting evacuation vehicles that Plan D was more efficient than Plan C, Plan C was more efficient than Plan B, and Plan B was more efficient than Plan A. Therefore, it can be concluded that the best plan among the four was Plan D. Plan C was the second best followed by Plan B. Plan A was the worst of the four plans.

However, for the above tests, it was assumed that the variance between the four plans was equal. To verify the statistical results, the same procedure was conducted, but the variances were assumed to be unequal.

**1. Two-sample T for Plan A vs Plan_B**

| | N | Mean |
|---|---|---|
| Plan: A | 10 | 57652 |
| Plan: B | 30 | 88184 |

Difference = mu Plan_A - mu Plan_B
Estimate for difference: -30531.9
T-Test of difference = 0 (vs >): T-Value = -404.89 P-Value = 1.000 DF = 15

**Figure 69**
**Significant mean difference of Plan A and Plan B**

**2.Two-sample T for Plan_D vs Plan_C**

| | N | Mean |
|---|---|---|
| Plan: D | 30 | 114075 |
| Plan: C | 30 | 98431 |

Difference = mu Plan_D - mu Plan_C
Estimate for difference: 15644
T-Test of difference = 0 (vs >): T-Value = 61.17 P-Value = 0.000 DF = 36

**Figure 70**
**Significant mean difference of Plan D and Plan C**

**3.Two-sample T for Plan_C vs Plan_B**

| | N | Mean |
|---|---|---|
| Plan: C | 30 | 98431 |
| Plan: B | 30 | 88184 |

Difference = mu Plan_C - mu Plan_B
Estimate for difference: 10246.5
T-Test of difference = 0 (vs >): T-Value = 108.92 P-Value = 0.000 DF = 39

**Figure 71**
**Significant mean difference of Plan C and Plan B**

These tables show the output results from MINITAB. From these tables it can be concluded that the three tests with unequal variances had the same results as the previous three tests with equal variances.

**Speed**

After concluding that the best plan among the four for this study was plan D, the following speed graphs were conducted to visualize the speed in the two routes (one using the normal outbound lanes from I-10 to I-55, and the other using the reverse lanes of I-10). From the speed data, the average speed for each link was estimated based on the three contraflow plans (Plans B to D).

Figure 72 shows the average speed per link using the normal outbound lanes for the three plans. The first two links had almost the same speed, but from link (52, 58) until link (18, 3) the speed of plans C and D are much lower than the speed of plan B. The reason for the reduction of speed was because plan C and D allowed vehicles entering into the normal outbound lanes of I-10 at link (3, 4) from the normal lanes of I-310. The additional volume entered at link (3, 4) created congestion on the previous links of I-10 that result in the reduction of speed. However, the increase of congestion on the normal lanes worked positively for the entire network. The decrease of speed or the increase of congestion at the particular links, forces more vehicles to use the reverse lanes. The reduction of speed disables evacuees to waive and take the right most lane on westbound I-10 that will lead them on the normal outbound lanes. This explains the reason why on Figure 72 Plans C and D had higher percentage of vehicles that used the reverse lanes compared with Plan B.

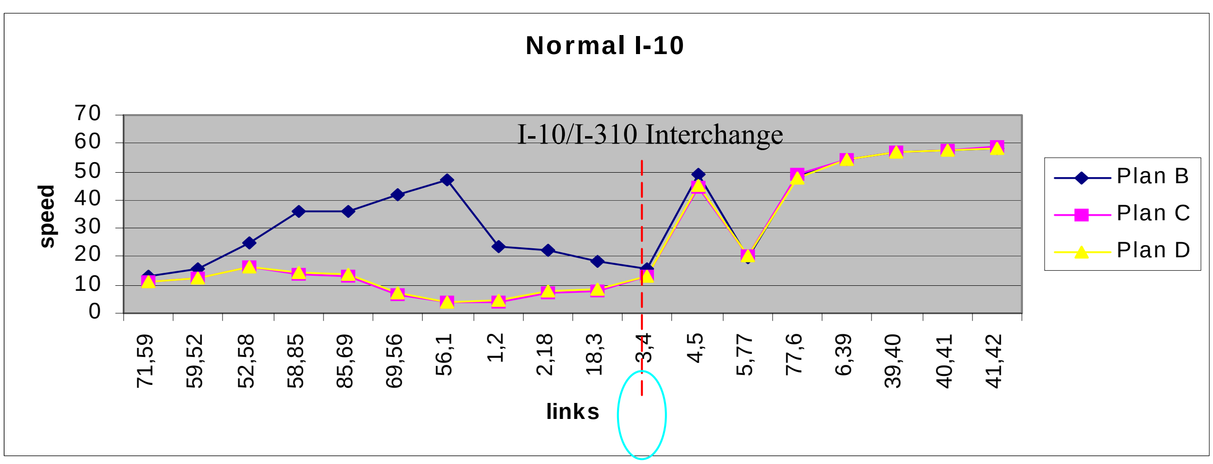


**Figure 72**
**Average speed on the normal I-10 for plans B, C and D during Period 17**

Figure 73 shows the average speed per link using the reverse lanes for the three-contraflow plans (Plans B to D). From link (71, 59) until link (85, 69), the speed characteristics were the same as in the normal I-10 since the vehicles did not reach the Kenner crossover. Link (69, 70) represents the median crossover. After the crossover, the speed characteristics for the three plans were the same. From this graph it can be concluded that even the volume on the reverse lanes was higher in Plans C and D, the speed remained approximately the same as in plan B. That means that there was no congestion on the reverse lanes for each of the three plans.

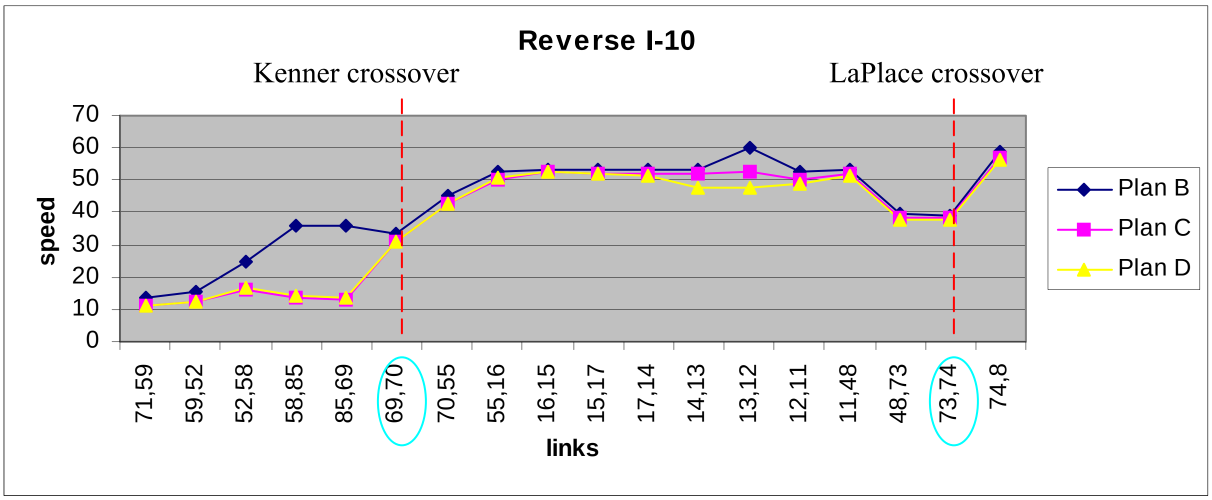


**Figure 73**
**Average speed on the reverse I-10 for the three contraflow plans at period 17**

The travel time for each route based on the four plans (Plans A to D) was calculated using the average speed data during Period 17 and the length of each link. From the travel time and length of the segment, the mean speed was estimated as shown in Table 21. From this table it was found that a maximum of about 31 minutes was required to clear the segment using Plan A. A maximum of around 25 minutes was required to clear the segment using Plan B. Using plan C, around 40 minutes were required to clear the segment since an additional flow volume entered from the normal lanes of I-310. A maximum of around 38 minutes was required to clear the segment using Plan D, which was less than the required time in Plan C. The possible reason for this was that based on Table 24, the amount of 52,804 exiting vehicles that used the normal lanes in Plan D was less than the amount of 52,855 exiting vehicles in Plan C.

**Table 24**
**Travel time and mean speed on the routes at Period 17 for the four plans**

| | | | | | |
|---|---|---|---|---|---|
| **Plan A** | **I-10 to I-55** | **Loyola to I-55** | **I-10 to I-10** | **Loyola to I-55** | |
| *Time (minutes)* | 29.53 | 20.30 | 30.34 | 21.10 | |
| *Mean Velocity (mph)* | 26.63 | 38.09 | 27.48 | 38.88 | |
| **Plan B** | **Normal I-10** | **Normal Loyola** | **Reverse I-10** | | |
| *Time (minutes)* | 24.33 | 22.06 | 17.09 | | |
| *Mean Velocity (mph)* | 32.33 | 35.06 | 48.85 | | |
| **Plan C** | **Normal I-10** | **Normal Loyola** | **Reverse I-10** | **Normal I-310** | |
| *Time (minutes)* | 39.51 | 37.02 | 19.46 | 19.23 | |
| *Mean Velocity (mph)* | 19.91 | 20.89 | 42.91 | 36.03 | |
| **Plan D** | **Normal I-10** | **Normal Loyola** | **Reverse I-10** | **Normal I-310** | **Reverse I-310** |
| *Time (minutes)* | 38.08 | 35.80 | 20.43 | 19.03 | 15.13 |
| *Mean Velocity (mph)* | 20.66 | 21.60 | 40.85 | 36.41 | 47.74 |

The mean velocity was calculated from the estimated travel time of each route for the four plans. For example, in each plan, the mean velocity was calculated based on the length of each route divided by the estimated travel time.

To verify that the travel time of each plan had a significant difference between their means, the same statistical test was used. The null hypothesis was that the means of the values of travel time for one plan minus the mean values of travel times for another plan was less or equal to zero. The alternative hypothesis was that the difference of the means was larger than zero. The travel time data that were used to test the means of our four plans were plotted in the following figure. Figure 74 illustrates the travel time data in dots for each run of the four plans. The numbers on the horizontal axes represent the travel time to discharge the segments in minutes.

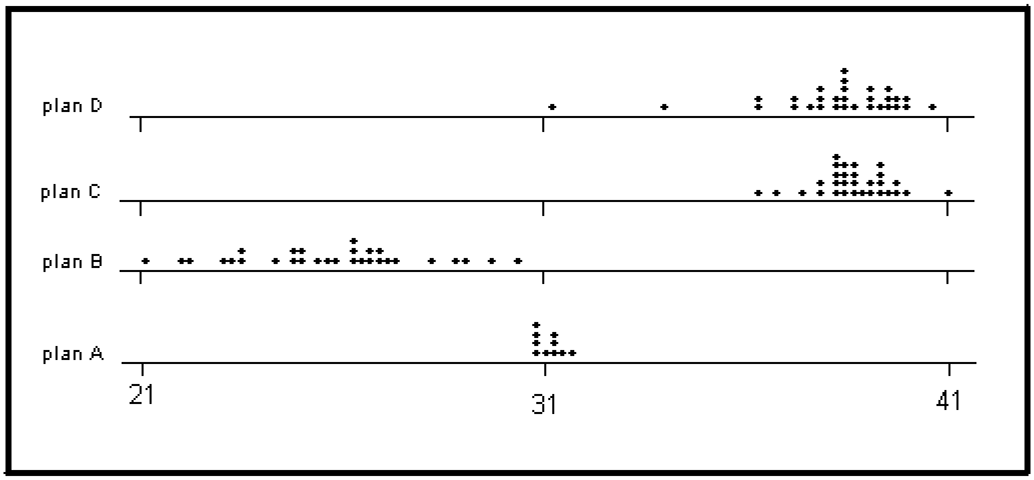


**Figure 74**
**Range of travel times to clear the segment for each plan in minutes**

**Testing the Difference Between the Means of the Four Plans**

First the difference between the means of Plan C and Plan B assuming equal variances was tested. The null hypothesis was that the mean value from Plan C minus the mean value from Plan B was less than or equal to zero. If it is zero, it means that there is no significant difference between the two plans. The alternative hypothesis was that the mean value from Plan C was larger than the mean value from Plan B. Figure 75 shows the results from MINITAB output. Plans C and B had a range of 30 values, and their mean values were 38.732 minutes and 25.77 minutes, respectively. The mean difference from these two plans was estimated to be 12.966 minutes.

Therefore, using Equation 3 revealed that the T-value was equal to 29.01. The Degrees of Freedom were equal to 58 (Number of observation of plan C plus the number of observation of plan B minus one). From these estimates the P-value was calculated using MINITAB. Since the p-value was almost zero and it is less than the value of a, the null hypothesis was rejected. That means that the mean travel time in plan C is larger than in plan B. Therefore, it can be concluded that Plan C needs more time to discharge the segment than plan B.

**Two-Sample T-Test and CI: plan C vs plan B**

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| Plan C | 30 | 38.732 | 0.922 | 0.17 |
| Plan B | 30 | 25.77 | 2.27 | 0.41 |

Difference = mu plan C - mu plan B
Estimate for difference: 12.966
95% lower bound for difference: 12.219
T-Test of difference = 0 (vs >): T-Value = 29.01 P-Value = 0.000 DF = 58
Both use Pooled StDev = 1.73

**Figure 75**
**Significant mean difference of Plan C and Plan B**

The same procedure was used to verify the difference between Plans D and C, and the output from the statistical package is shown below.

**Two-Sample T-Test and CI: plan D vs plan C**

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| Plan D | 30 | 38.24 | 1.89 | 0.35 |
| Plan C | 30 | 38.732 | 0.922 | 0.17 |

Difference = mu plan D - mu plan C
Estimate for difference: -0.488
95% lower bound for difference: -1.130
T-Test of difference = 0 (vs >): T-Value = -1.27 P-Value = 0.895 DF = 58
Both use Pooled StDev = 1.49

**Figure 76**
**Significant mean difference of Plan D and Plan C**

From the comparison between Plan D and C (table above), the null hypothesis was not rejected. The p-value, which was equal to 0.895, was larger than the a value. Therefore the null hypothesis was accepted since there was no strong evidence to conclude that Plan D was larger than Plan C. That means that there is no significance difference between the travel times in plans C and D.

From the three statistical tests, it was found that the travel times of Plans C and D were longer than the other plans. The travel time for Plan A was longer than plan B. This is because Plan B, with the same flow volume as in Plan A, used contraflow lanes for evacuation as well. However, for the above tests, it was assumed that the variance between the four plans was equal. To verify the statistical results, the same procedure was conducted but this time it was assumed that the variances were unequal.

**Two-Sample T-Test and CI: plan C vs plan B**

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| Plan C | 30 | 38.732 | 0.922 | 0.17 |
| Plan B | 30 | 25.77 | 2.27 | 0.41 |

Difference = mu plan C - mu plan B
Estimate for difference: 12.966
95% lower bound for difference: 12.213
T-Test of difference = 0 (vs >): T-Value = 29.01 P-Value = 0.000 DF = 38

**Figure 77**
**Significant mean difference of Plan C and Plan B**

**Two-Sample T-Test and CI: plan D vs plan C**

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| Plan D | 30 | 38.24 | 1.89 | 0.35 |
| Plan C | 30 | 38.732 | 0.922 | 0.17 |

Difference = mu plan C - mu plan B
Estimate for difference: -0.488
95% lower bound for difference: -1.134
T-Test of difference = 0 (vs >): T-Value = -1.27 P-Value = 0.894 DF = 42

**Figure 78**
**Significant mean difference of Plan D and Plan C**

The above tables show the output results from MINITAB and it can be concluded that the three tests with unequal variances had the same results as with equal variances.

**Termination Point Analyses**

In this section, 10 models with different configurations were compared and evaluated based on several Measures of Effectiveness (MOE), including total number of vehicles exiting the network, vehicle speed, delay time, volume, density, and move time over total time ratio (M/T ratio).

First, the network-wide performance was evaluated in terms of average speed, M/T ratio, delay time and total number of vehicles exiting the network. This comparison showed the overall performance of each model. Secondly, the average speed, delay time and M/T ratio on the contraflow and the normal flow routes were compared to show the different performance of each model based on different route configurations. Lastly, the traffic volume, speed, density and delay time were used to compare the performance on several critical links. These critical links included those merging area before the median crossover, intermediate links and entrance links.

To verify the differences of the MOE output results, statistical analyses were used to compare the models using the Statistical Analysis System (SAS) software package. One-way analysis of variance (ANOVA) was performed. The null hypothesis of ANOVA, $H_0 = \mu_1 = \mu_2 = \mu_3 = \ldots = \mu_{10}$, assumed that the all means of the MOE results of the 10 models were the same. In contrast, the alternative hypothesis, $H_1$, assumed that at least one of the means of the MOE results of the models was different.

In this study, since the traffic demand was the same over 16 time-periods, the MOE results at the end of simulation (TP16) represented the maximum congestion of each model. These results were then analyzed with one-way ANOVA. At $\alpha = 0.05$ significance level (i.e. 95 percent confident), 9 degrees of freedom (10 models – 1) and 290 (300 samples – 10 models), respectively, the $F_{critical}$ value is 1.912. The $F_{critical}$ value was used to compare all F-values obtained from the one-way ANOVA test in the following sections. If the F-value was larger than $F_{critical}$ value, then one-way ANOVA test rejected the null hypothesis and indicated that at least one of the operational MOE's means of the models was different.

Tukey testing was used after the one-way ANOVA test to make multiple pairwise comparisons between means when the groups had the same sample size. It was used to find where the difference existed for the means and was capable of ranking the means of MOE results. The Tukey's ranking tables presented in this study ranked the models using alphabetical order, where *A* has higher rank than *B*, and so on (see sample in Appendix D). Models with the same letters meant that they were not significantly different. Sometimes Tukey testing overlapped different alphabets in the same ranking (i.e. putting *A* and *B* in the same line). This signified non-significant differences in the ranking of the means. F-values and Tukey ranking tables were included after each statistical test for the MOE results in the following analysis comparisons.

## Overall Network Comparison

Network-Wide Performance Comparisons shows the F-values calculated from ANOVA for the various MOEs. The F-values ranged from 2,888 for the average speed to 21,927 for the delay time. All the F-values were all larger than the $F_{critical}$ of 1.912. Therefore, the null hypothesis was rejected, indicating that at least one of the operational MOEs means of the models was significantly different from the others. For an example, it showed that the average speed of Type A model was significantly different with the average speed of other models.

**Table 25**
**Network-wide average statistics at TP16 for MIN, MAX, AVE, STDEV and F-value comparison**

| TYPE | | A | $B_{25}$ | $B_{50}$ | $C_{25}$ | $C_{50}$ | $D_{25}$ | $D_{50}$ | $E_{25}$ | $E_{50}$ | F | F-Value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TOTAL VEHICLE-MILE | MIN | 17301.20 | 13162.20 | 12890.30 | 16580.90 | 17572.40 | 12808.30 | 13100.70 | 11243.10 | 12354.20 | 10485.90 | 8,250 |
| | MAX | 17672.80 | 13414.90 | 13197.10 | 17347.30 | 18160.90 | 13255.70 | 14383.30 | 11679.60 | 13368.90 | 10916.80 | |
| | AVE | 17502.31 | 13270.62 | 13072.35 | 17008.24 | 17867.78 | 13045.15 | 13768.86 | 11413.45 | 12861.30 | 10681.92 | |
| | STDEV | 102.70 | 68.95 | 66.60 | 166.03 | 129.80 | 111.48 | 302.01 | 110.17 | 207.68 | 98.51 | |
| MOVE TIME (VEHICLE-HOURS) | MIN | 267.14 | 164.53 | 160.68 | 253.99 | 272.82 | 184.05 | 206.91 | 137.73 | 175.97 | 98.01 | 14,006 |
| | MAX | 273.06 | 169.59 | 166.17 | 271.86 | 281.82 | 192.87 | 226.04 | 147.47 | 192.26 | 106.34 | |
| | AVE | 270.28 | 167.36 | 164.22 | 261.82 | 277.29 | 187.70 | 216.97 | 141.48 | 183.71 | 102.33 | |
| | STDEV | 1.73 | 1.39 | 1.26 | 3.99 | 2.17 | 2.05 | 4.64 | 2.30 | 3.43 | 1.76 | |
| DELAY TIME (VEHICLE-HOURS) | MIN | 231.04 | 838.91 | 836.39 | 498.35 | 99.95 | 1090.82 | 127.54 | 1640.59 | 983.59 | 1756.37 | 15,761 |
| | MAX | 317.11 | 870.21 | 866.42 | 739.55 | 224.91 | 1199.10 | 208.65 | 1689.01 | 1083.97 | 1796.23 | |
| | AVE | 274.58 | 854.43 | 851.22 | 649.36 | 175.56 | 1143.79 | 177.36 | 1670.88 | 1038.90 | 1773.05 | |
| | STDEV | 19.02 | 9.42 | 7.43 | 50.14 | 29.77 | 24.61 | 24.55 | 12.99 | 27.98 | 11.00 | |
| TOTAL TIME (VEHICLE-HOURS) | MIN | 501.29 | 1006.09 | 1000.61 | 770.21 | 381.58 | 1283.69 | 346.62 | 1786.94 | 1167.18 | 1859.55 | 14,615 |
| | MAX | 587.08 | 1037.68 | 1030.01 | 994.47 | 497.73 | 1387.36 | 428.61 | 1832.73 | 1265.54 | 1895.22 | |
| | AVE | 544.85 | 1021.79 | 1015.44 | 911.19 | 452.85 | 1331.49 | 394.33 | 1812.37 | 1222.61 | 1875.38 | |
| | STDEV | 18.07 | 8.84 | 7.22 | 46.68 | 28.72 | 23.65 | 23.05 | 12.57 | 27.05 | 10.51 | |
| AVE SPEED (MPH) | MIN | 29.73 | 12.77 | 12.66 | 16.90 | 35.31 | 9.40 | 31.85 | 6.17 | 9.89 | 5.59 | 2,888 |
| | MAX | 34.89 | 13.22 | 13.11 | 22.52 | 47.59 | 10.29 | 40.06 | 6.50 | 11.32 | 5.81 | |
| | AVE | 32.16 | 12.99 | 12.87 | 18.72 | 39.62 | 9.80 | 35.05 | 6.30 | 10.53 | 5.70 | |
| | STDEV | 1.17 | 0.13 | 0.11 | 1.17 | 2.77 | 0.22 | 2.41 | 0.08 | 0.32 | 0.05 | |
| MOVE/TOTAL | MIN | 0.4599 | 0.1593 | 0.1588 | 0.2563 | 0.5481 | 0.1355 | 0.5017 | 0.0762 | 0.1412 | 0.0518 | 3,172 |
| | MAX | 0.5391 | 0.1675 | 0.1645 | 0.3530 | 0.7381 | 0.1502 | 0.6320 | 0.0821 | 0.1628 | 0.0563 | |
| | AVE | 0.4966 | 0.1638 | 0.1617 | 0.2883 | 0.6149 | 0.1410 | 0.5523 | 0.0781 | 0.1503 | 0.0546 | |
| | STDEV | 0.0183 | 0.0023 | 0.0018 | 0.0200 | 0.0430 | 0.0035 | 0.0380 | 0.0014 | 0.0048 | 0.0010 | |
| DELAY TIME (MINUTES/MILE) | MIN | 0.7927 | 3.7839 | 3.8239 | 1.7237 | 0.3302 | 4.9557 | 0.5511 | 8.4767 | 4.4368 | 9.7485 | 21,927 |
| | MAX | 1.0901 | 3.9514 | 3.9872 | 2.6408 | 0.7679 | 5.5165 | 0.9386 | 8.9885 | 5.2115 | 10.1770 | |
| | AVE | 0.9415 | 3.8633 | 3.9071 | 2.2922 | 0.5899 | 5.2615 | 0.7742 | 8.7847 | 4.8486 | 9.9599 | |
| | STDEV | 0.0685 | 0.0501 | 0.0420 | 0.1926 | 0.1020 | 0.1386 | 0.1150 | 0.1191 | 0.1734 | 0.1056 | |
| TOTAL TIME (MINUTES/MILE) | MIN | 1.7199 | 4.5380 | 4.5770 | 2.6640 | 1.2607 | 5.8319 | 1.4979 | 9.2353 | 5.2997 | 10.3257 | 21,267 |
| | MAX | 2.0182 | 4.7001 | 4.7400 | 3.5511 | 1.6995 | 6.3810 | 1.8839 | 9.7294 | 6.0683 | 10.7329 | |
| | AVE | 1.8681 | 4.6199 | 4.6608 | 3.2158 | 1.5211 | 6.1248 | 1.7197 | 9.5284 | 5.7056 | 10.5347 | |
| | STDEV | 0.0681 | 0.0477 | 0.0407 | 0.1870 | 0.1018 | 0.1369 | 0.1152 | 0.1164 | 0.1725 | 0.1013 | |

Table 25 shows the Tukey's ranking based on variables available from the CORSIM network-wide statistics output results. As shown in the table, Type $C_{50}$, $D_{50}$ and A models ranked first, second, and third for both average speed and M/T ratio. All the average speeds were above 32 mph and M/T ratios were above 0.50. These results showed that the vehicles kept moving at half of the total travel time. Type F, $E_{25}$, $E_{50}$, and $D_{25}$ models had congested speeds (below 10 mph) with more than 1,000 vehicle-hours (veh-hrs) in delay time and less than 0.29 in M/T ratio. These results showed that the vehicles moved slowly and wasted more than 70 percent of the total travel time in congested traffic. Even though Type $B_{25}$ and

$B_{50}$ models had different exiting traffic percentages at the normal flow exit-ramp, their performances in terms of average speed and delay time were not significantly different. This showed that exiting more vehicles at the exit-ramp on the normal flow direction for Type B models located after the one-lane closure did not reduce the overall delay time. The average speed of $B_{25}$ and $B_{50}$ models were around 13 mph with M/T ratio around 0.16. These results showed that the evacuees wasted more than 84 percent of total travel time in the congested traffic. In other words, the bottleneck of the traffic flow occurred before the one-lane closure, and the different exiting traffic percentages did not greatly affect the overall average speed and delay time. By contrast, as shown in Table 26, the comparisons of $C_{50}$ and $D_{50}$ to $C_{25}$ and $D_{25}$ models showed that the different percentage of vehicle exits at the off-ramps contributed differently in average speed and delay time. As expected, exiting more traffic at the off-ramps for these models increased the overall average speed and reduced the overall delay time. Although Type A model maintained two-lane operation on both routes, it was not ranked the most efficient design. This was because Type $C_{50}$ and $D_{50}$ models had 50 percent exiting traffic at the available interchange that decreased the total delay time as well as increased the overall average speed.

As shown in Table 26, the overall performance of Type C models was better than Type D models. This was because Type C models only had one-lane closure on the contraflow direction, and Type D models had one-lane closure on both contraflow and normal flow directions. This meant that one-lane closure operation created more congestion and increased the delay time for the model. The overall performance ranking of Type $C_{50}$, $D_{50}$, and A models were the top three models in terms of both average speed and move/total ratio. This showed that with 50 percent of vehicles exiting at the available exit-ramp, travel speed increased and travel delay time decreased. These models required less travel time for the evacuees to reach their destination. Type E models had one exit-ramp on the normal flow direction and Type F models did not have any exit-ramp. Not surprisingly, the results showed that having less available exits in these models degraded the overall travel speed and move/total ratio. These models had serious congested traffic that required the evacuees to take about six to ten times longer in delay time compared to Type C models.

**Table 26**
**Tukey's ranking for network-wide statistics**

**Tukey's Studentized Range (HSD) Tests**

**TOTAL VEHICLE-MILE**

| TUKEY RANKING | MEAN | TYPE |
|---|---|---|
| A | 17867.78 | $C_{50}$ |
| B | 17502.31 | A |
| C | 17008.24 | $C_{25}$ |
| D | 13768.86 | $D_{50}$ |
| E | 13270.62 | $B_{25}$ |
| F | 13072.35 | $B_{50}$ |
| F | 13045.15 | $D_{25}$ |
| G | 12861.30 | $E_{50}$ |
| H | 11413.45 | $E_{25}$ |
| I | 10681.92 | F |

**TOTAL TIME (VEHICLE-HOURS)**

| TUKEY RANKING | MEAN | TYPE |
|---|---|---|
| A | 1875.38 | F |
| B | 1812.37 | $E_{25}$ |
| C | 1331.49 | $D_{25}$ |
| D | 1222.61 | $E_{50}$ |
| E | 1021.79 | $B_{25}$ |
| E | 1015.44 | $B_{50}$ |
| F | 911.19 | $C_{25}$ |
| G | 544.85 | A |
| H | 452.85 | $C_{50}$ |
| I | 394.33 | $D_{50}$ |

**MOVE TIME (VEHICLE-HOURS)**

| TUKEY RANKING | MEAN | TYPE |
|---|---|---|
| A | 277.29 | $C_{50}$ |
| B | 270.28 | A |
| C | 261.82 | $C_{25}$ |
| D | 216.97 | $D_{50}$ |
| E | 187.70 | $D_{25}$ |
| F | 183.71 | $E_{50}$ |
| G | 167.36 | $B_{25}$ |
| H | 164.22 | $B_{50}$ |
| I | 141.48 | $E_{25}$ |
| J | 102.33 | F |

**AVE SPEED ( MPH)**

| TUKEY RANKING | MEAN | TYPE |
|---|---|---|
| A | 39.62 | $C_{50}$ |
| B | 35.05 | $D_{50}$ |
| C | 32.16 | A |
| D | 18.72 | $C_{25}$ |
| E | 12.99 | $B_{25}$ |
| E | 12.87 | $B_{50}$ |
| F | 10.53 | $E_{50}$ |
| F | 9.80 | $D_{25}$ |
| G | 6.30 | $E_{25}$ |
| G | 5.70 | F |

**DELAY TIME (VEHICLE-HOURS)**

| TUKEY RANKING | MEAN | TYPE |
|---|---|---|
| A | 1773.05 | F |
| B | 1670.88 | $E_{25}$ |
| C | 1143.79 | $D_{25}$ |
| D | 1038.90 | $E_{50}$ |
| E | 854.43 | $B_{25}$ |
| E | 851.22 | $B_{50}$ |
| F | 649.36 | $C_{25}$ |
| G | 274.58 | A |
| H | 177.36 | $D_{50}$ |
| H | 175.56 | $C_{50}$ |

**MOVE/TOTAL RATIO**

| TUKEY RANKING | MEAN | TYPE |
|---|---|---|
| A | 0.61 | $C_{50}$ |
| B | 0.55 | $D_{50}$ |
| C | 0.50 | A |
| D | 0.29 | $C_{25}$ |
| E | 0.16 | $B_{25}$ |
| E | 0.16 | $B_{50}$ |
| F E | 0.15 | $E_{50}$ |
| F | 0.14 | $D_{25}$ |
| G | 0.08 | $E_{25}$ |
| H | 0.05 | F |

Note: Means with the same letter are not significantly different.

### Vehicles Processed Comparisons

The overall vehicles processed by each of the model configurations were compared in terms of *Vehicle Out/Vehicle In ratio (Out/In Ratio).* The *Out/In Ratio* indicated the percentage of total number of vehicles exiting the network with the available exit node(s) during the time period of interest. It was computed with the total vehicle number exiting the network divided by total number of vehicles entering the network. Here, the total vehicles entering network over four hours was 24,000 vehicles (i.e., 2,700 vph x 4 hours on the contraflow direction and 3,300 vph x 4 hours on the normal flow direction).

Figures 79 and 80 show the cumulative number of vehicles entering and exiting the network and the cumulative *Vehicle Out/Vehicle In ratio* at the end of TP16. In Figure 79, only Type A, $C_{25}$, $C_{50}$, and $D_{50}$ models had approximately 24,000 vehicles entering the network. Type $B_{25}$, $B_{50}$, $D_{25}$, $E_{25}$, $E_{50}$, and F models had fewer number of vehicles entering the network because these networks became saturated, congestion and the backed-up vehicles occurred preventing additional vehicles from entering the network.

Table 27 illustrates the Tukey's ranking of TP16 *Sum TP Vehicle Out*, *Sum Total Vehicle Out* and *Out/In Ratio*. The *Sum TP Vehicle Out* was the number of vehicles exiting the network during TP16. The *Sum Total Vehicle Out* and *Out/In Ratio* were the total number of vehicles exiting the network and ratio from the beginning of TP1 to the end of TP16. The *Out/In Ratio* indicated that Type $C_{50}$, $D_{50}$ and A models had over 96 percent (i.e. 23,000 vehicles) of vehicles exit the network, and Type $C_{25}$ model had around 90 percent (i.e. 21,600 vehicles) of vehicles exiting the network. As expected, models with more vehicles exiting at the available exit-ramps increased the *Out/In Ratio*, which meant the networks were more efficient in evacuating vehicles. In contrast, the *Out/In Ratio* for Type F and $E_{25}$ models indicated that 55 percent and 67 percent of the vehicles exited the network. This meant that more than 33 percent (around 7,920 vehicles) of the total amount of vehicles remained in the network models. These models also confront more congested traffic that slow down the evacuation process. During the last 15 minutes of simulation, only 822 and 956 vehicles exited Type F and $E_{25}$ models, respectively. These models only processed about 60 percent of the demand of 1,500 vehicles at that time period. This meant that 40 percent of the vehicles were queued outside these saturated network models. In contrast, around 1,450 vehicles exited from the Type $D_{50}$, $C_{50}$, and A network models in the same time-period of simulation. This figure was about 96 percent of 1,500 vehicles per 15 minutes were exiting the network models. In other words, these models were more efficient in the evacuation process compared to other models. The analysis of the *Out/In Ratio* results showed that 50 percent of turning movement at the exit-ramps produced 8 percent to 24 percent increases in vehicles exiting the network for Type C, D, E models. The results provide support for the idea that exiting more vehicles and using more exits before entering the termination point of the contraflow segments can improve the overall amount of evacuated vehicles. Ultimately, this could also save time in moving evacuees from the endangered areas.

**Table 27**
**Tukey's ranking of SUM TP vehicle out, sum total vehicle out and out/in ratio at TP16 comparison**

| Tukey's Studentized Range (HSD) Tests | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| SUM TP VEHICLE OUT | | | SUM TOTAL VEHICLE OUT | | | OUT/IN Ratio | | |
| TUKEY RANKING | MEAN | TYPE | TUKEY RANKING | MEAN | TYPE | TUKEY RANKING | MEAN | TYPE |
| A | 1,463 | $D_{50}$ | A | 23,444 | $C_{50}$ | A | 0.98 | $C_{50}$ |
| A | 1,462 | $C_{50}$ | B | 23,313 | $D_{50}$ | B | 0.97 | $D_{50}$ |
| A | 1,441 | A | C | 23,087 | A | C | 0.96 | A |
| B | 1,334 | $C_{25}$ | D | 21,611 | $C_{25}$ | D | 0.90 | $C_{25}$ |
| C | 1,190 | $E_{50}$ | E | 19,210 | $E_{50}$ | E | 0.80 | $E_{50}$ |
| D | 1,136 | $D_{25}$ | F | 18,869 | $D_{25}$ | F | 0.79 | $D_{25}$ |
| E | 1,089 | $B_{50}$ | G | 17,437 | $B_{25}$ | G | 0.73 | $B_{25}$ |
| E | 1,087 | $B_{25}$ | G | 17,429 | $B_{50}$ | G | 0.73 | $B_{50}$ |
| F | 959 | $E_{25}$ | H | 16,031 | $E_{25}$ | H | 0.67 | $E_{25}$ |
| G | 822 | F | I | 13,307 | F | I | 0.55 | F |
| Note: Means with the same letter are not significantly different. | | | | | | | | |

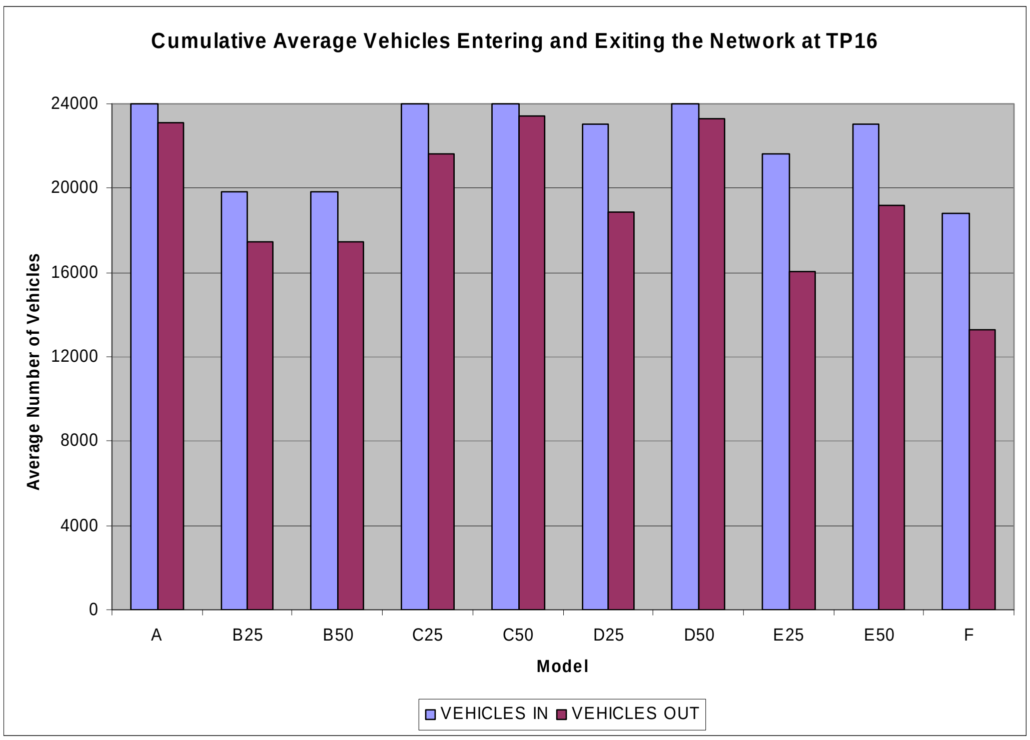


**Figure 79**
**Cumulative vehicles in and out of the network at TP 16 comparisons**

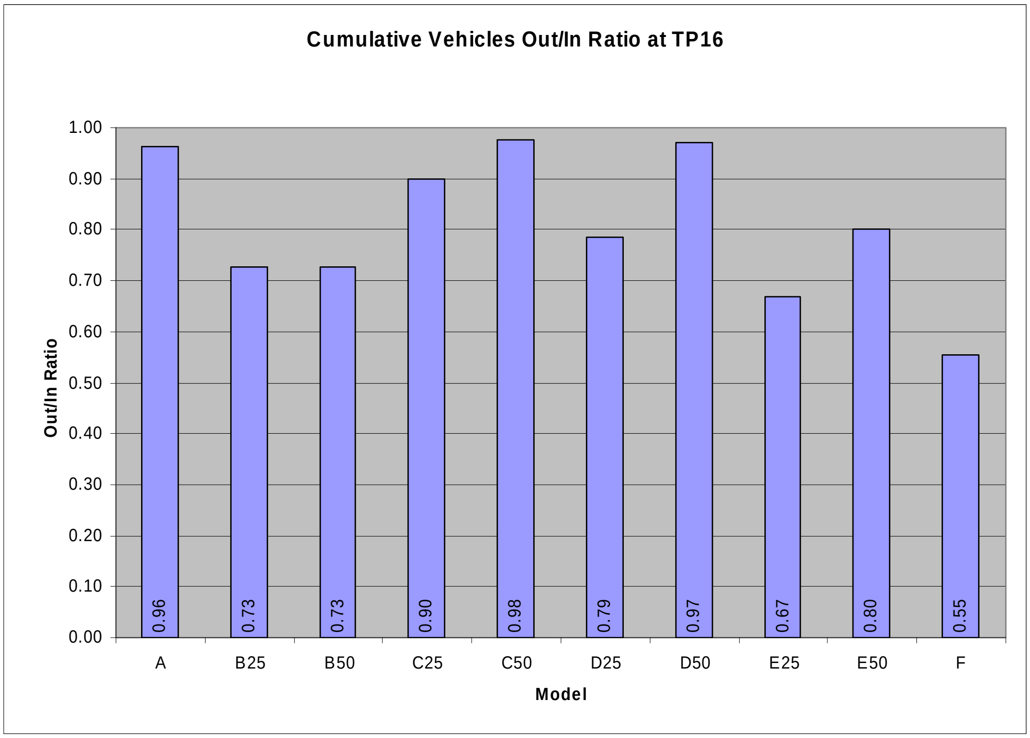


**Figure 80**
**Cumulative Vehicles Out/In Ratio at TP 16 Comparisons**

## Route Performance Comparisons

Contraflow and normal flow routes were selected to compare the routes' performance. The contraflow route spanned from link (52, 50) to link (6, 58) and the normal flow route spanned from link (53, 51) to link (6, 58) (See Table 28 for links information). The total travel time and delay time in term of seconds/vehicle for each route at the end of TP16 were calculated by summing up the total travel time and delay time of each link on each corresponding route. The average route speeds at the end of TP16 were calculated with dividing the total length by the total travel time on each route. Table 29 presents the Travel Time, Delay Time, Move/Total Ratio (M/T ratio), Average Route Speed, and F-value at the end of TP16 for contraflow and normal flow routes. *Extra Move Time in %* shows the percentage of delay time compared to the estimated move time. As shown in Table 29, all the F-values were larger than the $F_{critical}$ value of 1.912 showed that at least one of the total times, delay times and average route speeds of the models was significantly different with other models.

**Table 28**
**Link order and properties table for contraflow and normal flow routes**

| Link Order for Contraflow Route | | | | | Link Order for Normal Flow Route | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Link Order | Direction | Link | Speed Limit (MPH) | Length (FT) | Link Order | Direction | Link | Speed Limit (MPH) | Length (FT) |
| 1 | Contraflow | ( 52, 50) | 65 | 5,280 | 1 | Normal | ( 53, 51) | 65 | 5,280 |
| 2 | Contraflow | ( 50, 48) | 65 | 5,280 | 2 | Normal | ( 51, 49) | 65 | 5,280 |
| 3 | Contraflow | ( 48, 46) | 65 | 5,280 | 3 | Normal | ( 49, 47) | 65 | 5,280 |
| 4 | Contraflow | ( 46, 44) | 65 | 5,280 | 4 | Normal | ( 47, 45) | 65 | 5,280 |
| 5 | Contraflow | ( 44, 42) | 65 | 5,280 | 5 | Normal | ( 45, 43) | 65 | 5,280 |
| 6 | Contraflow | ( 42, 40) | 65 | 1,320 | 6 | Normal | ( 43, 41) | 65 | 1,320 |
| 7 | Contraflow | ( 40, 38) | 65 | 2,640 | 7 | Normal | ( 41, 39) | 65 | 2,640 |
| 8 | Contraflow | ( 38, 36) | 65 | 1,320 | 8 | Normal | ( 39, 37) | 65 | 1,320 |
| 9 | Contraflow | ( 36, 34) | 65 | 5,280 | 9 | Normal | ( 37, 35) | 65 | 5,280 |
| 10 | Contraflow | ( 34, 32) | 65 | 5,280 | 10 | Normal | ( 35, 33) | 65 | 5,280 |
| 11 | Contraflow | ( 32, 30) | 65 | 5,280 | 11 | Normal | ( 33, 31) | 65 | 5,280 |
| 12 | Contraflow | ( 30, 28) | 65 | 5,280 | 12 | Normal | ( 31, 29) | 65 | 5,280 |
| 13 | Contraflow | ( 28, 26) | 65 | 1,320 | 13 | Normal | ( 29, 27) | 65 | 1,320 |
| 14 | Contraflow | ( 26, 24) | 65 | 1,320 | 14 | Normal | ( 27, 25) | 65 | 1,320 |
| 15 | Contraflow | ( 24, 22) | 65 | 720 | 15 | Normal | ( 25, 23) | 65 | 720 |
| 16 | Contraflow | ( 22, 20) | 65 | 600 | 16 | Normal | ( 23, 21) | 65 | 600 |
| 17 | Contraflow | ( 20, 19) | 65 | 1,320 | 17 | Normal | ( 21, 15) | 65 | 1,320 |
| 18 | Contraflow | ( 19, 18) | 65 | 1,410 | 18 | Normal | ( 15, 14) | 65 | 1,410 |
| 19 | Contraflow | ( 18, 17) | 65 | 500 | 18.1** | Normal | ( 15, 55) | 35 | 484 |
| 20 | Contraflow | ( 17, 16) | 45 | 500 | 19 | Normal | ( 14, 13) | 65 | 500 |
| 21 | Contraflow | ( 16, 10) | 45 | 600 | 20 | Normal | ( 13, 12) | 45 | 500 |
| 22 | Contraflow | ( 10, 8) | 45 | 450 | 21 | Normal | ( 12, 11) | 45 | 600 |
| 23 | Contraflow | ( 8, 1) | 45 | 500 | 22 | Normal | ( 11, 9) | 45 | 450 |
| 24.3* | Contraflow | ( 1, 2) | 45 | 383 | 23 | Normal | ( 9, 7) | 45 | 500 |
| 25 | Normal | ( 2, 4) | 65 | 500 | 24 | Normal | ( 7, 2) | 45 | 370 |
| 26 | Normal | ( 4, 5) | 65 | 350 | 25 | Normal | ( 2, 4) | 65 | 500 |
| 27 | Normal | ( 5, 6) | 65 | 150 | 26 | Normal | ( 4, 5) | 65 | 350 |
| 28 | Normal | ( 6, 58) | 65 | 5,280 | 27 | Normal | ( 5, 6) | 65 | 150 |
| | | | | | 28 | Normal | ( 6, 58) | 65 | 5,280 |

Note: * This link is a median crossover
** This link only apply to Type A

**Table 29**
**Travel time, delay time, M/T ratio, average route speed, and F-value at TP16 for contraflow and normal flow routes comparison**

**Travel Time on Contraflow Routes Comparison**

| TYPE | | TOTAL TIME (SEC/VEH) | DELAY TIME (SEC/VEH) | M/T | Extra Move Time in % | AVE Route Speed |
|---|---|---|---|---|---|---|
| A | MIN | 782.04 | 50.14 | | | |
| | MAX | 800.07 | 68.07 | | | |
| | MEAN | 789.42 | 57.45 | 0.93 | 8% | 59.34 |
| | STDEV | 4.47 | 4.42 | | | |
| $B_{25}$ | MIN | 782.57 | 50.57 | | | |
| | MAX | 806.51 | 74.51 | | | |
| | MEAN | 793.00 | 61.00 | 0.92 | 8% | 59.07 |
| | STDEV | 4.92 | 4.92 | | | |
| $B_{50}$ | MIN | 783.65 | 51.76 | | | |
| | MAX | 802.82 | 70.82 | | | |
| | MEAN | 792.52 | 60.53 | 0.92 | 8% | 59.11 |
| | STDEV | 5.35 | 5.34 | | | |
| $C_{25}$ | MIN | 3171.72 | 2439.71 | | | |
| | MAX | 4515.89 | 3783.89 | | | |
| | MEAN | 4006.18 | 3274.18 | 0.18 | 447% | 11.75 |
| | STDEV | 286.94 | 286.94 | | | |
| $C_{50}$ | MIN | 784.26 | 52.26 | | | |
| | MAX | 799.67 | 67.66 | | | |
| | MEAN | 790.26 | 58.27 | 0.93 | 8% | 59.28 |
| | STDEV | 3.49 | 3.48 | | | |
| $D_{25}$ | MIN | 3183.08 | 2451.08 | | | |
| | MAX | 4306.63 | 3574.63 | | | |
| | MEAN | 3748.67 | 3016.67 | 0.20 | 412% | 12.54 |
| | STDEV | 216.06 | 216.06 | | | |
| $D_{50}$ | MIN | 774.28 | 42.27 | | | |
| | MAX | 787.95 | 55.95 | | | |
| | MEAN | 780.57 | 48.58 | 0.94 | 7% | 60.01 |
| | STDEV | 3.86 | 3.84 | | | |
| $E_{25}$ | MIN | 8036.48 | 7304.48 | | | |
| | MAX | 8460.44 | 7728.44 | | | |
| | MEAN | 8243.07 | 7511.07 | 0.09 | 1026% | 5.68 |
| | STDEV | 107.33 | 107.33 | | | |
| $E_{50}$ | MIN | 7958.59 | 7226.58 | | | |
| | MAX | 8468.56 | 7736.56 | | | |
| | MEAN | 8249.37 | 7517.36 | 0.09 | 1027% | 5.68 |
| | STDEV | 113.15 | 113.15 | | | |
| F | MIN | 8014.41 | 7282.40 | | | |
| | MAX | 8425.84 | 7693.84 | | | |
| | MEAN | 8242.51 | 7510.51 | 0.09 | 1026% | 5.68 |
| | STDEV | 103.57 | 103.57 | | | |
| F Value within models | | 21198 | 21198 | | | 113528 |

**Travel Time on Normal Flow Routes Comparison**

| TYPE | | TOTAL TIME (SEC/VEH) | DELAY TIME (SEC/VEH) | M/T | Extra Move Time in % | AVE Route Speed |
|---|---|---|---|---|---|---|
| A | MIN | 1656.09 | 1041.78 | | | |
| | MAX | 2051.27 | 1436.97 | | | |
| | MEAN | 1845.87 | 1231.56 | 0.33 | 200% | 21.69 |
| | STDEV | 96.82 | 96.82 | | | |
| $B_{25}$ | MIN | 7602.88 | 6871.08 | | | |
| | MAX | 8079.12 | 7347.31 | | | |
| | MEAN | 7812.58 | 7080.77 | 0.09 | 968% | 6.00 |
| | STDEV | 114.01 | 114.01 | | | |
| $B_{50}$ | MIN | 7607.00 | 6875.75 | | | |
| | MAX | 8004.20 | 7272.64 | | | |
| | MEAN | 7777.91 | 7046.37 | 0.09 | 963% | 6.02 |
| | STDEV | 97.51 | 97.48 | | | |
| $C_{25}$ | MIN | 1228.90 | 497.72 | | | |
| | MAX | 1684.87 | 953.71 | | | |
| | MEAN | 1449.01 | 717.84 | 0.51 | 98% | 32.51 |
| | STDEV | 112.07 | 112.07 | | | |
| $C_{50}$ | MIN | 1117.60 | 386.50 | | | |
| | MAX | 1754.78 | 1023.57 | | | |
| | MEAN | 1484.42 | 753.27 | 0.49 | 103% | 31.85 |
| | STDEV | 142.51 | 142.49 | | | |
| $D_{25}$ | MIN | 6643.69 | 5911.89 | | | |
| | MAX | 6991.03 | 6259.22 | | | |
| | MEAN | 6845.67 | 6113.86 | 0.11 | 835% | 6.84 |
| | STDEV | 99.69 | 99.69 | | | |
| $D_{50}$ | MIN | 1280.06 | 548.26 | | | |
| | MAX | 1681.33 | 949.52 | | | |
| | MEAN | 1513.86 | 782.06 | 0.48 | 107% | 31.13 |
| | STDEV | 119.66 | 119.66 | | | |
| $E_{25}$ | MIN | 6584.81 | 5853.00 | | | |
| | MAX | 7043.47 | 6311.67 | | | |
| | MEAN | 6878.78 | 6146.97 | 0.11 | 840% | 6.81 |
| | STDEV | 111.01 | 111.01 | | | |
| $E_{50}$ | MIN | 1265.78 | 533.97 | | | |
| | MAX | 1685.93 | 954.12 | | | |
| | MEAN | 1497.35 | 765.54 | 0.49 | 105% | 31.49 |
| | STDEV | 121.37 | 121.37 | | | |
| F | MIN | 7985.75 | 7253.94 | | | |
| | MAX | 8443.21 | 7711.40 | | | |
| | MEAN | 8204.46 | 7472.65 | 0.09 | 1021% | 5.71 |
| | STDEV | 121.07 | 121.07 | | | |
| F Value within models | | 22943 | 22786 | | | 1516 |

### Contraflow Routes Statistics Comparisons

Table 30 illustrates the Tukey's ranking for contraflow route statistics. The delay time and average route speed for the Type $E_{25}$, $E_{50}$ and F models were around 7,511 seconds/vehicle (sec/veh) and 6 mph. As expected, since these models did not have available exit-ramp on the routes, evacuees took the longest time to reach the destination. The average route speeds for the Type $D_{50}$, A, $C_{50}$, $B_{50}$ and $B_{25}$ models were above 59 mph with delay time of less than 61 sec/veh. These models obviously did not have congestion and the evacuees used the shortest time to reach the destination. The results for Type $B_{25}$ and $B_{50}$ models illustrated that there was no significant difference in delay time and average route speed because barrier dividers were used to force all traffic on the left lane to exit at the off-ramp. By contrast, Type $C_{25}$, $C_{50}$, $D_{25}$, and $D_{50}$ models did not have a barrier divider. Type $C_{25}$ and $D_{25}$ models had slower average route speed (around 12 mph) and longer delay time of 3,100 sec/veh compared to Type $C_{50}$ and $D_{50}$ models at 59 mph, with less than 58 sec/veh in delay time. The delay time of Type $C_{25}$ and $D_{25}$ models increased approximately four times higher than the normal travel time. This showed that the more exiting vehicles exiting at the available exit-ramps reduced the delay time and traffic congestion.

The performance ranked Type $D_{50}$, A, $C_{50}$, $B_{50}$, $B_{25}$, $D_{25}$, $C_{25}$, $E_{25}$, $E_{50}$, and F in terms of M/T ratio and average route speed. As expected, these results showed that 50 percent of the vehicles exiting at the available exit-ramp increased the average route speed and decreased the travel delay time. These models took less travel time for the evacuees to reach the destination. Type $D_{25}$, $C_{25}$, $E_{25}$, $E_{50}$, and F models had congested traffic that required the evacuees to take longer time to egress from the endangered areas.

**Table 30**
**Tukey's ranking for contraflow route statistics**

**Tukey's Studentized Range (HSD) Tests**

| TOTAL TIME (SEC/VEH) | | | DELAY TIME (SEC/VEH) | | |
|---|---|---|---|---|---|
| TUKEY RANKING | MEAN | TYPE | TUKEY RANKING | MEAN | TYPE |
| A | 8,249 | $E_{50}$ | A | 7,517 | $E_{50}$ |
| A | 8,243 | $E_{25}$ | A | 7,511 | $E_{25}$ |
| A | 8,243 | F | A | 7,511 | F |
| B | 4,006 | $C_{25}$ | B | 3,274 | $C_{25}$ |
| C | 3,749 | $D_{25}$ | C | 3,017 | $D_{25}$ |
| D | 793 | $B_{25}$ | D | 61 | $B_{25}$ |
| D | 793 | $B_{50}$ | D | 61 | $B_{50}$ |
| D | 790 | $C_{50}$ | D | 58 | $C_{50}$ |
| D | 789 | A | D | 57 | A |
| D | 781 | $D_{50}$ | D | 49 | $D_{50}$ |

| M/T | | | Extra Move Time in % | | |
|---|---|---|---|---|---|
| TUKEY RANKING | MEAN | TYPE | TUKEY RANKING | MEAN | TYPE |
| A | 0.94 | $D_{50}$ | A | 1027% | $E_{50}$ |
| B | 0.93 | A | A | 1026% | $E_{25}$ |
| B | 0.93 | $C_{50}$ | A | 1026% | F |
| B | 0.92 | $B_{50}$ | B | 447% | $C_{25}$ |
| B | 0.92 | $B_{25}$ | C | 412% | $D_{25}$ |
| C | 0.20 | $D_{25}$ | D | 8% | $B_{25}$ |
| D | 0.18 | $C_{25}$ | D | 8% | $B_{50}$ |
| E | 0.09 | F | D | 8% | $C_{50}$ |
| E | 0.09 | $E_{25}$ | D | 8% | A |
| E | 0.09 | $E_{50}$ | D | 7% | $D_{50}$ |

| AVE Speed | | | AVE Speed/AVE FFS | | |
|---|---|---|---|---|---|
| TUKEY RANKING | MEAN | TYPE | TUKEY RANKING | MEAN | TYPE |
| A | 60.01 | $D_{50}$ | A | 0.94 | $D_{50}$ |
| B | 59.34 | A | B | 0.93 | A |
| B | 59.28 | $C_{50}$ | B | 0.93 | $C_{50}$ |
| B | 59.11 | $B_{50}$ | B | 0.92 | $B_{50}$ |
| B | 59.07 | $B_{25}$ | B | 0.92 | $B_{25}$ |
| C | 12.54 | $D_{25}$ | C | 0.20 | $D_{25}$ |
| D | 11.75 | $C_{25}$ | D | 0.18 | $C_{25}$ |
| E | 5.68 | F | E | 0.09 | F |
| E | 5.68 | $E_{25}$ | E | 0.09 | $E_{25}$ |
| E | 5.68 | $E_{50}$ | E | 0.09 | $E_{50}$ |

Note: Means with the same letter are not significantly different.

**Tukey's Studentized Range (HSD) Tests**

| TOTAL TIME (SEC/VEH) | | | DELAY TIME (SEC/VEH) | | |
|---|---|---|---|---|---|
| TUKEY RANKING | MEAN | TYPE | TUKEY RANKING | MEAN | TYPE |
| A | 8,204 | F | A | 7,473 | F |
| B | 7,813 | $B_{25}$ | B | 7,081 | $B_{25}$ |
| B | 7,778 | $B_{50}$ | B | 7,046 | $B_{50}$ |
| C | 6,879 | $E_{25}$ | C | 6,147 | $E_{25}$ |
| C | 6,846 | $D_{25}$ | C | 6,114 | $D_{25}$ |
| D | 1,846 | A | D | 1,232 | A |
| E | 1,514 | $D_{50}$ | E | 782 | $D_{50}$ |
| E | 1,497 | $E_{50}$ | E | 766 | $E_{50}$ |
| E | 1,484 | $C_{50}$ | E | 753 | $C_{50}$ |
| E | 1,449 | $C_{25}$ | E | 718 | $C_{25}$ |

| M/T | | | Extra Move Time in % | | |
|---|---|---|---|---|---|
| TUKEY RANKING | MEAN | TYPE | TUKEY RANKING | MEAN | TYPE |
| A | 0.51 | $C_{25}$ | A | 1021% | F |
| A | 0.50 | $C_{50}$ | B | 968% | $B_{25}$ |
| A | 0.49 | $E_{50}$ | B | 963% | $B_{50}$ |
| A | 0.49 | $D_{50}$ | C | 840% | $E_{25}$ |
| B | 0.33 | A | C | 835% | $D_{25}$ |
| C | 0.11 | $D_{25}$ | D | 200% | A |
| C | 0.11 | $E_{25}$ | E | 107% | $D_{50}$ |
| C | 0.09 | $B_{50}$ | E | 105% | $E_{50}$ |
| C | 0.09 | $B_{25}$ | E | 103% | $C_{50}$ |
| C | 0.09 | F | E | 98% | $C_{25}$ |

| AVE Speed | | | AVE Speed/AVE FFS | | |
|---|---|---|---|---|---|
| TUKEY RANKING | MEAN | TYPE | TUKEY RANKING | MEAN | TYPE |
| A | 32.51 | $C_{25}$ | A | 0.51 | $C_{25}$ |
| A | 31.85 | $C_{50}$ | A | 0.50 | $C_{50}$ |
| A | 31.49 | $E_{50}$ | A | 0.49 | $E_{50}$ |
| A | 31.13 | $D_{50}$ | A | 0.49 | $D_{50}$ |
| B | 21.69 | A | B | 0.33 | A |
| C | 6.84 | $D_{25}$ | C | 0.11 | $D_{25}$ |
| C | 6.81 | $E_{25}$ | C | 0.11 | $E_{25}$ |
| C | 6.02 | $B_{50}$ | C | 0.09 | $B_{50}$ |
| C | 6.00 | $B_{25}$ | C | 0.09 | $B_{25}$ |
| C | 5.71 | F | C | 0.09 | F |

Note: Means with the same letter are not significantly different.

### Normal Flow Routes Statistics Comparisons

Table 31 illustrates the Tukey's ranking for normal flow route statistics. The delay times for the Type F, $B_{25}$, $B_{50}$, $E_{25}$, and $D_{25}$ models ranged from 6,100 sec/veh to 7,472 sec/veh with average route speeds of around 6 mph. The Type F model did not have available exit-ramp, Type B models located the exit-ramp after one-lane closure, and Type $E_{25}$, and $D_{25}$ models has less exiting traffic at the exit-ramp. All these factors led these models to have longer delay times and slow average route speeds. The delay times for the Type A, $D_{50}$, $E_{50}$, $C_{50}$ and $C_{25}$ models ranged from 1,231 sec/veh to 717 sec/veh. The Type A model had an average route speed at 22 mph; the Type $D_{50}$, $E_{50}$, $C_{50}$ and $C_{25}$ models were around 31 mph. The Type A model had longer delay time and slower average route speed because it did not have exit-ramp on route, unlike Type $D_{50}$, $E_{50}$, $C_{50}$ and $C_{25}$ models. Type $C_{25}$ and $C_{50}$ models used a barrier divider to force all traffic on using the right lane to exit at the off-ramp, which was assumed to achieve 50 percent exiting traffic. By contrast, Type $D_{25}$, $D_{50}$, $E_{25}$, and $E_{50}$ models do not have barrier divider at the off-ramp. Hence, the delay time for Type $D_{25}$ and $E_{25}$ models were 8 times higher compared to Type $D_{50}$ and $E_{50}$ models. The performance ranked Type $C_{25}$, $C_{50}$, $E_{50}$, $D_{50}$, A, $D_{25}$, $E_{25}$, $B_{50}$, $B_{25}$, and F in terms of M/T ratio and average route speed. These results showed that with a 50 percent exiting traffic at the available exit-ramp increased the average route speed, decreased the travel delay time and obviously required less travel time for the evacuees to reach their destination.

Table 31 illustrates the extra move time and total travel time comparisons for the contraflow and normal flow routes. For the routes that did not have an exit-ramp, the delay times increased about 10 times higher than the normal move time. At a demand of 2,700 vph, the delay time was about 4 times higher than the estimated move time for routes that had 25 percent exiting traffic at the off-ramp. By contrast, 50 percent exiting traffic at off-ramps generated a delay time 8 percent higher than the estimated move time. At a demand of 3,300 vph, the delay time was about 8 times higher than the estimated move time for routes that had 25 percent exiting traffic at the off-ramp. On the other hand, with 50 percent of exiting traffic at off-ramp, the delay time was about 105 percent higher than the normal estimated move time. The longest total travel time for the contraflow and normal flow routes was around 137 minutes/vehicle (min/veh). The total travel times for both routes were similar because both routes reached saturated flow conditions. As the normal flow route had higher traffic demand, the shortest delay times for the contraflow and normal flow routes were different. The shortest delay time for the contraflow and normal flow were around 13 min/veh and 25 min/veh, respectively. All these results for both contraflow and normal routes showed that 50 percent vehicles exiting at the available exit-ramps improved the evacuation process, increased the average route’s speed, and decreased delay times significantly. Obviously, having more available exit-ramps and exiting more vehicles prior to the termination point expedited the evacuation process and could save more lives.

**Table 31**
**Extra move time and total travel time comparisons**

| | **Extra Move Time %** (i.e. Delay Time) | |
|---|---|---|
| | **Contraflow Direction 2,700 vph** | **Normal Flow Direction 3,300 vph** |
| **No Exit-Ramp** | 1,000% | 1,000% |
| **25% Exiting Traffic at Off-Ramp** | 430% | 838% |
| **50% Exiting Traffic at Off-Ramp** | 8% | 105% |
| | **Total Travel Time** (minutes/vehicle) | |
| **No Exit-Ramp** | 137 | 137 |
| **25% Exiting Traffic at Off-Ramp** | 67 | 115 |
| **50% Exiting Traffic at Off-Ramp** | 13 | 25 |

### Links Performance Comparisons

The CORSIM output results throughout the 16 time-periods are presented in the following sections. Representative link segments were selected to compare the effectiveness of the system efficiency. These links are listed as follow:
- the link before the median crossover – link (8, 1)
- the merging area before the lane drop – link (18,17)
- the links located 4 miles ahead the median crossover – link (34,32) and (35,33)
- the entrance links on contraflow – link (52,50) and normal flow – link (53,51).

The first two links were selected to represent the traffic conditions before the median crossover and before lane-closure area. The others were selected to represent the traffic conditions at the intermediate and entrance segments of the models. These links were selected to determine the bottleneck of the freeway and represent the traffic operation of the contraflow termination point designs. All the link statistical results at the end of simulation (i.e. TP16) were analyzed with one-way ANOVA and Tukey statistical test procedure.

**Output results before median crossover – link (8, 1)**
Link (8, 1) was located on the contraflow direction before the median crossover and had 500 ft. in length and 45 mph as the speed limit. Figure 81 shows the statistics and F-value comparisons for link (8, 1) at TP 16. Since all the F-values of the variables were larger than the $F_{critical}$ value, this showed that at least one of the operational MOE's means of the models was significantly different. Tukey testing in Figure 81 shows that Type $D_{25}$, F, $E_{25}$, $E_{50}$, and $C_{25}$ models had the same average volumes around 1,640 vphpl. The average volumes for

Type $C_{50}$, $D_{50}$, A, $B_{25}$, and $B_{50}$ models were around 1,330 vphpl throughout 16 time-periods (see

Figure 81). These results showed that the maximum capacity for the 1-lane freeway before the median crossover could reach 1,640 vphpl.

Figure 82 shows that all models with different average volumes had average speed of above 40 mph throughout 4 hours simulation. This meant that no traffic congestion occurred at this link. As shown in Figure 83, the average densities of all models ranged from 40 vehicles per mile per lane (vpmpl) to 31 vpmpl at the end of TP16. From figure 84, the average delay times for all models in this link were constantly less than sec/veh. This result showed no congestion occurred on this link.

Figure 85 indicates the M/T ratios for all models were above 0.90. All of these results proved that the transition on the contraflow direction before the median crossover for all the models had smooth traffic flow without significant delay. These results showed that no congested traffic appeared on this link, which indicated that the bottleneck of the network was not on this link.

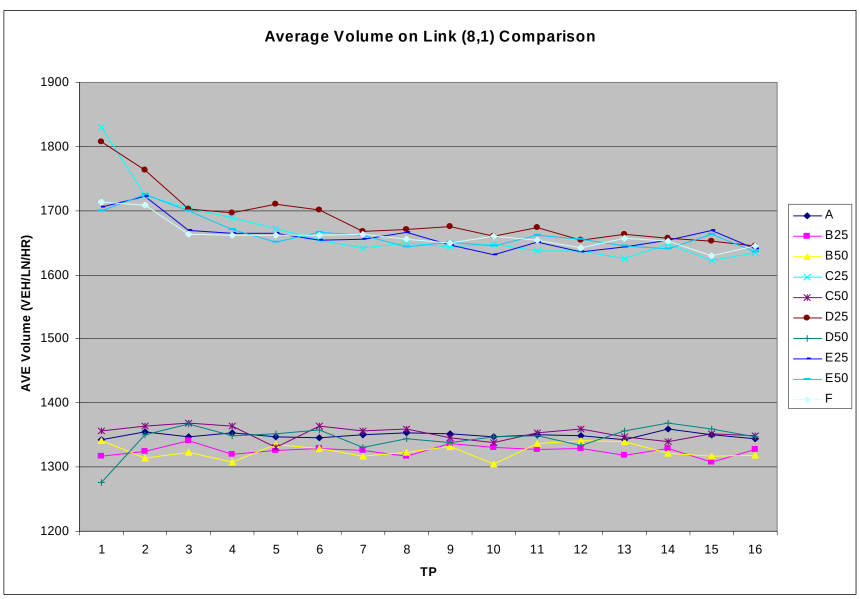


**Figure 81**
**Average volume on contraflow direction before median crossover comparison - link (8, 1)**

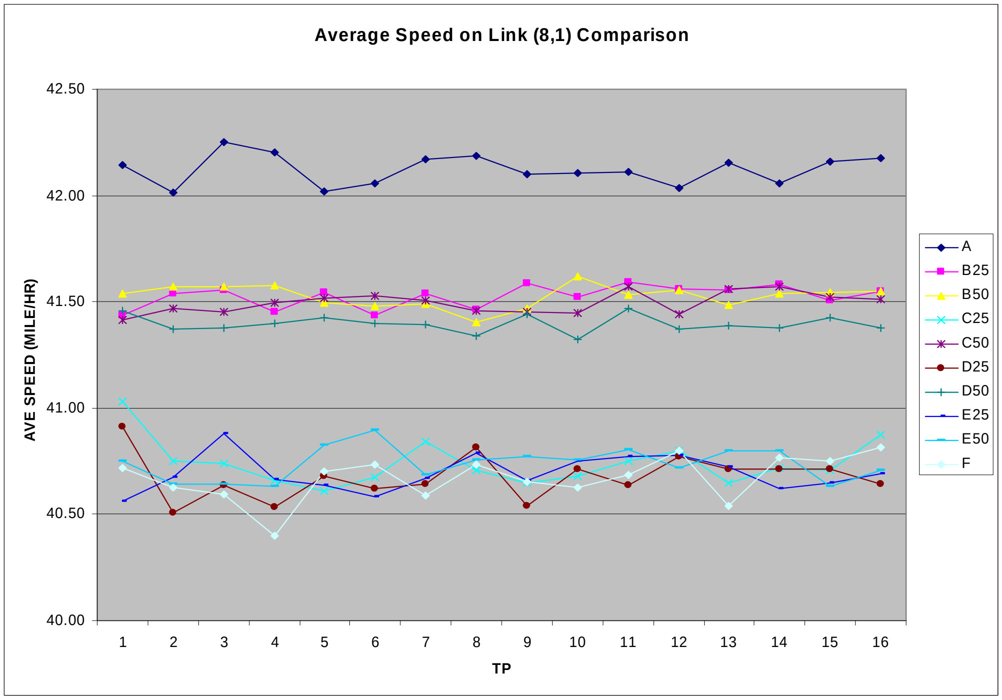


**Figure 82**
**Average speed on contraflow direction before median crossover comparison - link (8, 1)**

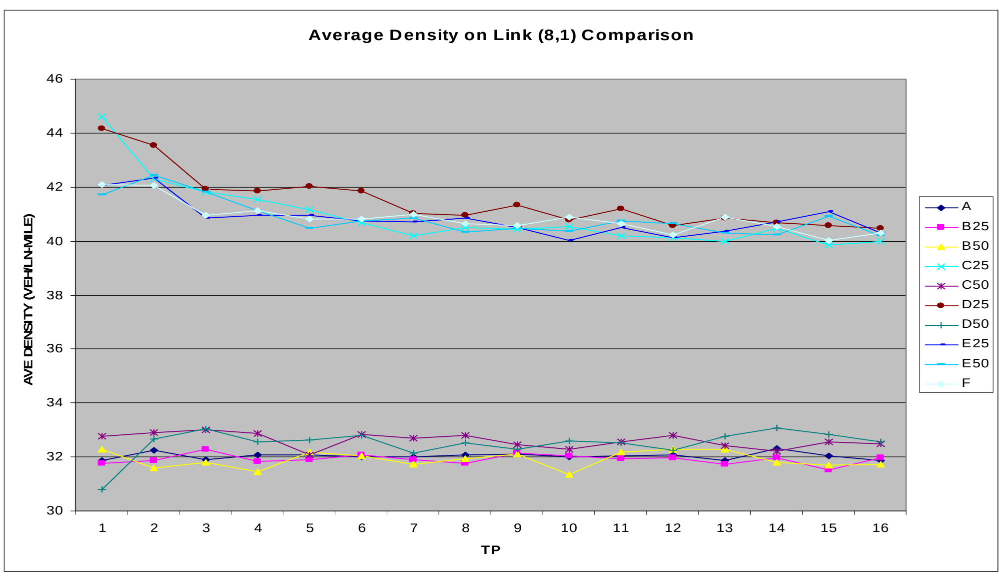


**Figure 83**
**Average density on contraflow direction before median crossover comparison – link (8, 1)**

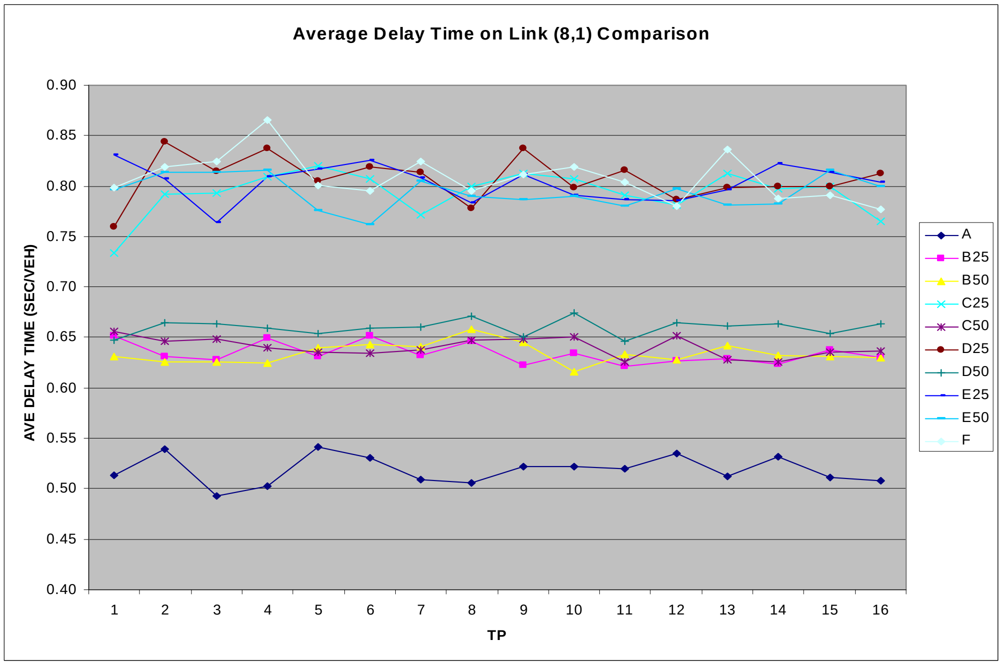


**Figure 84**
**Average delay time on contraflow direction before median crossover comparison - link (8, 1)**

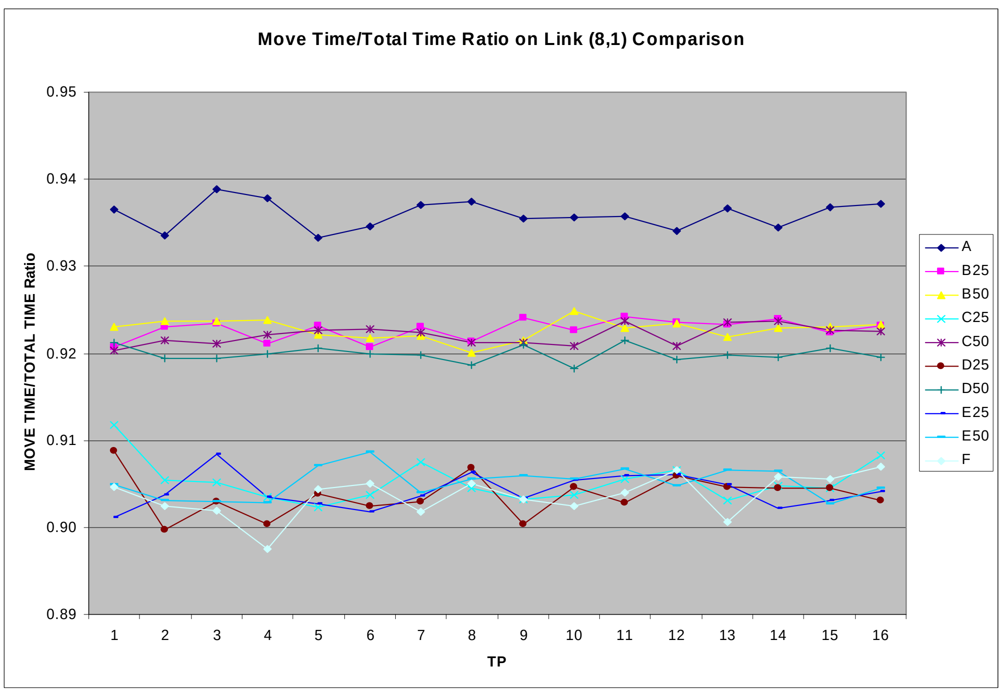


**Figure 85**
**Move time/total time ratio on contraflow direction before median crossover comparison - link (8, 1)**

**Table 32**
**Link (8, 1) statistics at TP 16 for MIN, MAX, AVE, STDEV and F-value comparison**

| TYPE | | VEHICLES IN | VEHICLES OUT | VEH-MILES | VEH-MIN | TOTAL TIME (SEC/VEH) | DELAY TIME (SEC/VEH) | M/T | TOTAL TIME (VEH-MIN/VEH-MILE) | DELAY TIME (VEH-MIN/VEH-MILE) | VOLUME (VEH/LN/HR) | DENSITY (VEH/LN-MILE) | SPEED (MILE/HR) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | MIN | 644.00 | 641.00 | 61.30 | 86.50 | 7.98 | 0.40 | 0.93 | 1.40 | 0.07 | 1,294.66 | 30.45 | 41.64 |
| | MAX | 711.00 | 709.00 | 67.30 | 95.90 | 8.19 | 0.61 | 0.95 | 1.44 | 0.11 | 1,421.38 | 33.76 | 42.72 |
| | MEAN | 672.53 | 672.13 | 63.66 | 90.57 | 8.08 | 0.51 | 0.94 | 1.42 | 0.09 | 1,344.57 | 31.88 | 42.18 |
| | STDEV | 14.43 | 14.41 | 1.34 | 1.96 | 0.05 | 0.05 | 0.01 | 0.01 | 0.01 | 28.39 | 0.69 | 0.25 |
| $B_{25}$ | MIN | 297.00 | 299.00 | 28.20 | 40.00 | 8.06 | 0.48 | 0.91 | 1.42 | 0.09 | 1,191.17 | 28.16 | 40.88 |
| | MAX | 358.00 | 361.00 | 33.90 | 49.50 | 8.34 | 0.76 | 0.94 | 1.47 | 0.13 | 1,431.94 | 34.85 | 42.30 |
| | MEAN | 331.93 | 331.97 | 31.44 | 45.41 | 8.21 | 0.63 | 0.92 | 1.44 | 0.11 | 1,328.17 | 31.97 | 41.55 |
| | STDEV | 14.22 | 14.49 | 1.35 | 1.99 | 0.08 | 0.08 | 0.01 | 0.01 | 0.01 | 56.94 | 1.40 | 0.40 |
| $B_{50}$ | MIN | 300.00 | 301.00 | 28.40 | 41.10 | 8.08 | 0.50 | 0.91 | 1.42 | 0.09 | 1,199.62 | 28.93 | 40.77 |
| | MAX | 358.00 | 357.00 | 33.70 | 48.80 | 8.36 | 0.79 | 0.94 | 1.47 | 0.14 | 1,423.49 | 34.36 | 42.22 |
| | MEAN | 329.30 | 329.93 | 31.20 | 45.06 | 8.21 | 0.63 | 0.92 | 1.44 | 0.11 | 1,318.03 | 31.72 | 41.55 |
| | STDEV | 13.06 | 12.88 | 1.23 | 1.72 | 0.06 | 0.06 | 0.01 | 0.01 | 0.01 | 52.05 | 1.21 | 0.28 |
| $C_{25}$ | MIN | 386.00 | 389.00 | 36.70 | 53.80 | 8.19 | 0.61 | 0.88 | 1.44 | 0.11 | 1,550.21 | 37.88 | 39.41 |
| | MAX | 435.00 | 441.00 | 41.50 | 61.20 | 8.65 | 1.07 | 0.93 | 1.52 | 0.19 | 1,752.96 | 43.08 | 41.65 |
| | MEAN | 407.73 | 409.23 | 38.69 | 56.80 | 8.34 | 0.77 | 0.91 | 1.47 | 0.13 | 1,634.27 | 39.99 | 40.87 |
| | STDEV | 11.10 | 11.70 | 1.08 | 1.73 | 0.09 | 0.09 | 0.01 | 0.02 | 0.02 | 45.54 | 1.22 | 0.41 |
| $C_{50}$ | MIN | 302.00 | 306.00 | 28.70 | 41.40 | 8.07 | 0.50 | 0.91 | 1.42 | 0.09 | 1,212.29 | 29.15 | 40.93 |
| | MAX | 360.00 | 363.00 | 34.10 | 49.40 | 8.33 | 0.75 | 0.94 | 1.47 | 0.13 | 1,440.38 | 34.78 | 42.23 |
| | MEAN | 336.87 | 337.27 | 31.92 | 46.14 | 8.21 | 0.64 | 0.92 | 1.45 | 0.11 | 1,348.30 | 32.48 | 41.51 |
| | STDEV | 15.54 | 15.75 | 1.49 | 2.19 | 0.07 | 0.07 | 0.01 | 0.01 | 0.01 | 63.09 | 1.54 | 0.35 |
| $D_{25}$ | MIN | 393.00 | 396.00 | 37.30 | 54.80 | 8.24 | 0.67 | 0.89 | 1.45 | 0.12 | 1,575.55 | 38.58 | 39.93 |
| | MAX | 438.00 | 439.00 | 41.50 | 60.90 | 8.54 | 0.96 | 0.92 | 1.50 | 0.17 | 1,752.96 | 42.87 | 41.37 |
| | MEAN | 411.07 | 411.63 | 38.95 | 57.50 | 8.39 | 0.81 | 0.90 | 1.48 | 0.14 | 1,645.39 | 40.48 | 40.64 |
| | STDEV | 11.40 | 11.78 | 1.10 | 1.50 | 0.09 | 0.09 | 0.01 | 0.02 | 0.02 | 46.31 | 1.06 | 0.42 |
| $D_{50}$ | MIN | 308.00 | 309.00 | 29.20 | 42.60 | 8.14 | 0.57 | 0.91 | 1.43 | 0.10 | 1,233.41 | 29.99 | 40.98 |
| | MAX | 364.00 | 364.00 | 34.50 | 50.10 | 8.32 | 0.74 | 0.93 | 1.46 | 0.13 | 1,457.28 | 35.27 | 41.87 |
| | MEAN | 336.97 | 336.67 | 31.90 | 46.25 | 8.24 | 0.66 | 0.92 | 1.45 | 0.12 | 1,347.46 | 32.56 | 41.38 |
| | STDEV | 13.39 | 13.56 | 1.30 | 1.83 | 0.05 | 0.05 | 0.01 | 0.01 | 0.01 | 54.77 | 1.29 | 0.25 |
| $E_{25}$ | MIN | 387.00 | 386.00 | 36.70 | 54.10 | 8.24 | 0.66 | 0.87 | 1.45 | 0.12 | 1,550.21 | 38.09 | 39.24 |
| | MAX | 447.00 | 445.00 | 42.20 | 63.00 | 8.69 | 1.11 | 0.92 | 1.53 | 0.20 | 1,782.53 | 44.35 | 41.39 |
| | MEAN | 410.80 | 409.40 | 38.83 | 57.26 | 8.38 | 0.80 | 0.90 | 1.47 | 0.14 | 1,640.04 | 40.31 | 40.69 |
| | STDEV | 15.98 | 15.80 | 1.49 | 2.29 | 0.12 | 0.12 | 0.01 | 0.02 | 0.02 | 63.03 | 1.61 | 0.57 |
| $E_{50}$ | MIN | 385.00 | 383.00 | 36.30 | 53.70 | 8.18 | 0.61 | 0.88 | 1.44 | 0.11 | 1,533.31 | 37.80 | 39.64 |
| | MAX | 430.00 | 430.00 | 40.70 | 61.60 | 8.60 | 1.02 | 0.93 | 1.51 | 0.18 | 1,719.17 | 43.37 | 41.66 |
| | MEAN | 409.37 | 408.73 | 38.73 | 57.09 | 8.38 | 0.80 | 0.90 | 1.47 | 0.14 | 1,635.81 | 40.19 | 40.71 |
| | STDEV | 13.57 | 13.58 | 1.29 | 2.13 | 0.10 | 0.10 | 0.01 | 0.02 | 0.02 | 54.46 | 1.50 | 0.50 |
| F | MIN | 382.00 | 387.00 | 36.40 | 53.90 | 8.15 | 0.57 | 0.88 | 1.43 | 0.10 | 1,537.54 | 37.95 | 39.73 |
| | MAX | 439.00 | 439.00 | 41.60 | 60.60 | 8.58 | 1.00 | 0.93 | 1.51 | 0.18 | 1,757.18 | 42.66 | 41.83 |
| | MEAN | 411.73 | 410.80 | 38.95 | 57.25 | 8.35 | 0.78 | 0.91 | 1.47 | 0.14 | 1,645.11 | 40.31 | 40.82 |
| | STDEV | 14.45 | 13.64 | 1.32 | 1.90 | 0.09 | 0.09 | 0.01 | 0.02 | 0.02 | 55.66 | 1.34 | 0.45 |
| F Value within models | | 1,612 | 1,600 | 1,611 | 1,444 | 48 | 48 | 49 | 48 | 48 | 274 | 322 | 49 |

**Table 33**
**Tukey's ranking for link (8, 1) statistics at TP 16**

**Tukey's Studentized Range (HSD) Tests**

| VEHICLES IN | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 673 | A |
| B | 412 | F |
| B | 411 | $D_{25}$ |
| B | 411 | $E_{25}$ |
| B | 409 | $E_{50}$ |
| B | 408 | $C_{25}$ |
| C | 337 | $D_{50}$ |
| C | 337 | $C_{50}$ |
| C | 332 | $B_{25}$ |
| C | 329 | $B_{50}$ |

| TOTAL TIME (SEC/VEH) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 8.39 | $D_{25}$ |
| A | 8.38 | $E_{25}$ |
| A | 8.38 | $E_{50}$ |
| A | 8.35 | F |
| A | 8.34 | $C_{25}$ |
| B | 8.24 | $D_{50}$ |
| B | 8.21 | $C_{50}$ |
| B | 8.21 | $B_{25}$ |
| B | 8.21 | $B_{50}$ |
| C | 8.08 | A |

| DELAY TIME (VEH-MIN/VEH-MILE) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 0.14 | $D_{25}$ |
| A | 0.14 | $E_{25}$ |
| A | 0.14 | $E_{50}$ |
| A | 0.14 | F |
| A | 0.13 | $C_{25}$ |
| B | 0.12 | $D_{50}$ |
| B | 0.11 | $C_{50}$ |
| B | 0.11 | $B_{25}$ |
| B | 0.11 | $B_{50}$ |
| C | 0.09 | A |

| VEHICLES OUT | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 672 | A |
| B | 412 | $D_{25}$ |
| B | 411 | F |
| B | 409 | $E_{25}$ |
| B | 409 | $C_{25}$ |
| B | 409 | $E_{50}$ |
| C | 337 | $C_{50}$ |
| C | 337 | $D_{50}$ |
| C | 332 | $B_{25}$ |
| C | 330 | $B_{50}$ |

| DELAY TIME (SEC/VEH) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 0.81 | $D_{25}$ |
| A | 0.80 | $E_{25}$ |
| A | 0.80 | $E_{50}$ |
| A | 0.78 | F |
| A | 0.77 | $C_{25}$ |
| B | 0.66 | $D_{50}$ |
| B | 0.64 | $C_{50}$ |
| B | 0.63 | $B_{25}$ |
| B | 0.63 | $B_{50}$ |
| C | 0.51 | A |

| VOLUME (VEH/LN/HR) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 1,645 | $D_{25}$ |
| A | 1,645 | F |
| A | 1,640 | $E_{25}$ |
| A | 1,636 | $E_{50}$ |
| A | 1,634 | $C_{25}$ |
| B | 1,348 | $C_{50}$ |
| B | 1,347 | $D_{50}$ |
| B | 1,345 | A |
| B | 1,328 | $B_{25}$ |
| B | 1,318 | $B_{50}$ |

| VEH-MILES | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 63.66 | A |
| B | 38.95 | $D_{25}$ |
| B | 38.95 | F |
| B | 38.83 | $E_{25}$ |
| B | 38.73 | $E_{50}$ |
| B | 38.69 | $C_{25}$ |
| C | 31.92 | $C_{50}$ |
| C | 31.90 | $D_{50}$ |
| C | 31.44 | $B_{25}$ |
| C | 31.20 | $B_{50}$ |

| M/T RATIO | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 0.94 | A |
| B | 0.92 | $B_{25}$ |
| B | 0.92 | $B_{50}$ |
| B | 0.92 | $C_{50}$ |
| B | 0.92 | $D_{50}$ |
| C | 0.91 | $C_{25}$ |
| C | 0.91 | F |
| C | 0.90 | $E_{50}$ |
| C | 0.90 | $E_{25}$ |
| C | 0.90 | $D_{25}$ |

| DENSITY (VEH/LN-MILE) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 40.48 | $D_{25}$ |
| A | 40.31 | $E_{25}$ |
| A | 40.31 | F |
| A | 40.19 | $E_{50}$ |
| A | 39.99 | $C_{25}$ |
| B | 32.56 | $D_{50}$ |
| B | 32.48 | $C_{50}$ |
| B | 31.97 | $B_{25}$ |
| B | 31.88 | A |
| B | 31.72 | $B_{50}$ |

| VEH-MIN | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 90.57 | A |
| B | 57.50 | $D_{25}$ |
| B | 57.26 | $E_{25}$ |
| B | 57.25 | F |
| B | 57.09 | $E_{50}$ |
| B | 56.80 | $C_{25}$ |
| C | 46.25 | $D_{50}$ |
| C | 46.14 | $C_{50}$ |
| C | 45.41 | $B_{25}$ |
| C | 45.06 | $B_{50}$ |

| TOTAL TIME (VEH-MIN/VEH-MILE) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 1.48 | $D_{25}$ |
| A | 1.47 | $E_{25}$ |
| A | 1.47 | $E_{50}$ |
| A | 1.47 | F |
| A | 1.47 | $C_{25}$ |
| B | 1.45 | $D_{50}$ |
| B | 1.45 | $C_{50}$ |
| B | 1.44 | $B_{25}$ |
| B | 1.44 | $B_{50}$ |
| C | 1.42 | A |

| SPEED (MILE/HR) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 42.18 | A |
| B | 41.55 | $B_{25}$ |
| B | 41.55 | $B_{50}$ |
| B | 41.51 | $C_{50}$ |
| B | 41.38 | $D_{50}$ |
| C | 40.87 | $C_{25}$ |
| C | 40.82 | F |
| C | 40.71 | $E_{50}$ |
| C | 40.69 | $E_{25}$ |
| C | 40.64 | $D_{25}$ |

Note: Means with the same letter are not significantly different.

**Output Results of Merging Area before Lane Drop – Link (18,17)**

Link (18, 17) was 500 ft. in length and 1,000 ft. upstream of the lane drop area at link (16, 10) for the Type C, D, E, and F models. Link (18, 17) for Type B models operated in 1 lane (right lane closed); in contrast, this link for the Type A model operated in 2 lanes. The speed limit for this link was 65 mph for all models. Figure 86 shows the statistics and F-value comparisons for this link. The F-values for all models ranged from 1,584 to 10,018, which were all larger than the $F_{critical}$ value of 1.912. Hence, the null hypothesis was rejected that indicated at least one of the operational MOEs means of the models was different from the others. Figure 86 shows the Tukey ranking for this link at TP16.

Figure 86 illustrates that the average volumes for Type A, $B_{25}$, and $B_{50}$ models ranged from 1,346 vphpl to 1,311 vphpl. The average volumes for Type $D_{25}$, $E_{25}$, F, $E_{50}$, and $C_{25}$ models were around 820 vphpl, and Type $C_{50}$ and $D_{50}$ models were around 670 vphpl. Figure 87 shows that the average speeds of Type A, $D_{50}$, $B_{50}$, $B_{25}$, and $C_{50}$ models reached around 57 mph constantly over 4 hours simulation. Obviously, these models operated in uncongested condition with a smooth evacuation process. By contrast, Type $C_{25}$, $D_{25}$, $E_{25}$, $E_{50}$, and F models reached a constant average speed of around 5 mph after TP4. These models showed congested traffic and queued vehicles appeared to have merging conflicts which slowed down the evacuation process. Figure 88 illustrates that the higher speed models had relatively low densities of about 12 vpmpl and 23 vpmpl at free flow conditions. The slower speed models had relatively high density above 145 vpmpl at saturated flow conditions. The results showed that the congested traffic's density was 12 times higher than the non-congested traffic.

Figure 89 also shows that the average delays for the high average density models were approximately 60 sec/veh after TP6, and the low average density models were less than 1 sec/veh over 4 hours simulation.

As shown in figure 90, the M/T ratios for the high speed models were above 0.88, and the low speed models were below 0.09. Based on these results and the TRAFVU observation, the lane drop area on downstream link (i.e. Link (16, 10)) for the $C_{25}$, $D_{25}$, $E_{25}$, $E_{50}$, and F models created merging conflicts and saturated flow at the merge area on link (18, 17). As expected, the lane drop area on downstream link was the bottleneck of the freeway. These results showed that merging a two-lane freeway into a one-lane freeway affected the two-lane freeway to have a maximum congested volume of around 820 vphpl. This bottleneck controlled the maximum flow at the downstream one-lane links to reach around 1,640 vphpl. This was the maximum capacity of the one-lane freeway after the one-lane closure area.

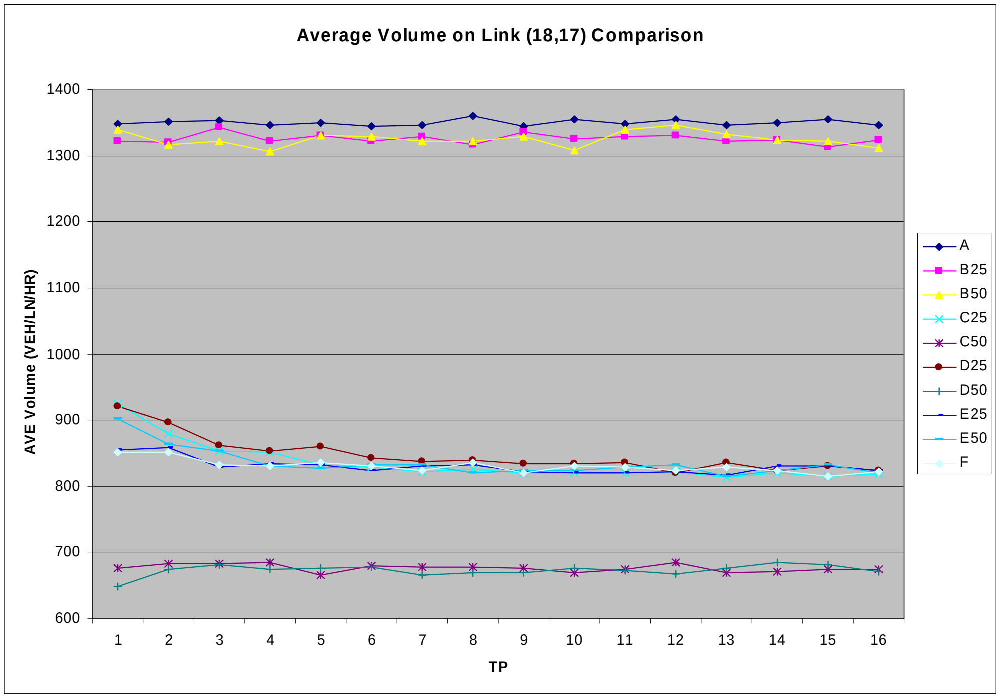


**Figure 86**
**Average volume on contraflow direction before merging area comparison - link (18, 17)**

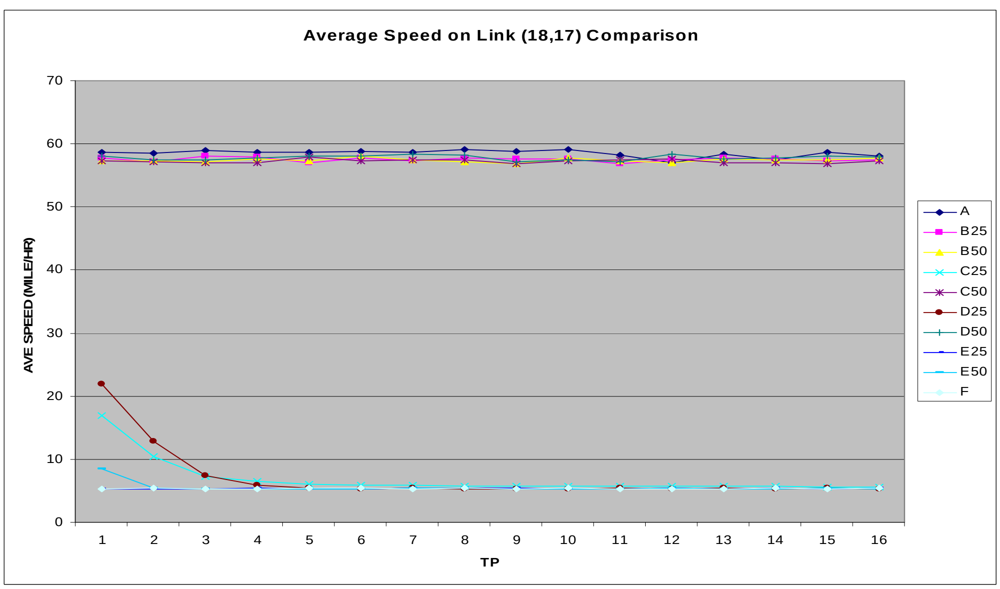


**Figure 87**
**Average speed on contraflow direction before merging area comparison - link (18, 17)**

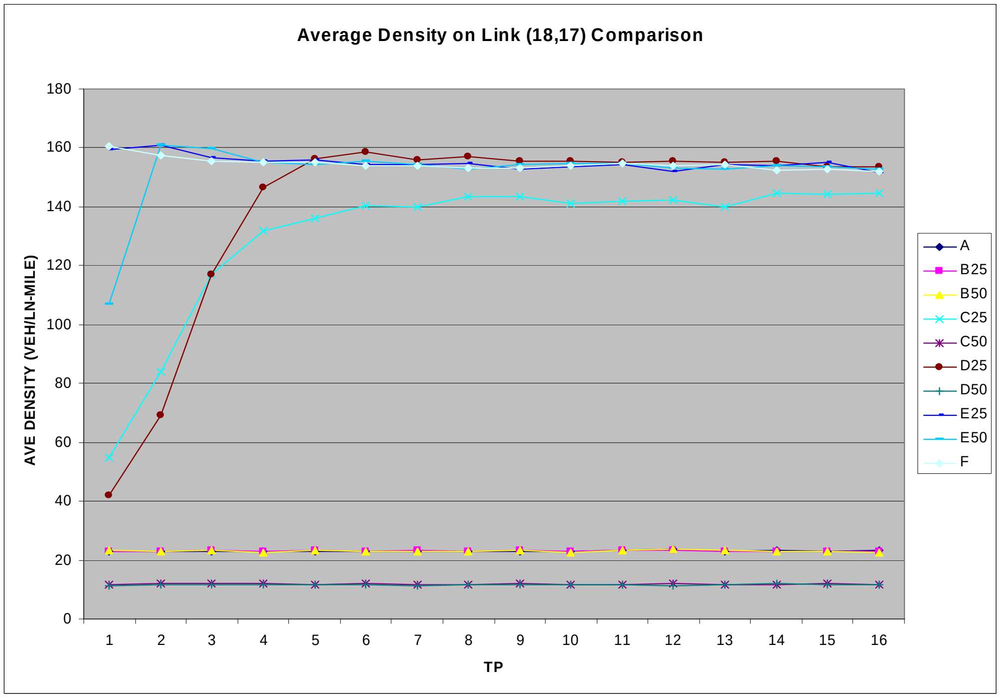


**Figure 88**
**Average density on contraflow direction before merging area comparison - link (18, 17)**

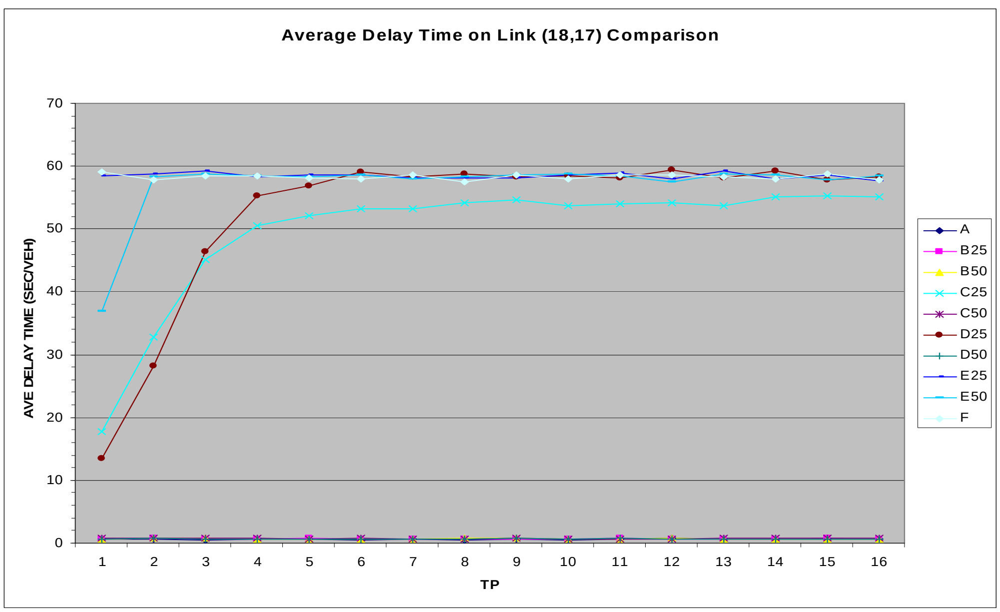


**Figure 89**
**Average delay time on contraflow direction before merging area comparison - link (18, 17)**

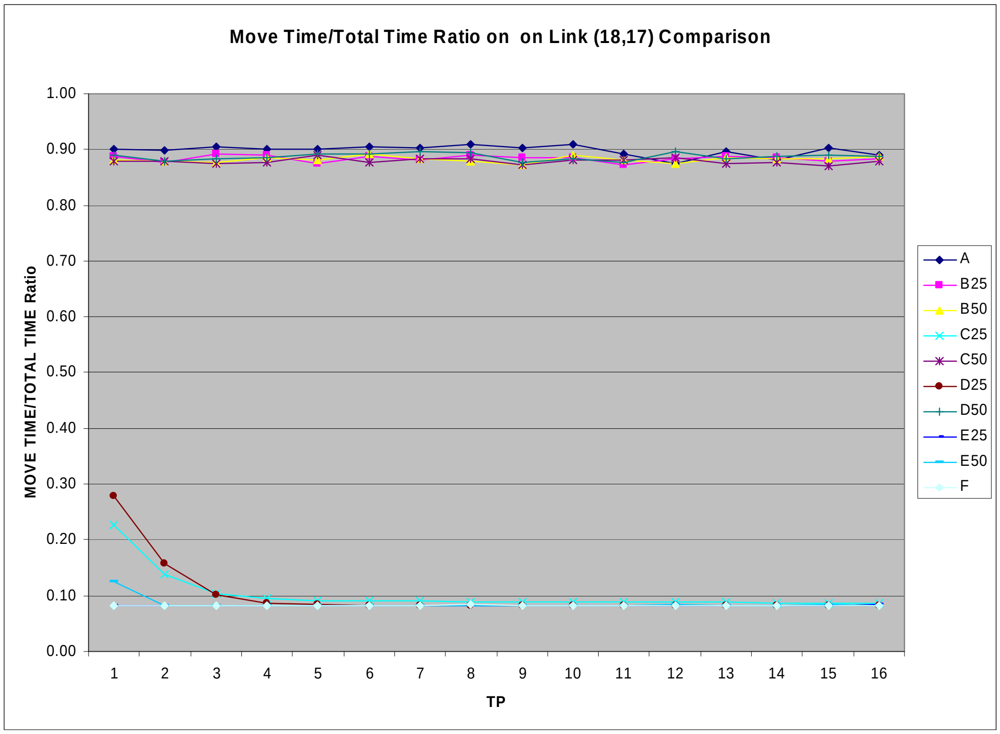


**Figure 90**
**Move time/total time ratio on contraflow direction before merging area comparison - link (18, 17)**

## Table 34
## Link (18,17) statistics at TP 16 for MIN, MAX, AVE, STDEV and F-value comparison

| TYPE | | VEHICLES IN | VEHICLES OUT | VEH-MILES | VEH-MIN | TOTAL TIME (SEC/VEH) | DELAY TIME (SEC/VEH) | M/T | TOTAL TIME (VEH-MIN/VEH-MILE) | DELAY TIME (VEH-MIN/VEH-MILE) | VOLUME (VEH/LN/HR) | DENSITY (VEH/LN-MILE) | SPEED (MILE/HR) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | MIN | 648.00 | 640.00 | 61.00 | 62.10 | 5.59 | 0.35 | 0.72 | 0.98 | 0.06 | 1,288.32 | 21.86 | 46.60 |
| | MAX | 690.00 | 691.00 | 65.40 | 83.70 | 7.32 | 2.07 | 0.94 | 1.29 | 0.36 | 1,381.25 | 29.46 | 60.97 |
| | MEAN | 673.37 | 673.03 | 63.75 | 66.10 | 5.89 | 0.65 | 0.89 | 1.04 | 0.11 | 1,346.40 | 23.27 | 58.08 |
| | STDEV | 9.28 | 10.34 | 0.90 | 4.53 | 0.39 | 0.39 | 0.05 | 0.07 | 0.07 | 18.95 | 1.59 | 3.27 |
| $B_{25}$ | MIN | 284.00 | 285.00 | 26.80 | 27.30 | 5.68 | 0.44 | 0.83 | 1.00 | 0.08 | 1,132.03 | 19.22 | 54.23 |
| | MAX | 364.00 | 363.00 | 34.40 | 37.70 | 6.29 | 1.04 | 0.92 | 1.11 | 0.18 | 1,453.06 | 26.54 | 60.00 |
| | MEAN | 331.40 | 330.67 | 31.32 | 32.74 | 5.94 | 0.69 | 0.88 | 1.05 | 0.12 | 1,322.96 | 23.05 | 57.45 |
| | STDEV | 17.54 | 17.62 | 1.68 | 2.06 | 0.15 | 0.15 | 0.02 | 0.03 | 0.03 | 70.82 | 1.45 | 1.41 |
| $B_{50}$ | MIN | 304.00 | 298.00 | 28.50 | 29.70 | 5.70 | 0.46 | 0.81 | 1.00 | 0.08 | 1,203.84 | 20.91 | 52.48 |
| | MAX | 363.00 | 361.00 | 34.20 | 39.10 | 6.50 | 1.25 | 0.92 | 1.14 | 0.22 | 1,444.61 | 27.53 | 59.80 |
| | MEAN | 327.47 | 327.80 | 31.04 | 32.31 | 5.91 | 0.67 | 0.89 | 1.04 | 0.12 | 1,310.99 | 22.75 | 57.70 |
| | STDEV | 11.76 | 12.26 | 1.12 | 1.81 | 0.16 | 0.16 | 0.02 | 0.03 | 0.03 | 47.47 | 1.28 | 1.53 |
| $C_{25}$ | MIN | 390.00 | 389.00 | 36.90 | 365.60 | 54.46 | 49.21 | 0.08 | 9.58 | 8.66 | 779.33 | 128.69 | 5.09 |
| | MAX | 441.00 | 435.00 | 41.20 | 445.80 | 67.01 | 61.76 | 0.10 | 11.79 | 10.87 | 870.14 | 156.92 | 6.26 |
| | MEAN | 408.63 | 409.43 | 38.75 | 411.50 | 60.37 | 55.13 | 0.09 | 10.63 | 9.70 | 818.47 | 144.85 | 5.66 |
| | STDEV | 12.48 | 11.43 | 1.12 | 19.22 | 3.12 | 3.12 | 0.00 | 0.55 | 0.55 | 23.65 | 6.77 | 0.30 |
| $C_{50}$ | MIN | 314.00 | 310.00 | 29.60 | 30.20 | 5.70 | 0.46 | 0.74 | 1.00 | 0.08 | 625.15 | 10.63 | 48.29 |
| | MAX | 362.00 | 359.00 | 34.20 | 41.50 | 7.06 | 1.82 | 0.92 | 1.24 | 0.32 | 722.30 | 14.61 | 59.80 |
| | MEAN | 337.17 | 337.37 | 31.96 | 33.63 | 5.97 | 0.73 | 0.88 | 1.05 | 0.13 | 675.00 | 11.84 | 57.23 |
| | STDEV | 13.66 | 14.24 | 1.33 | 2.86 | 0.31 | 0.31 | 0.04 | 0.06 | 0.06 | 28.07 | 1.01 | 2.73 |
| $D_{25}$ | MIN | 384.00 | 384.00 | 36.50 | 398.90 | 59.57 | 54.33 | 0.08 | 10.49 | 9.56 | 770.88 | 140.41 | 5.06 |
| | MAX | 445.00 | 448.00 | 42.40 | 466.80 | 67.36 | 62.11 | 0.09 | 11.85 | 10.93 | 895.49 | 164.31 | 5.72 |
| | MEAN | 411.17 | 411.93 | 39.00 | 436.21 | 63.59 | 58.35 | 0.08 | 11.19 | 10.27 | 823.61 | 153.55 | 5.37 |
| | STDEV | 11.97 | 13.58 | 1.21 | 13.39 | 2.22 | 2.22 | 0.00 | 0.39 | 0.39 | 25.46 | 4.71 | 0.19 |
| $D_{50}$ | MIN | 309.00 | 308.00 | 29.20 | 29.50 | 5.65 | 0.40 | 0.73 | 0.99 | 0.07 | 616.70 | 10.38 | 47.37 |
| | MAX | 365.00 | 364.00 | 34.60 | 39.90 | 7.20 | 1.95 | 0.93 | 1.27 | 0.34 | 730.75 | 14.04 | 60.39 |
| | MEAN | 335.37 | 335.33 | 31.76 | 33.04 | 5.91 | 0.66 | 0.89 | 1.04 | 0.12 | 670.77 | 11.63 | 57.85 |
| | STDEV | 14.07 | 13.82 | 1.32 | 2.42 | 0.32 | 0.32 | 0.04 | 0.06 | 0.06 | 27.92 | 0.85 | 2.76 |
| $E_{25}$ | MIN | 389.00 | 385.00 | 36.70 | 399.80 | 59.36 | 54.11 | 0.08 | 10.45 | 9.52 | 775.10 | 140.73 | 5.15 |
| | MAX | 437.00 | 445.00 | 41.50 | 458.70 | 66.16 | 60.92 | 0.09 | 11.64 | 10.72 | 876.48 | 161.46 | 5.74 |
| | MEAN | 411.77 | 411.40 | 39.00 | 430.97 | 62.82 | 57.58 | 0.08 | 11.06 | 10.13 | 823.61 | 151.70 | 5.43 |
| | STDEV | 14.64 | 15.39 | 1.43 | 15.56 | 2.00 | 2.00 | 0.00 | 0.35 | 0.35 | 30.13 | 5.48 | 0.17 |
| $E_{50}$ | MIN | 389.00 | 391.00 | 37.10 | 398.70 | 59.69 | 54.45 | 0.08 | 10.51 | 9.58 | 783.55 | 140.34 | 4.97 |
| | MAX | 449.00 | 449.00 | 42.60 | 459.00 | 68.55 | 63.30 | 0.09 | 12.06 | 11.14 | 899.71 | 161.57 | 5.71 |
| | MEAN | 410.97 | 410.13 | 38.83 | 434.49 | 63.63 | 58.38 | 0.08 | 11.20 | 10.28 | 820.02 | 152.94 | 5.37 |
| | STDEV | 14.33 | 14.58 | 1.35 | 15.26 | 2.46 | 2.46 | 0.00 | 0.43 | 0.43 | 28.59 | 5.37 | 0.21 |
| F | MIN | 378.00 | 378.00 | 35.80 | 396.60 | 57.90 | 52.66 | 0.08 | 10.19 | 9.27 | 756.10 | 139.60 | 5.05 |
| | MAX | 443.00 | 447.00 | 42.10 | 460.50 | 67.47 | 62.22 | 0.09 | 11.87 | 10.95 | 889.15 | 162.10 | 5.89 |
| | MEAN | 411.47 | 410.93 | 38.95 | 432.18 | 63.09 | 57.85 | 0.08 | 11.10 | 10.18 | 822.69 | 152.13 | 5.41 |
| | STDEV | 14.09 | 15.13 | 1.37 | 14.16 | 2.57 | 2.57 | 0.00 | 0.45 | 0.45 | 28.92 | 4.98 | 0.22 |
| F Value within models | | 1,692 | 1,584 | 1,650 | 10,018 | 8,472 | 8,472 | 7,486 | 8,472 | 8,472 | 1,702 | 9,207 | 7,486 |

## Table 35
## Tukey's ranking for link (18,17) statistics at TP 16

**Tukey's Studentized Range (HSD) Tests**

| VEHICLES IN | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 673 | A |
| B | 412 | $E_{25}$ |
| B | 411 | F |
| B | 411 | $D_{25}$ |
| B | 411 | $E_{50}$ |
| B | 409 | $C_{25}$ |
| C | 337 | $C_{50}$ |
| C | 335 | $D_{50}$ |
| C | 331 | $B_{25}$ |
| C | 327 | $B_{50}$ |

| TOTAL TIME (SEC/VEH) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 63.63 | $E_{50}$ |
| A | 63.59 | $D_{25}$ |
| A | 63.09 | F |
| A | 62.82 | $E_{25}$ |
| B | 60.37 | $C_{25}$ |
| C | 5.97 | $C_{50}$ |
| C | 5.94 | $B_{25}$ |
| C | 5.91 | $B_{50}$ |
| C | 5.91 | $D_{50}$ |
| C | 5.89 | A |

| DELAY TIME (VEH-MIN/VEH-MILE) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 10.27 | $E_{50}$ |
| A | 10.27 | $D_{25}$ |
| A | 10.18 | F |
| A | 10.13 | $E_{25}$ |
| B | 9.70 | $C_{25}$ |
| C | 0.13 | $C_{50}$ |
| C | 0.12 | $B_{25}$ |
| C | 0.12 | $B_{50}$ |
| C | 0.12 | $D_{50}$ |
| C | 0.11 | A |

| VEHICLES OUT | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 673 | A |
| B | 412 | $D_{25}$ |
| B | 411 | $E_{25}$ |
| B | 411 | F |
| B | 410 | $E_{50}$ |
| B | 409 | $C_{25}$ |
| C | 337 | $C_{50}$ |
| C | 335 | $D_{50}$ |
| C | 331 | $B_{25}$ |
| C | 328 | $B_{50}$ |

| DELAY TIME (SEC/VEH) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 58.38 | $E_{50}$ |
| A | 58.35 | $D_{25}$ |
| A | 57.85 | F |
| A | 57.58 | $E_{25}$ |
| B | 55.13 | $C_{25}$ |
| C | 0.73 | $C_{50}$ |
| C | 0.69 | $B_{25}$ |
| C | 0.67 | $B_{50}$ |
| C | 0.66 | $D_{50}$ |
| C | 0.65 | A |

| VOLUME (VEH/LN/HR) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 1,346 | A |
| B A | 1,323 | $B_{25}$ |
| B | 1,311 | $B_{50}$ |
| C | 824 | $D_{25}$ |
| C | 824 | $E_{25}$ |
| C | 823 | F |
| C | 820 | $E_{50}$ |
| C | 818 | $C_{25}$ |
| D | 675 | $C_{50}$ |
| D | 671 | $D_{50}$ |

| VEH-MILES | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 63.75 | A |
| B | 39.00 | $D_{25}$ |
| B | 39.00 | $E_{25}$ |
| B | 38.95 | F |
| B | 38.83 | $E_{50}$ |
| B | 38.75 | $C_{25}$ |
| C | 31.96 | $C_{50}$ |
| C | 31.76 | $D_{50}$ |
| C | 31.32 | $B_{25}$ |
| C | 31.04 | $B_{50}$ |

| M/T RATIO | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 0.89 | A |
| A | 0.89 | $D_{50}$ |
| A | 0.89 | $B_{50}$ |
| A | 0.88 | $B_{25}$ |
| A | 0.88 | $C_{50}$ |
| B | 0.09 | $C_{25}$ |
| B | 0.08 | $E_{25}$ |
| B | 0.08 | F |
| B | 0.08 | $D_{25}$ |
| B | 0.08 | $E_{50}$ |

| DENSITY (VEH/LN-MILE) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 153.55 | $D_{25}$ |
| A | 152.94 | $E_{50}$ |
| A | 152.13 | F |
| A | 151.70 | $E_{25}$ |
| B | 144.85 | $C_{25}$ |
| C | 23.27 | A |
| C | 23.05 | $B_{25}$ |
| C | 22.75 | $B_{50}$ |
| D | 11.84 | $C_{50}$ |
| D | 11.63 | $D_{50}$ |

| VEH-MIN | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 436.21 | $D_{25}$ |
| A | 434.49 | $E_{50}$ |
| A | 432.18 | F |
| A | 430.97 | $E_{25}$ |
| B | 411.50 | $C_{25}$ |
| C | 66.10 | A |
| D | 33.63 | $C_{50}$ |
| D | 33.04 | $D_{50}$ |
| D | 32.74 | $B_{25}$ |
| D | 32.31 | $B_{50}$ |

| TOTAL TIME (VEH-MIN/VEH-MILE) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 11.20 | $E_{50}$ |
| A | 11.19 | $D_{25}$ |
| A | 11.10 | F |
| A | 11.06 | $E_{25}$ |
| B | 10.63 | $C_{25}$ |
| C | 1.05 | $C_{50}$ |
| C | 1.05 | $B_{25}$ |
| C | 1.04 | $B_{50}$ |
| C | 1.04 | $D_{50}$ |
| C | 1.04 | A |

| SPEED (MILE/HR) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 58.08 | A |
| A | 57.85 | $D_{50}$ |
| A | 57.70 | $B_{50}$ |
| A | 57.45 | $B_{25}$ |
| A | 57.23 | $C_{50}$ |
| B | 5.66 | $C_{25}$ |
| B | 5.43 | $E_{25}$ |
| B | 5.41 | F |
| B | 5.37 | $D_{25}$ |
| B | 5.37 | $E_{50}$ |

Note: Means with the same letter are not significantly different.

**Output Results of Intermediate Link (34, 32) Comparison**

Link (34, 32) was a contraflow direction link with a length of 5,280 ft. and a 65 mph speed limit. It was located 1¾ mile after the upstream interchange, and approximately 4 miles ahead the median crossover. Table 35 shows the statistics and F-value comparisons for this link at TP16. As all of the F-values were larger than the $F_{critical}$ value of 1.912, the null hypothesis was rejected and stated that at least one of the operational MOE's means of the models was significantly different. Table 35 shows the Tukey ranking at TP16.

Figure 91 shows the average volumes for Type $C_{50}$, $B_{50}$, A, and $B_{25}$ models were around 1,350 vphpl and Type $D_{50}$ model was about 675 vphpl throughout 16 time periods. These models had constant average volumes throughout 16 time periods because no congested traffic appeared on this link. The Type $C_{25}$ model started to have congested traffic from TP6, and the average volume dropped to around 1,095 vphpl at TP16. Similarly, Type $D_{25}$, $E_{50}$, $E_{25}$, and F models reached maximum congestion from TP6 and reached 820 vphpl at the end of TP16.

Figure 92 indicates that at the end of simulation, Type $C_{25}$, $D_{25}$, $E_{25}$, $E_{50}$ and F models ranged from 5 mph to 7 mph, and Type $D_{50}$, $C_{50}$, A. $B_{50}$, and $B_{25}$ models were above 60 mph. The slow speed models were grouped as the congested models because the average speeds were about one tenth of the free flow speed and the faster speed models were grouped as non-congested models.

Figure 93 illustrates that densities for the congested models ranged from 141 vpmpl to 162 vpmpl, and the non-congested models ranged from 22 vpmpl to 11 vpmpl. Similarly, the congested traffic normally had density 12 times higher than the non-congested traffic. Figure 94 shows that the average delay times for congested models ranged from 409 sec/veh to 668 sec/veh, and the non-congested models were less than 4 sec/veh.

Figure 95 shows that the M/T ratios for non-congested models were above 0.92 and the congested models were less than 0.11. As expected, these results showed that $D_{50}$, $C_{50}$, $B_{50}$, A, and $B_{25}$ models had smooth traffic flow and better mobility of traffic compared to the congested models. The results showed that exiting more vehicles at the available exit-ramps increased the average speed and decreased the evacuation delay time. Compared to link (18, 17), this link had the similar highest congested density around 160 vpmpl at 5 mph in speed. This showed that Type $D_{25}$, $E_{25}$, $E_{50}$ and F models were congested from link (18, 17) to this link.

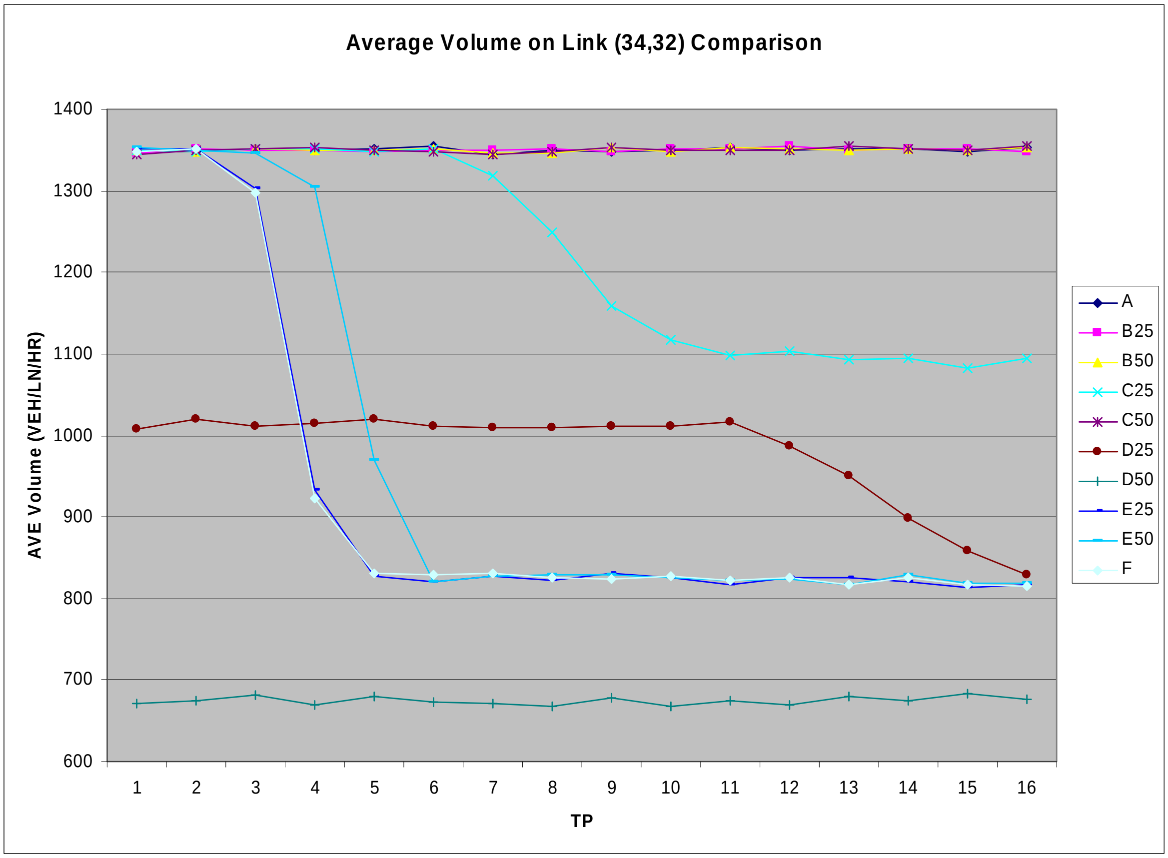


**Figure 91**
**Average volume on contraflow link (34, 32) comparison**

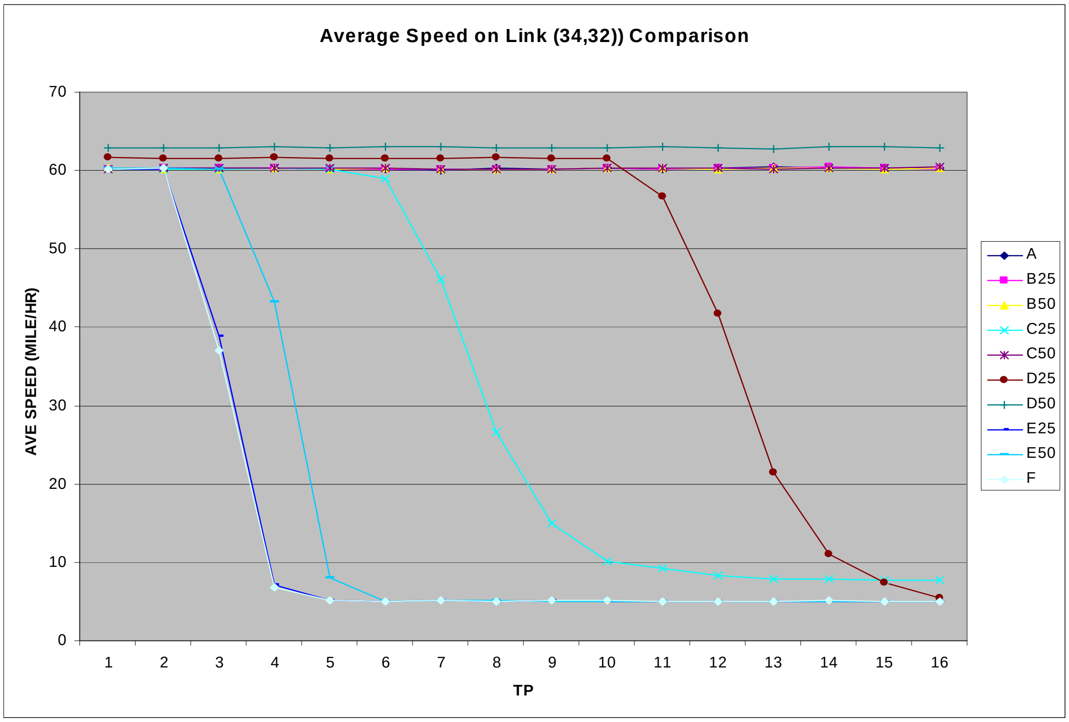


**Figure 92**
**Average speed on contraflow link (34, 32) comparison**

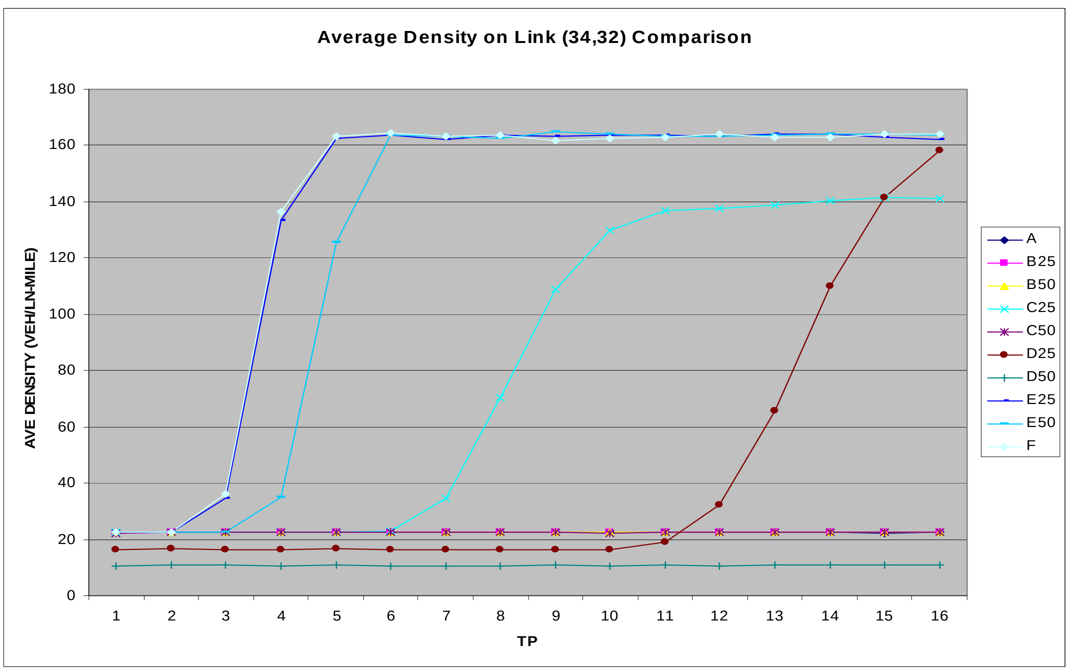


**Figure 93**
**Average density on contraflow link (34, 32) comparison**

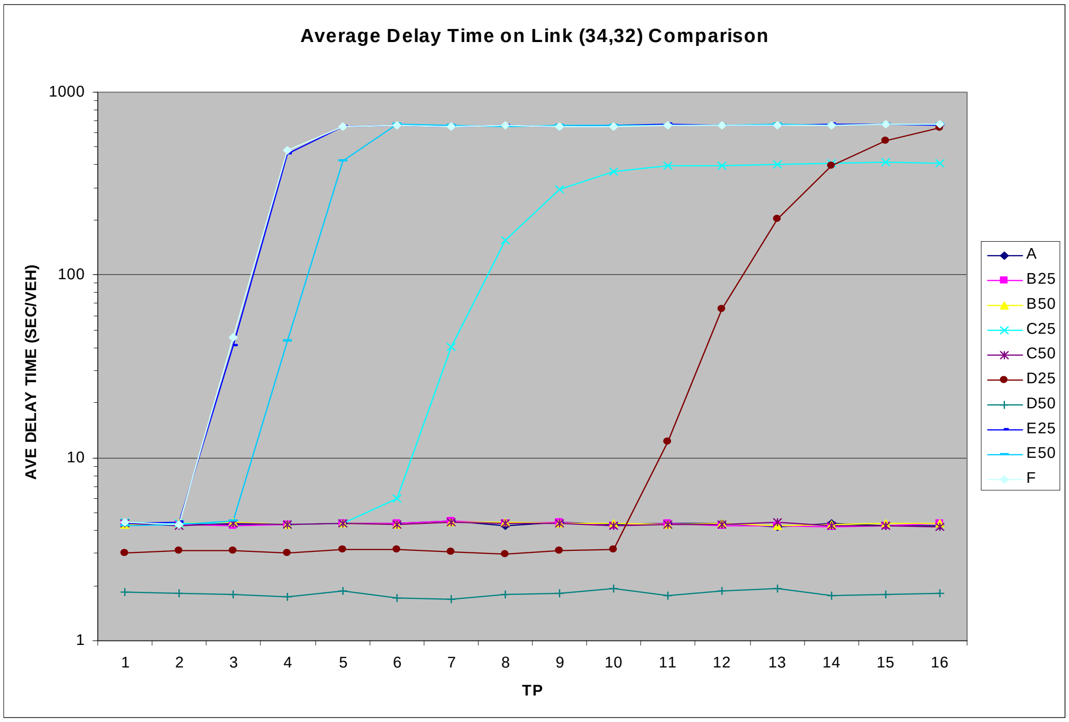


**Figure 94**
**Average delay time on contraflow link (34, 32) comparison**

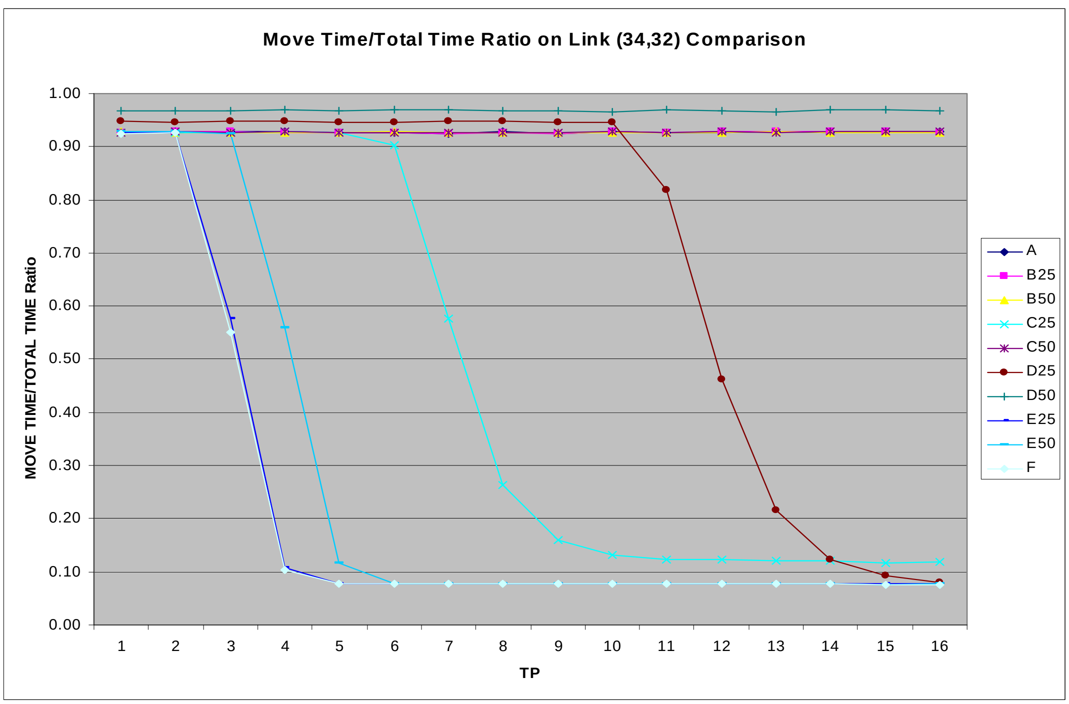


**Figure 95**
**Move time/total time ratio on contraflow link (34, 32) comparison**

## Table 36
## Link (34,32) statistics at TP 16 for MIN, MAX, AVE, STDEV and F-value comparison

| TYPE | | VEHICLES IN | VEHICLES OUT | VEH-MILES | VEH-MIN | TOTAL TIME (SEC/VEH) | DELAY TIME (SEC/VEH) | M/T | TOTAL TIME (VEH-MIN/VEH-MILE) | DELAY TIME (VEH-MIN/VEH-MILE) | VOLUME (VEH/LN/HR) | DENSITY (VEH/LN-MILE) | SPEED (MILE/HR) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | MIN | 651.00 | 653.00 | 666.70 | 657.80 | 58.88 | 3.49 | 0.92 | 0.98 | 0.06 | 1,333.40 | 21.93 | 59.72 |
| | MAX | 694.00 | 693.00 | 691.30 | 689.60 | 60.28 | 4.89 | 0.94 | 1.00 | 0.08 | 1,382.60 | 22.99 | 61.14 |
| | MEAN | 675.13 | 673.77 | 676.43 | 672.02 | 59.61 | 4.22 | 0.93 | 0.99 | 0.07 | 1,352.86 | 22.40 | 60.40 |
| | STDEV | 10.33 | 9.24 | 6.90 | 8.73 | 0.36 | 0.36 | 0.01 | 0.01 | 0.01 | 13.80 | 0.29 | 0.37 |
| $B_{25}$ | MIN | 655.00 | 653.00 | 661.70 | 654.10 | 58.83 | 3.45 | 0.90 | 0.98 | 0.06 | 1,323.40 | 21.80 | 58.61 |
| | MAX | 694.00 | 697.00 | 689.80 | 689.90 | 61.43 | 6.04 | 0.94 | 1.02 | 0.10 | 1,379.60 | 23.00 | 61.19 |
| | MEAN | 675.53 | 673.03 | 674.27 | 671.66 | 59.77 | 4.38 | 0.93 | 1.00 | 0.07 | 1,348.53 | 22.39 | 60.24 |
| | STDEV | 8.41 | 10.44 | 7.42 | 9.38 | 0.55 | 0.55 | 0.01 | 0.01 | 0.01 | 14.84 | 0.31 | 0.55 |
| $B_{50}$ | MIN | 664.00 | 658.00 | 663.30 | 658.30 | 58.87 | 3.48 | 0.91 | 0.98 | 0.06 | 1,326.60 | 21.94 | 59.45 |
| | MAX | 687.00 | 690.00 | 688.80 | 687.40 | 60.56 | 5.17 | 0.94 | 1.01 | 0.09 | 1,377.60 | 22.91 | 61.15 |
| | MEAN | 676.93 | 675.53 | 676.71 | 673.77 | 59.74 | 4.35 | 0.93 | 1.00 | 0.07 | 1,353.42 | 22.46 | 60.26 |
| | STDEV | 5.97 | 8.46 | 6.18 | 7.36 | 0.43 | 0.43 | 0.01 | 0.01 | 0.01 | 12.37 | 0.25 | 0.43 |
| $C_{25}$ | MIN | 515.00 | 518.00 | 519.60 | 4,086.40 | 435.04 | 379.66 | 0.11 | 7.25 | 6.33 | 1,039.20 | 136.21 | 7.33 |
| | MAX | 591.00 | 582.00 | 578.00 | 4,371.10 | 490.84 | 435.46 | 0.13 | 8.18 | 7.26 | 1,156.00 | 145.70 | 8.28 |
| | MEAN | 545.13 | 547.63 | 547.68 | 4,236.50 | 464.46 | 409.08 | 0.12 | 7.74 | 6.82 | 1,095.36 | 141.22 | 7.76 |
| | STDEV | 18.81 | 15.92 | 14.65 | 79.47 | 15.75 | 15.75 | 0.00 | 0.26 | 0.26 | 29.29 | 2.65 | 0.26 |
| $C_{50}$ | MIN | 663.00 | 663.00 | 665.80 | 656.90 | 58.92 | 3.54 | 0.92 | 0.98 | 0.06 | 1,331.60 | 21.90 | 59.59 |
| | MAX | 692.00 | 696.00 | 694.10 | 688.40 | 60.41 | 5.03 | 0.94 | 1.01 | 0.08 | 1,388.20 | 22.95 | 61.10 |
| | MEAN | 675.40 | 678.10 | 677.74 | 673.24 | 59.60 | 4.22 | 0.93 | 0.99 | 0.07 | 1,355.49 | 22.44 | 60.40 |
| | STDEV | 8.06 | 7.88 | 6.93 | 8.12 | 0.35 | 0.35 | 0.01 | 0.01 | 0.01 | 13.85 | 0.27 | 0.36 |
| $D_{25}$ | MIN | 394.00 | 384.00 | 395.40 | 2,024.00 | 248.90 | 193.52 | 0.07 | 4.15 | 3.23 | 790.80 | 67.47 | 4.75 |
| | MAX | 519.00 | 445.00 | 487.90 | 5,088.30 | 757.50 | 702.11 | 0.22 | 12.62 | 11.70 | 975.80 | 169.61 | 14.46 |
| | MEAN | 429.10 | 414.40 | 414.68 | 4,749.61 | 690.57 | 635.18 | 0.08 | 11.51 | 10.59 | 829.37 | 158.32 | 5.45 |
| | STDEV | 30.27 | 14.34 | 16.47 | 599.83 | 97.89 | 97.89 | 0.03 | 1.63 | 1.63 | 32.93 | 19.99 | 1.78 |
| $D_{50}$ | MIN | 306.00 | 306.00 | 303.40 | 286.80 | 56.61 | 1.23 | 0.96 | 0.94 | 0.02 | 606.80 | 9.56 | 62.15 |
| | MAX | 366.00 | 363.00 | 364.10 | 345.80 | 57.92 | 2.54 | 0.98 | 0.97 | 0.04 | 728.20 | 11.53 | 63.59 |
| | MEAN | 338.30 | 338.93 | 337.92 | 322.24 | 57.21 | 1.83 | 0.97 | 0.95 | 0.03 | 675.84 | 10.74 | 62.92 |
| | STDEV | 12.90 | 13.49 | 12.67 | 12.55 | 0.35 | 0.35 | 0.01 | 0.01 | 0.01 | 25.33 | 0.42 | 0.39 |
| $E_{25}$ | MIN | 387.00 | 380.00 | 387.60 | 4,662.30 | 673.42 | 618.04 | 0.07 | 11.22 | 10.30 | 775.20 | 155.41 | 4.78 |
| | MAX | 432.00 | 427.00 | 434.40 | 5,003.40 | 753.56 | 698.18 | 0.08 | 12.56 | 11.64 | 868.80 | 166.78 | 5.35 |
| | MEAN | 412.37 | 408.07 | 408.05 | 4,860.99 | 715.26 | 659.88 | 0.08 | 11.92 | 11.00 | 816.11 | 162.03 | 5.04 |
| | STDEV | 14.19 | 12.89 | 12.15 | 86.57 | 21.21 | 21.21 | 0.00 | 0.35 | 0.35 | 24.29 | 2.89 | 0.15 |
| $E_{50}$ | MIN | 395.00 | 377.00 | 387.70 | 4,672.70 | 671.85 | 616.46 | 0.07 | 11.20 | 10.27 | 775.40 | 155.76 | 4.72 |
| | MAX | 427.00 | 432.00 | 431.80 | 5,101.10 | 762.42 | 707.03 | 0.08 | 12.71 | 11.78 | 863.60 | 170.04 | 5.36 |
| | MEAN | 411.87 | 412.37 | 409.44 | 4,908.52 | 719.59 | 664.21 | 0.08 | 11.99 | 11.07 | 818.88 | 163.62 | 5.01 |
| | STDEV | 8.63 | 12.63 | 9.27 | 104.63 | 20.10 | 20.10 | 0.00 | 0.34 | 0.34 | 18.55 | 3.49 | 0.14 |
| F | MIN | 379.00 | 392.00 | 387.60 | 4,747.50 | 686.17 | 630.78 | 0.07 | 11.44 | 10.51 | 775.20 | 158.25 | 4.67 |
| | MAX | 436.00 | 426.00 | 421.30 | 5,100.60 | 771.65 | 716.26 | 0.08 | 12.86 | 11.94 | 842.60 | 170.02 | 5.25 |
| | MEAN | 407.33 | 410.37 | 407.47 | 4,916.11 | 724.17 | 668.78 | 0.08 | 12.07 | 11.15 | 814.94 | 163.87 | 4.97 |
| | STDEV | 11.56 | 9.51 | 9.22 | 95.70 | 18.26 | 18.26 | 0.00 | 0.30 | 0.30 | 18.45 | 3.19 | 0.12 |
| F Value within models | | 2,742 | 4,260 | 5,202 | 3,645 | 2,907 | 2,907 | 60,753 | 2,907 | 2,907 | 5,202 | 3,645 | 60,753 |

**Table 37**
**Tukey's ranking for link (34,32) statistics at TP 16**

**Tukey's Studentized Range (HSD) Tests**

**VEHICLES IN**

| TUKEY RANKING | MEAN | TYPE |
|---|---|---|
| A | 677 | $B_{50}$ |
| A | 676 | $B_{25}$ |
| A | 675 | $C_{50}$ |
| A | 675 | A |
| B | 545 | $C_{25}$ |
| C | 429 | $D_{25}$ |
| D | 412 | $E_{25}$ |
| D | 412 | $E_{50}$ |
| D | 407 | F |
| E | 338 | $D_{50}$ |

**TOTAL TIME (SEC/VEH)**

| TUKEY RANKING | MEAN | TYPE |
|---|---|---|
| A | 724.17 | F |
| A | 719.59 | $E_{50}$ |
| B A | 715.26 | $E_{25}$ |
| B | 690.57 | $D_{25}$ |
| C | 464.46 | $C_{25}$ |
| D | 59.77 | $B_{25}$ |
| D | 59.74 | $B_{50}$ |
| D | 59.61 | A |
| D | 59.60 | $C_{50}$ |
| D | 57.21 | $D_{50}$ |

**DELAY TIME (VEH-MIN/VEH-MILE)**

| TUKEY RANKING | MEAN | TYPE |
|---|---|---|
| A | 11.15 | F |
| A | 11.07 | $E_{50}$ |
| B A | 11.00 | $E_{25}$ |
| B | 10.59 | $D_{25}$ |
| C | 6.82 | $C_{25}$ |
| D | 0.07 | $B_{25}$ |
| D | 0.07 | $B_{50}$ |
| D | 0.07 | A |
| D | 0.07 | $C_{50}$ |
| D | 0.03 | $D_{50}$ |

**VEHICLES OUT**

| TUKEY RANKING | MEAN | TYPE |
|---|---|---|
| A | 678 | $C_{50}$ |
| A | 676 | $B_{50}$ |
| A | 674 | A |
| A | 673 | $B_{25}$ |
| B | 548 | $C_{25}$ |
| C | 414 | $D_{25}$ |
| C | 412 | $E_{50}$ |
| C | 410 | F |
| C | 408 | $E_{25}$ |
| D | 339 | $D_{50}$ |

**DELAY TIME (SEC/VEH)**

| TUKEY RANKING | MEAN | TYPE |
|---|---|---|
| A | 668.78 | F |
| A | 664.21 | $E_{50}$ |
| B A | 659.88 | $E_{25}$ |
| B | 635.18 | $D_{25}$ |
| C | 409.08 | $C_{25}$ |
| D | 4.38 | $B_{25}$ |
| D | 4.36 | $B_{50}$ |
| D | 4.22 | A |
| D | 4.22 | $C_{50}$ |
| D | 1.83 | $D_{50}$ |

**VOLUME (VEH/LN/HR)**

| TUKEY RANKING | MEAN | TYPE |
|---|---|---|
| A | 1,355 | $C_{50}$ |
| A | 1,353 | $B_{50}$ |
| A | 1,353 | A |
| A | 1,349 | $B_{25}$ |
| B | 1,095 | $C_{25}$ |
| C | 829 | $D_{25}$ |
| C | 819 | $E_{50}$ |
| C | 816 | $E_{25}$ |
| C | 815 | F |
| D | 676 | $D_{50}$ |

**VEH-MILES**

| TUKEY RANKING | MEAN | TYPE |
|---|---|---|
| A | 677.74 | $C_{50}$ |
| A | 676.71 | $B_{50}$ |
| A | 676.43 | A |
| A | 674.27 | $B_{25}$ |
| B | 547.68 | $C_{25}$ |
| C | 414.68 | $D_{25}$ |
| C | 409.44 | $E_{50}$ |
| C | 408.05 | $E_{25}$ |
| C | 407.47 | F |
| D | 337.92 | $D_{50}$ |

**M/T RATIO**

| TUKEY RANKING | MEAN | TYPE |
|---|---|---|
| A | 0.97 | $D_{50}$ |
| B | 0.93 | $C_{50}$ |
| B | 0.93 | A |
| B | 0.93 | $B_{50}$ |
| B | 0.93 | $B_{25}$ |
| C | 0.12 | $C_{25}$ |
| D | 0.08 | $D_{25}$ |
| D | 0.08 | $E_{25}$ |
| D | 0.08 | $E_{50}$ |
| D | 0.08 | F |

**DENSITY (VEH/LN-MILE)**

| TUKEY RANKING | MEAN | TYPE |
|---|---|---|
| A | 163.87 | F |
| B A | 163.62 | $E_{50}$ |
| B A | 162.03 | $E_{25}$ |
| B | 158.32 | $D_{25}$ |
| C | 141.22 | $C_{25}$ |
| D | 22.46 | $B_{50}$ |
| D | 22.44 | $C_{50}$ |
| D | 22.40 | A |
| D | 22.39 | $B_{25}$ |
| E | 10.74 | $D_{50}$ |

**VEH-MIN**

| TUKEY RANKING | MEAN | TYPE |
|---|---|---|
| A | 4,916.11 | F |
| B A | 4,908.52 | $E_{50}$ |
| B A | 4,860.99 | $E_{25}$ |
| B | 4,749.61 | $D_{25}$ |
| C | 4,236.50 | $C_{25}$ |
| D | 673.77 | $B_{50}$ |
| D | 673.24 | $C_{50}$ |
| D | 672.02 | A |
| D | 671.66 | $B_{25}$ |
| E | 322.24 | $D_{50}$ |

**TOTAL TIME (VEH-MIN/VEH-MILE)**

| TUKEY RANKING | MEAN | TYPE |
|---|---|---|
| A | 12.07 | F |
| A | 11.99 | $E_{50}$ |
| B A | 11.92 | $E_{25}$ |
| B | 11.51 | $D_{25}$ |
| C | 7.74 | $C_{25}$ |
| D | 1.00 | $B_{25}$ |
| D | 1.00 | $B_{50}$ |
| D | 0.99 | A |
| D | 0.99 | $C_{50}$ |
| D | 0.95 | $D_{50}$ |

**SPEED (MILE/HR)**

| TUKEY RANKING | MEAN | TYPE |
|---|---|---|
| A | 62.92 | $D_{50}$ |
| B | 60.40 | $C_{50}$ |
| B | 60.40 | A |
| B | 60.26 | $B_{50}$ |
| B | 60.24 | $B_{25}$ |
| C | 7.76 | $C_{25}$ |
| D | 5.45 | $D_{25}$ |
| D | 5.04 | $E_{25}$ |
| D | 5.01 | $E_{50}$ |
| D | 4.97 | F |

Note: Means with the same letter are not significantly different.

**Output Results of Intermediate Link (35, 33) Comparison**

Link (35, 33) had the same geometry attributes and speed limit as Link (34, 32), but it was a normal flow direction. Table 37 shows the statistics and F-value comparisons for this link at TP16. Similarly, all the F-values were larger than the $F_{critical}$ value of 1.912. This rejected the null hypothesis and stated that at least one of operational MOEs means of the models was significantly different. Hence, Tukey testing was used to rank the models as shown in Figure 96.

Figure 96 illustrates that the average volumes at the end of TP16 for Type $C_{25}$, and $C_{50}$ models were around 1,590 vphpl. Type A dropped to 1,529 vphpl constantly after TP8, and Type $E_{50}$, $D_{50}$, F, $B_{25}$, $E_{25}$, $D_{25}$, and $B_{50}$ models were around 820 vphpl constantly after TP7. Figures 97 and 98 show the average speed and density over four hours simulation. Type F, $B_{25}$, $E_{25}$, $D_{25}$, and $B_{50}$ models have an average speed of around 5 mph at a density about 163 vpmpl. These models confronted congestion. Type $C_{25}$, $C_{50}$ and A models have average speeds range from 15 mph to 21 mph with densities range from 83 vpmpl to 101 vpmpl. These models experienced moderate congestion and maintaining high traffic volume. By contrast, as Type $E_{50}$ and $D_{50}$ models had 50 percent traffic exiting at the upstream exit-ramp, these models had high average speed (i.e. above 60 mph) and a non-congested density of below 14 vpmpl. As expected, exiting more vehicles before the available exit-ramps can prevent traffic congestion.

Figure 99 shows that the average delay times for congested models were longer than 655 sec/veh, the moderate congested models range from 183 sec/veh to 133 sec/veh, and the non-congested models were less than 3 sec/veh. Figure 100 shows that the M/T ratios for non-congested models were above 0.96, the moderate congested models ranged from 0.33 to 0.23, and the congested models were less than 0.08. As expected, these results showed that exiting more vehicles at the available exit-ramps increased the average speed and required less travel time. Compared to link (18, 17) and (34, 32), the highest congested traffic density reached around 160 vpmpl at 5 mph in average speed.

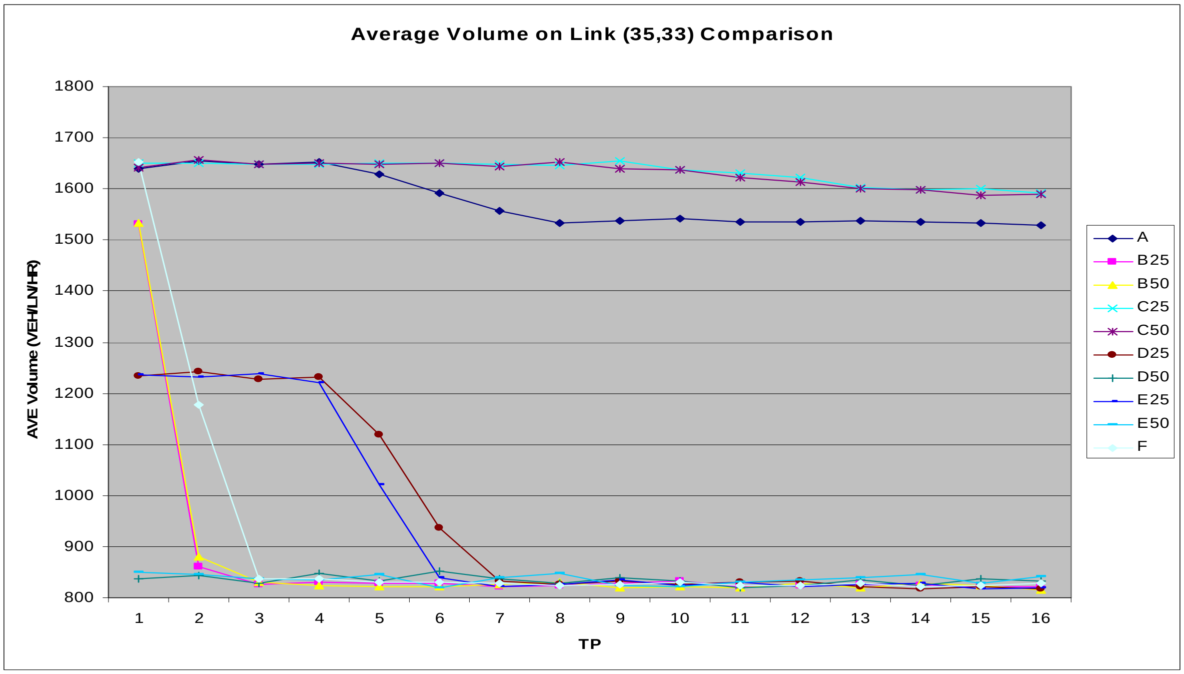


**Figure 96**
**Average volume on normal flow link (35, 33) comparison**

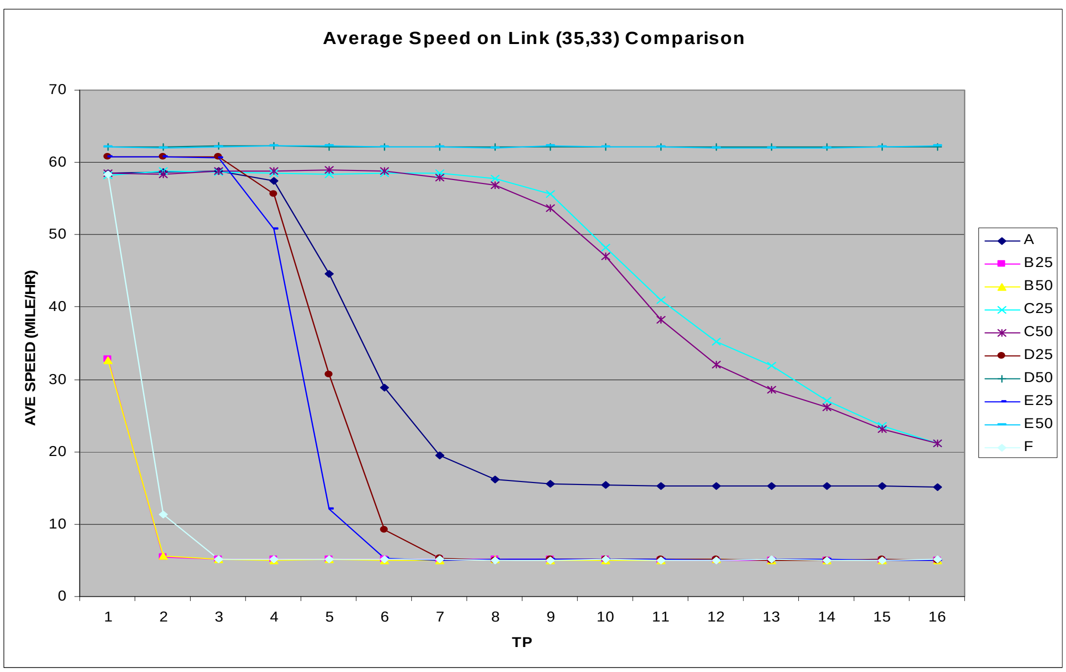


**Figure 97**
**Average speed on normal flow link (35, 33) comparison**

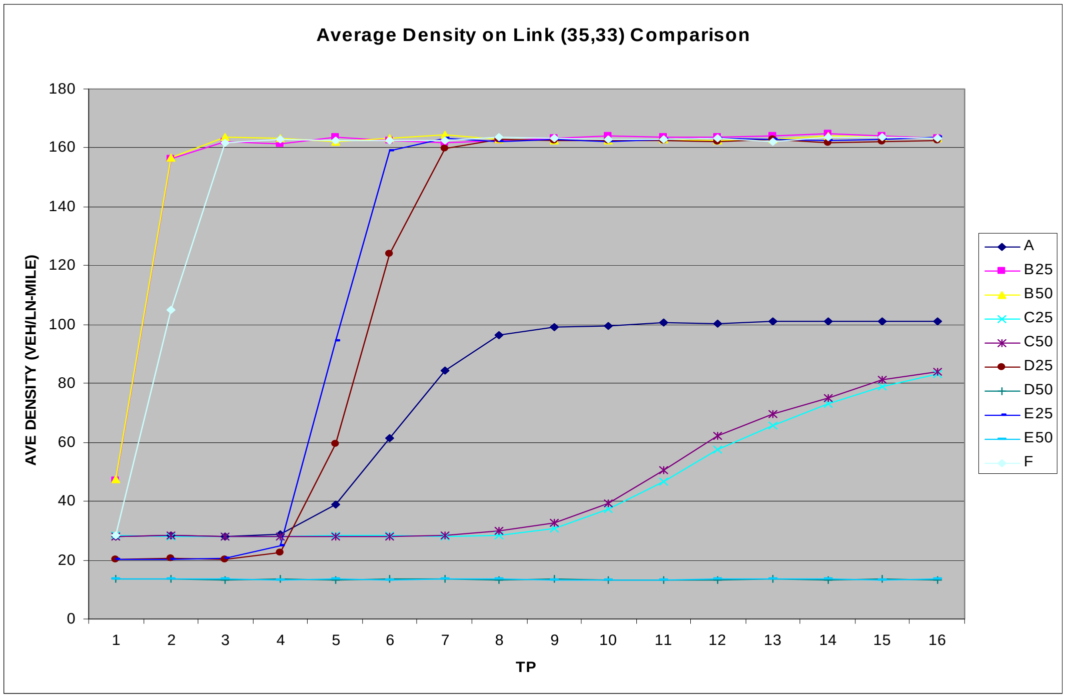


**Figure 98**
**Average density on normal flow link (35, 33) comparison**

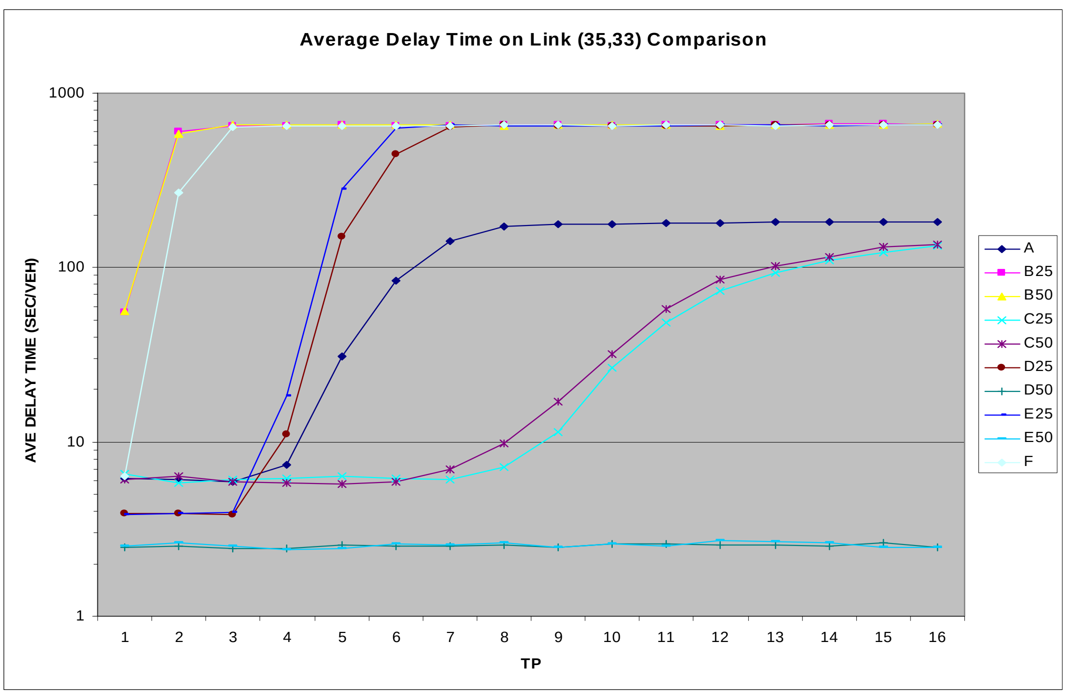


**Figure 99**
**Average delay time on normal flow link (35, 33) comparison**

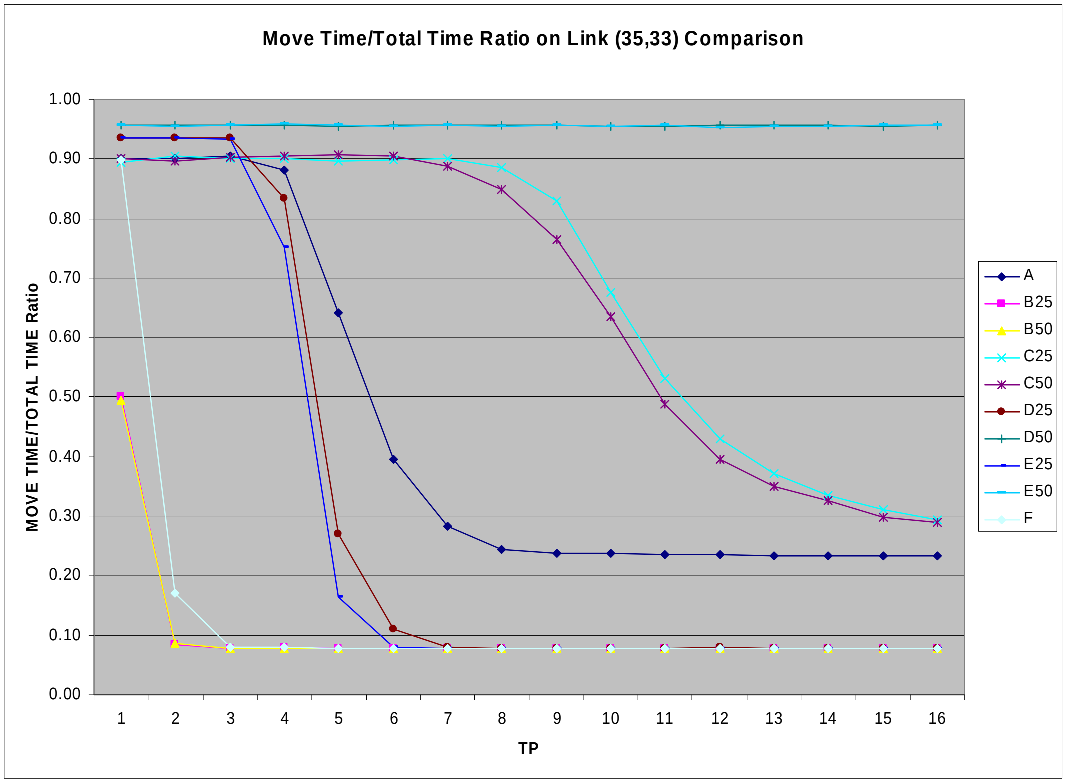


**Figure 100**
**Move time/total time ratio on normal flow link (35, 33) comparison**

## Table 38
## Link (35,33) statistics at TP 16 for MIN, MAX, AVE, STDEV and F-value comparison

| TYPE | | VEHICLES IN | VEHICLES OUT | VEH-MILES | VEH-MIN | TOTAL TIME (SEC/VEH) | DELAY TIME (SEC/VEH) | M/T | TOTAL TIME (VEH-MIN/VEH-MILE) | DELAY TIME (VEH-MIN/VEH-MILE) | VOLUME (VEH/LN/HR) | DENSITY (VEH/LN-MILE) | SPEED (MILE/HR) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | MIN | 738.00 | 734.00 | 737.10 | 2,881.10 | 221.31 | 165.93 | 0.22 | 3.69 | 2.77 | 1,474.20 | 96.04 | 14.12 |
| | MAX | 799.00 | 800.00 | 797.30 | 3,194.70 | 254.99 | 199.60 | 0.25 | 4.25 | 3.33 | 1,594.60 | 106.49 | 16.27 |
| | MEAN | 761.37 | 767.40 | 764.56 | 3,032.99 | 238.14 | 182.76 | 0.23 | 3.97 | 3.05 | 1,529.13 | 101.10 | 15.14 |
| | STDEV | 15.71 | 14.43 | 14.44 | 84.54 | 9.28 | 9.28 | 0.01 | 0.15 | 0.15 | 28.88 | 2.82 | 0.59 |
| $B_{25}$ | MIN | 391.00 | 391.00 | 387.90 | 4,773.60 | 678.23 | 622.84 | 0.07 | 11.30 | 10.38 | 775.80 | 159.12 | 4.76 |
| | MAX | 435.00 | 435.00 | 433.30 | 5,094.80 | 756.94 | 701.55 | 0.08 | 12.62 | 11.69 | 866.60 | 169.83 | 5.31 |
| | MEAN | 412.73 | 412.63 | 411.21 | 4,894.69 | 714.66 | 659.28 | 0.08 | 11.91 | 10.99 | 822.42 | 163.16 | 5.04 |
| | STDEV | 11.36 | 12.37 | 10.67 | 75.33 | 21.84 | 21.84 | 0.00 | 0.36 | 0.36 | 21.35 | 2.51 | 0.15 |
| $B_{50}$ | MIN | 383.00 | 378.00 | 385.30 | 4,664.20 | 686.77 | 631.39 | 0.07 | 11.45 | 10.52 | 770.60 | 155.47 | 4.63 |
| | MAX | 435.00 | 443.00 | 428.20 | 5,107.50 | 777.93 | 722.54 | 0.08 | 12.97 | 12.04 | 856.40 | 170.25 | 5.24 |
| | MEAN | 409.80 | 411.87 | 407.53 | 4,902.62 | 722.15 | 666.77 | 0.08 | 12.04 | 11.11 | 815.07 | 163.42 | 4.99 |
| | STDEV | 14.60 | 16.72 | 12.21 | 112.87 | 18.42 | 18.42 | 0.00 | 0.31 | 0.31 | 24.42 | 3.76 | 0.13 |
| $C_{25}$ | MIN | 744.00 | 751.00 | 745.40 | 901.60 | 65.26 | 9.88 | 0.22 | 1.09 | 0.16 | 1,490.80 | 30.05 | 14.62 |
| | MAX | 837.00 | 838.00 | 828.90 | 3,080.50 | 246.28 | 190.89 | 0.85 | 4.10 | 3.18 | 1,657.80 | 102.68 | 55.16 |
| | MEAN | 804.57 | 793.83 | 796.26 | 2,493.05 | 188.70 | 133.31 | 0.33 | 3.15 | 2.22 | 1,592.52 | 83.10 | 21.18 |
| | STDEV | 23.04 | 25.22 | 22.98 | 580.60 | 46.38 | 46.38 | 0.14 | 0.77 | 0.77 | 45.96 | 19.35 | 9.28 |
| $C_{50}$ | MIN | 724.00 | 732.00 | 727.00 | 835.90 | 60.78 | 5.39 | 0.20 | 1.01 | 0.09 | 1,454.00 | 27.86 | 13.23 |
| | MAX | 848.00 | 831.00 | 835.10 | 3,297.10 | 272.11 | 216.73 | 0.91 | 4.54 | 3.61 | 1,670.20 | 109.90 | 59.23 |
| | MEAN | 800.63 | 789.10 | 795.14 | 2,521.70 | 191.20 | 135.82 | 0.33 | 3.19 | 2.26 | 1,590.29 | 84.06 | 21.17 |
| | STDEV | 26.61 | 23.91 | 22.85 | 622.69 | 50.11 | 50.11 | 0.15 | 0.84 | 0.84 | 45.69 | 20.76 | 9.94 |
| $D_{25}$ | MIN | 383.00 | 384.00 | 391.20 | 4,651.80 | 671.08 | 615.69 | 0.07 | 11.18 | 10.26 | 782.40 | 155.06 | 4.75 |
| | MAX | 435.00 | 436.00 | 428.30 | 5,074.90 | 758.45 | 703.06 | 0.08 | 12.64 | 11.72 | 856.60 | 169.16 | 5.36 |
| | MEAN | 412.00 | 408.53 | 408.93 | 4,875.63 | 715.66 | 660.27 | 0.08 | 11.93 | 11.00 | 817.85 | 162.52 | 5.03 |
| | STDEV | 11.44 | 13.15 | 8.85 | 98.20 | 19.49 | 19.49 | 0.00 | 0.32 | 0.32 | 17.69 | 3.27 | 0.14 |
| $D_{50}$ | MIN | 369.00 | 374.00 | 376.20 | 359.30 | 57.27 | 1.88 | 0.94 | 0.95 | 0.03 | 752.40 | 11.98 | 61.34 |
| | MAX | 459.00 | 458.00 | 460.00 | 441.40 | 58.69 | 3.30 | 0.97 | 0.98 | 0.06 | 920.00 | 14.71 | 62.86 |
| | MEAN | 416.37 | 414.20 | 415.89 | 401.13 | 57.87 | 2.48 | 0.96 | 0.96 | 0.04 | 831.78 | 13.37 | 62.21 |
| | STDEV | 23.83 | 24.41 | 23.76 | 23.25 | 0.37 | 0.37 | 0.01 | 0.01 | 0.01 | 47.52 | 0.77 | 0.39 |
| $E_{25}$ | MIN | 382.00 | 386.00 | 384.80 | 4,709.80 | 650.58 | 595.20 | 0.07 | 10.84 | 9.92 | 769.60 | 156.99 | 4.74 |
| | MAX | 441.00 | 436.00 | 438.90 | 5,192.90 | 759.58 | 704.20 | 0.09 | 12.66 | 11.74 | 877.80 | 173.10 | 5.53 |
| | MEAN | 412.47 | 411.83 | 410.00 | 4,906.70 | 718.71 | 663.32 | 0.08 | 11.98 | 11.06 | 820.00 | 163.56 | 5.02 |
| | STDEV | 15.21 | 13.80 | 13.37 | 102.23 | 25.18 | 25.18 | 0.00 | 0.42 | 0.42 | 26.74 | 3.41 | 0.18 |
| $E_{50}$ | MIN | 378.00 | 370.00 | 377.90 | 359.60 | 57.09 | 1.71 | 0.94 | 0.95 | 0.03 | 755.80 | 11.99 | 61.17 |
| | MAX | 463.00 | 455.00 | 455.00 | 444.00 | 58.85 | 3.47 | 0.97 | 0.98 | 0.06 | 910.00 | 14.80 | 63.05 |
| | MEAN | 420.67 | 420.80 | 420.19 | 405.27 | 57.86 | 2.48 | 0.96 | 0.96 | 0.04 | 840.38 | 13.51 | 62.22 |
| | STDEV | 21.88 | 20.48 | 20.00 | 20.87 | 0.39 | 0.39 | 0.01 | 0.01 | 0.01 | 40.00 | 0.70 | 0.42 |
| F | MIN | 393.00 | 390.00 | 392.50 | 4,728.30 | 658.10 | 602.71 | 0.07 | 10.97 | 10.05 | 785.00 | 157.61 | 4.79 |
| | MAX | 438.00 | 458.00 | 438.60 | 5,180.60 | 752.29 | 696.91 | 0.08 | 12.54 | 11.62 | 877.20 | 172.69 | 5.47 |
| | MEAN | 414.87 | 415.10 | 413.66 | 4,897.02 | 710.69 | 655.30 | 0.08 | 11.84 | 10.92 | 827.33 | 163.23 | 5.07 |
| | STDEV | 11.51 | 17.19 | 11.69 | 119.33 | 21.88 | 21.88 | 0.00 | 0.36 | 0.36 | 23.39 | 3.98 | 0.16 |
| F Value within models | | 2,929 | 2,723 | 3,387 | 1,308 | 3,963 | 3,963 | 844 | 3,963 | 3,963 | 3,387 | 1,308 | 844 |

**Table 39**
**Tukey's ranking for link (35,33) statistics at TP 16**

Tukey's Studentized Range (HSD) Tests

| VEHICLES IN | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 805 | $C_{25}$ |
| A | 801 | $C_{50}$ |
| B | 761 | A |
| C | 421 | $E_{50}$ |
| C | 416 | $D_{50}$ |
| C | 415 | F |
| C | 413 | $B_{25}$ |
| C | 412 | $E_{25}$ |
| C | 412 | $D_{25}$ |
| C | 410 | $B_{50}$ |

| TOTAL TIME (SEC/VEH) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 722.15 | $B_{50}$ |
| A | 718.71 | $E_{25}$ |
| A | 715.66 | $D_{25}$ |
| A | 714.66 | $B_{25}$ |
| A | 710.69 | F |
| B | 238.14 | A |
| C | 191.20 | $C_{50}$ |
| C | 188.70 | $C_{25}$ |
| D | 57.87 | $D_{50}$ |
| D | 57.86 | $E_{50}$ |

| DELAY TIME (VEH-MIN/VEH-MILE) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 11.11 | $B_{50}$ |
| A | 11.06 | $E_{25}$ |
| A | 11.00 | $D_{25}$ |
| A | 10.99 | $B_{25}$ |
| A | 10.92 | F |
| B | 3.05 | A |
| C | 2.26 | $C_{50}$ |
| C | 2.22 | $C_{25}$ |
| D | 0.04 | $D_{50}$ |
| D | 0.04 | $E_{50}$ |

| VEHICLES OUT | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 794 | $C_{25}$ |
| A | 789 | $C_{50}$ |
| B | 767 | A |
| C | 421 | $E_{50}$ |
| C | 415 | F |
| C | 414 | $D_{50}$ |
| C | 413 | $B_{25}$ |
| C | 412 | $B_{50}$ |
| C | 412 | $E_{25}$ |
| C | 409 | $D_{25}$ |

| DELAY TIME (SEC/VEH) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 666.77 | $B_{50}$ |
| A | 663.32 | $E_{25}$ |
| A | 660.27 | $D_{25}$ |
| A | 659.28 | $B_{25}$ |
| A | 655.30 | F |
| B | 182.76 | A |
| C | 135.82 | $C_{50}$ |
| C | 133.31 | $C_{25}$ |
| D | 2.49 | $D_{50}$ |
| D | 2.48 | $E_{50}$ |

| VOLUME (VEH/LN/HR) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 1,593 | $C_{25}$ |
| A | 1,590 | $C_{50}$ |
| B | 1,529 | A |
| C | 840 | $E_{50}$ |
| C | 832 | $D_{50}$ |
| C | 827 | F |
| C | 822 | $B_{25}$ |
| C | 820 | $E_{25}$ |
| C | 818 | $D_{25}$ |
| C | 815 | $B_{50}$ |

| VEH-MILES | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 796.26 | $C_{25}$ |
| A | 795.14 | $C_{50}$ |
| B | 764.56 | A |
| C | 420.19 | $E_{50}$ |
| C | 415.89 | $D_{50}$ |
| C | 413.66 | F |
| C | 411.21 | $B_{25}$ |
| C | 410.00 | $E_{25}$ |
| C | 408.93 | $D_{25}$ |
| C | 407.53 | $B_{50}$ |

| M/T RATIO | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 0.96 | $E_{50}$ |
| A | 0.96 | $D_{50}$ |
| B | 0.33 | $C_{25}$ |
| B | 0.33 | $C_{50}$ |
| C | 0.23 | A |
| D | 0.08 | F |
| D | 0.08 | $B_{25}$ |
| D | 0.08 | $D_{25}$ |
| D | 0.08 | $E_{25}$ |
| D | 0.08 | $B_{50}$ |

| DENSITY (VEH/LN-MILE) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 163.56 | $E_{25}$ |
| A | 163.42 | $B_{50}$ |
| A | 163.23 | F |
| A | 163.16 | $B_{25}$ |
| A | 162.52 | $D_{25}$ |
| B | 101.10 | A |
| C | 84.06 | $C_{50}$ |
| C | 83.10 | $C_{25}$ |
| D | 13.51 | $E_{50}$ |
| D | 13.37 | $D_{50}$ |

| VEH-MIN | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 4,906.70 | $E_{25}$ |
| A | 4,902.62 | $B_{50}$ |
| A | 4,897.02 | F |
| A | 4,894.69 | $B_{25}$ |
| A | 4,875.63 | $D_{25}$ |
| B | 3,032.99 | A |
| C | 2,521.70 | $C_{50}$ |
| C | 2,493.05 | $C_{25}$ |
| D | 405.27 | $E_{50}$ |
| D | 401.13 | $D_{50}$ |

| TOTAL TIME (VEH-MIN/VEH-MILE) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 12.04 | $B_{50}$ |
| A | 11.98 | $E_{25}$ |
| A | 11.93 | $D_{25}$ |
| A | 11.91 | $B_{25}$ |
| A | 11.84 | F |
| B | 3.97 | A |
| C | 3.19 | $C_{50}$ |
| C | 3.15 | $C_{25}$ |
| D | 0.96 | $D_{50}$ |
| D | 0.96 | $E_{50}$ |

| SPEED (MILE/HR) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 62.22 | $E_{50}$ |
| A | 62.21 | $D_{50}$ |
| B | 21.18 | $C_{25}$ |
| B | 21.18 | $C_{50}$ |
| C | 15.14 | A |
| D | 5.07 | F |
| D | 5.04 | $B_{25}$ |
| D | 5.03 | $D_{25}$ |
| D | 5.02 | $E_{25}$ |
| D | 4.99 | $B_{50}$ |

Note: Means with the same letter are not significantly different.

**Output Results of Entrance Link (52,50) Comparison**

Link (52, 50) was an entrance link on the contraflow direction with a length of 5,280 ft. and 65 mph as the speed limit. The CORSIM output results showed that Type E and F models had queued vehicles before this link; in contrast, Type A, B, C and D models did not have queued vehicles.

Figure 101 shows the statistics and F-value of this link at TP16. As all the F-values were larger than the $F_{critical}$ value of 1.912, the null hypothesis was rejected. This stated that at least one of the operational MOEs means of the models was significantly different. Figure 101 shows the Tukey ranking of this link.

Figure 101 shows that Type E and F models were around 820 vphpl after TP14, and Type A, B, C and D models were around 1,350 vphpl throughout each time-period. Figure 102 and Figure 103 show the average speed and density throughout the 4 hours simulation. The average speeds for the Type E and F models were around 5 mph at 164 vpmpl after TP14, and the other models were around 63 mph at 21 vpmpl throughout 4 hours simulation. These results showed that the congested models had average speed about one tenth of the non-congested models.

As expected, Figure 104 shows that the delay times for congested models (more than 660 sec/veh) were much higher then the non-congested models (around 2 sec/veh).
Figure 105 shows that the M/T ratios for the non-congested models were 0.96, which was about 12 times higher than the congested models (around 0.08). These results showed that the congested models wasted more than 90 percent of the total travel time on this link. As expected, these results showed that exiting vehicles at the available exit-ramps increased the average speed and required less travel time. Compared to links (18, 17), (34, 32), and (35, 33), the highest congested traffic condition of this link reached around 160 vpmpl in density at around 5 mph in average speed. This showed that Type E and F models had congested traffic spanned from link (18, 17) to the entrance link after TP14.

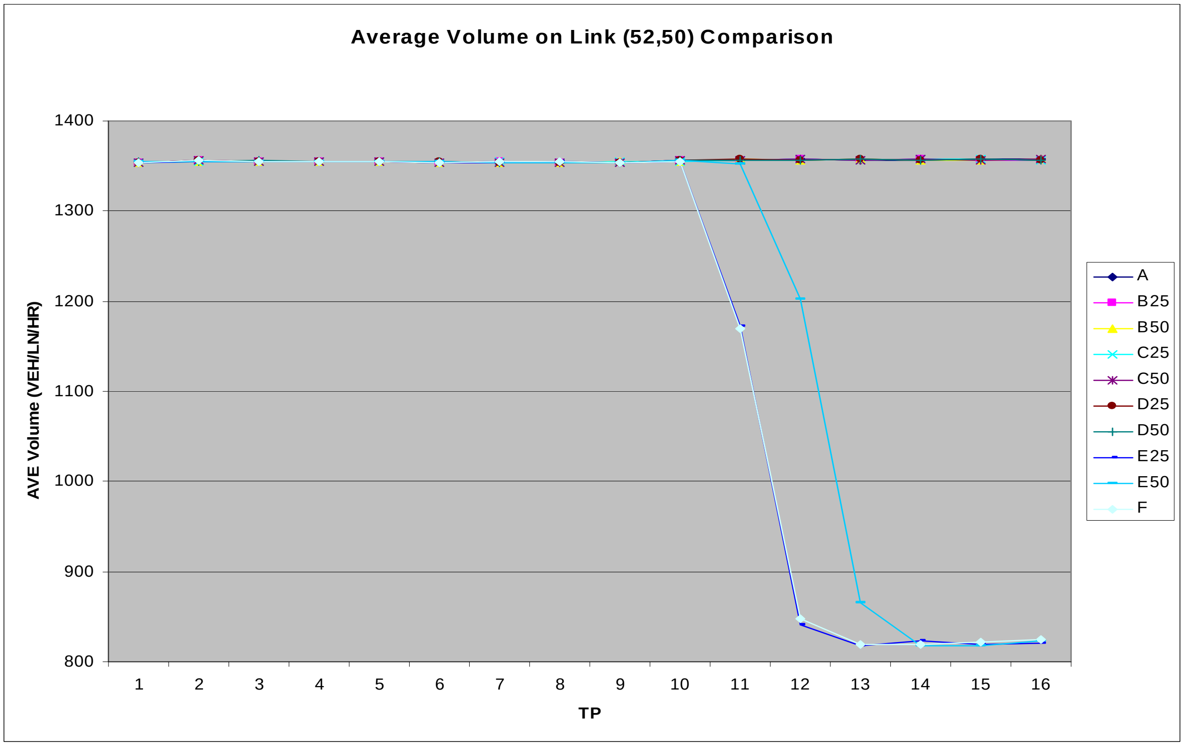


**Figure 101**
**Average volume on contraflow direction entrance link comparison - link (52, 50)**

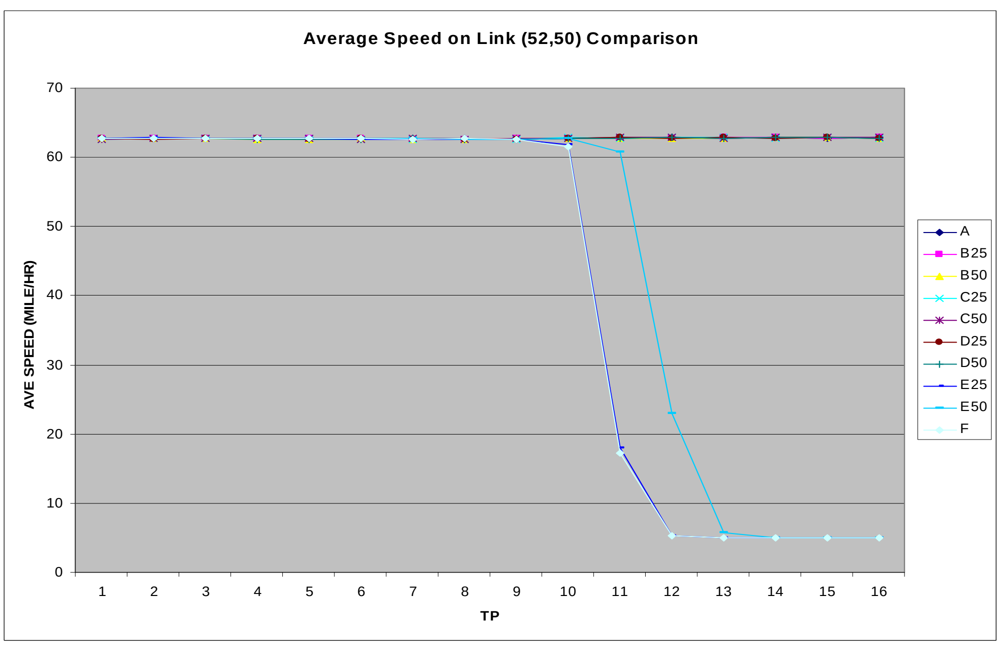


**Figure 102**
**Average speed on contraflow direction entrance link comparison - link (52, 50)**

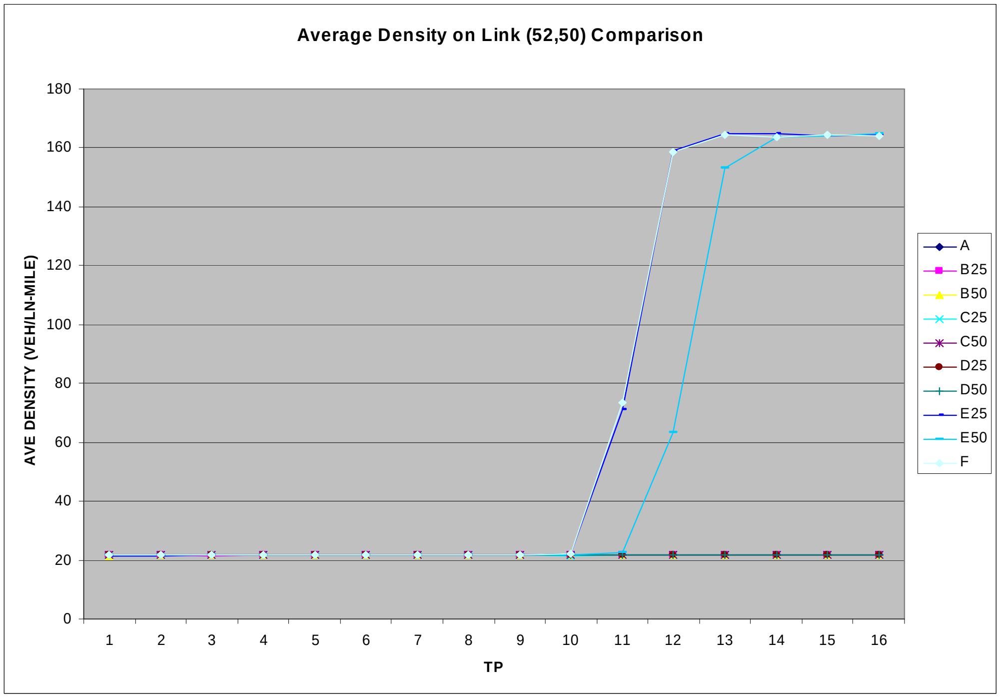


**Figure 103**
**Average density on contraflow direction entrance link comparison - link (52, 50)**

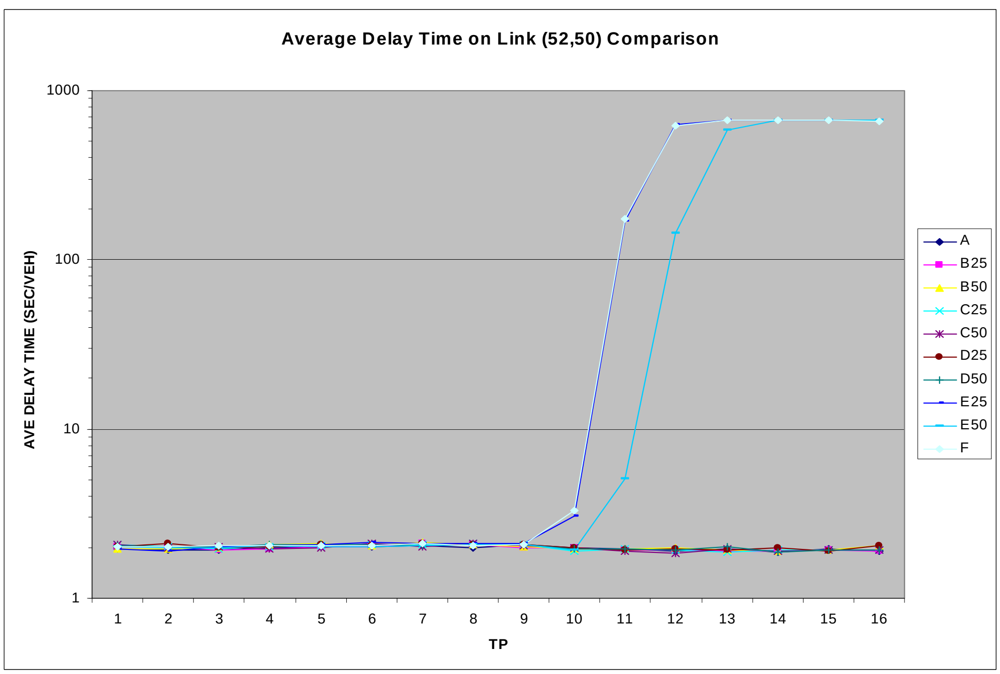


**Figure 104**
**Average delay time on contraflow direction entrance link comparison - link (52, 50)**

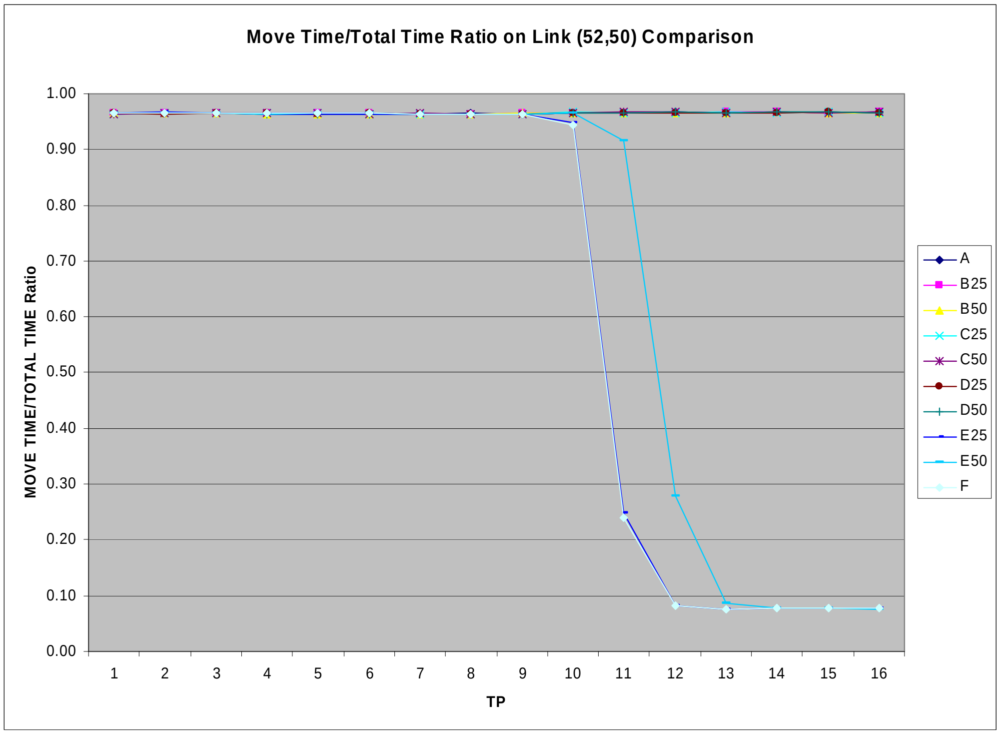


**Figure 105**
**Move time/total time ratio on contraflow direction entrance link comparison - link (52, 50)**

**Table 40**
**Link (52,50) statistics at TP 16 for MIN, MAX, AVE, STDEV and F-value comparison**

| TYPE | | VEHICLES IN | VEHICLES OUT | VEH-MILES | VEH-MIN | TOTAL TIME (SEC/VEH) | DELAY TIME (SEC/VEH) | M/T | TOTAL TIME (VEH-MIN/VEH-MILE) | DELAY TIME (VEH-MIN/VEH-MILE) | VOLUME (VEH/LN/HR) | DENSITY (VEH/LN-MILE) | SPEED (MILE/HR) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | MIN | 675.00 | 672.00 | 677.70 | 644.50 | 56.98 | 1.59 | 0.96 | 0.95 | 0.03 | 1,355.40 | 21.48 | 62.53 |
| | MAX | 675.00 | 680.00 | 679.40 | 650.60 | 57.58 | 2.19 | 0.97 | 0.96 | 0.04 | 1,358.80 | 21.69 | 63.18 |
| | MEAN | 675.00 | 675.40 | 678.66 | 647.92 | 57.28 | 1.90 | 0.97 | 0.95 | 0.03 | 1,357.31 | 21.60 | 62.85 |
| | STDEV | - | 2.24 | 0.48 | 1.68 | 0.16 | 0.16 | 0.00 | 0.00 | 0.00 | 0.96 | 0.06 | 0.18 |
| $B_{25}$ | MIN | 675.00 | 670.00 | 677.50 | 642.70 | 56.86 | 1.47 | 0.96 | 0.95 | 0.02 | 1,355.00 | 21.42 | 62.37 |
| | MAX | 675.00 | 681.00 | 679.80 | 652.80 | 57.72 | 2.33 | 0.97 | 0.96 | 0.04 | 1,359.60 | 21.76 | 63.32 |
| | MEAN | 675.00 | 675.40 | 678.46 | 647.80 | 57.29 | 1.90 | 0.97 | 0.95 | 0.03 | 1,356.93 | 21.59 | 62.84 |
| | STDEV | - | 2.30 | 0.58 | 2.71 | 0.23 | 0.23 | 0.00 | 0.00 | 0.00 | 1.17 | 0.09 | 0.26 |
| $B_{50}$ | MIN | 675.00 | 670.00 | 677.20 | 644.00 | 56.94 | 1.56 | 0.96 | 0.95 | 0.03 | 1,354.40 | 21.47 | 62.33 |
| | MAX | 675.00 | 678.00 | 679.50 | 653.70 | 57.76 | 2.37 | 0.97 | 0.96 | 0.04 | 1,359.00 | 21.79 | 63.22 |
| | MEAN | 675.00 | 675.27 | 678.54 | 649.34 | 57.42 | 2.03 | 0.96 | 0.96 | 0.03 | 1,357.07 | 21.64 | 62.70 |
| | STDEV | - | 1.76 | 0.59 | 2.44 | 0.21 | 0.21 | 0.00 | 0.00 | 0.00 | 1.19 | 0.08 | 0.23 |
| $C_{25}$ | MIN | 675.00 | 672.00 | 677.30 | 645.40 | 57.07 | 1.69 | 0.96 | 0.95 | 0.03 | 1,354.60 | 21.51 | 62.48 |
| | MAX | 675.00 | 678.00 | 679.20 | 652.00 | 57.62 | 2.24 | 0.97 | 0.96 | 0.04 | 1,358.40 | 21.73 | 63.08 |
| | MEAN | 675.00 | 675.40 | 678.46 | 648.23 | 57.33 | 1.94 | 0.97 | 0.96 | 0.03 | 1,356.91 | 21.61 | 62.80 |
| | STDEV | - | 1.81 | 0.46 | 1.75 | 0.15 | 0.15 | 0.00 | 0.00 | 0.00 | 0.92 | 0.06 | 0.17 |
| $C_{50}$ | MIN | 675.00 | 672.00 | 677.90 | 644.60 | 56.94 | 1.56 | 0.96 | 0.95 | 0.03 | 1,355.80 | 21.49 | 62.39 |
| | MAX | 675.00 | 679.00 | 679.90 | 653.90 | 57.71 | 2.32 | 0.97 | 0.96 | 0.04 | 1,359.80 | 21.80 | 63.22 |
| | MEAN | 675.00 | 674.70 | 678.66 | 648.11 | 57.30 | 1.91 | 0.97 | 0.96 | 0.03 | 1,357.32 | 21.60 | 62.83 |
| | STDEV | - | 1.86 | 0.53 | 2.15 | 0.18 | 0.18 | 0.00 | 0.00 | 0.00 | 1.05 | 0.07 | 0.19 |
| $D_{25}$ | MIN | 675.00 | 669.00 | 677.20 | 644.60 | 57.05 | 1.67 | 0.96 | 0.95 | 0.03 | 1,354.40 | 21.49 | 62.34 |
| | MAX | 675.00 | 678.00 | 679.80 | 652.30 | 57.75 | 2.37 | 0.97 | 0.96 | 0.04 | 1,359.60 | 21.74 | 63.10 |
| | MEAN | 675.00 | 674.50 | 678.43 | 649.23 | 57.42 | 2.03 | 0.96 | 0.96 | 0.03 | 1,356.87 | 21.64 | 62.70 |
| | STDEV | - | 2.24 | 0.59 | 2.05 | 0.18 | 0.18 | 0.00 | 0.00 | 0.00 | 1.18 | 0.07 | 0.20 |
| $D_{50}$ | MIN | 675.00 | 670.00 | 677.40 | 642.30 | 56.82 | 1.44 | 0.96 | 0.95 | 0.02 | 1,354.80 | 21.41 | 62.20 |
| | MAX | 675.00 | 678.00 | 679.50 | 653.70 | 57.88 | 2.49 | 0.97 | 0.96 | 0.04 | 1,359.00 | 21.79 | 63.35 |
| | MEAN | 675.00 | 674.67 | 678.38 | 648.12 | 57.32 | 1.94 | 0.97 | 0.96 | 0.03 | 1,356.76 | 21.60 | 62.80 |
| | STDEV | - | 1.73 | 0.57 | 2.63 | 0.23 | 0.23 | 0.00 | 0.00 | 0.00 | 1.13 | 0.09 | 0.25 |
| $E_{25}$ | MIN | 387.00 | 386.00 | 388.30 | 4,717.40 | 679.61 | 624.23 | 0.07 | 11.33 | 10.40 | 776.60 | 157.25 | 4.74 |
| | MAX | 443.00 | 435.00 | 437.20 | 5,142.70 | 760.24 | 704.85 | 0.08 | 12.67 | 11.75 | 874.40 | 171.42 | 5.30 |
| | MEAN | 410.87 | 410.87 | 410.10 | 4,934.62 | 722.34 | 666.96 | 0.08 | 12.04 | 11.12 | 820.20 | 164.49 | 4.99 |
| | STDEV | 12.63 | 10.82 | 10.95 | 110.20 | 21.28 | 21.28 | 0.00 | 0.35 | 0.35 | 21.89 | 3.67 | 0.15 |
| $E_{50}$ | MIN | 393.00 | 385.00 | 397.30 | 4,752.80 | 675.78 | 620.40 | 0.07 | 11.26 | 10.34 | 794.60 | 158.43 | 4.68 |
| | MAX | 442.00 | 443.00 | 434.20 | 5,260.70 | 769.20 | 713.82 | 0.08 | 12.82 | 11.90 | 868.40 | 175.36 | 5.33 |
| | MEAN | 411.20 | 413.10 | 411.32 | 4,949.25 | 722.41 | 667.02 | 0.08 | 12.04 | 11.12 | 822.64 | 164.98 | 4.99 |
| | STDEV | 12.01 | 13.35 | 11.32 | 111.17 | 23.29 | 23.29 | 0.00 | 0.39 | 0.39 | 22.64 | 3.71 | 0.16 |
| F | MIN | 378.00 | 394.00 | 390.80 | 4,698.90 | 657.81 | 602.43 | 0.07 | 10.96 | 10.04 | 781.60 | 156.63 | 4.64 |
| | MAX | 439.00 | 441.00 | 439.40 | 5,095.40 | 776.28 | 720.90 | 0.08 | 12.94 | 12.02 | 878.80 | 169.85 | 5.47 |
| | MEAN | 412.43 | 414.00 | 412.25 | 4,917.73 | 716.50 | 661.12 | 0.08 | 11.94 | 11.02 | 824.50 | 163.92 | 5.03 |
| | STDEV | 14.00 | 11.84 | 13.21 | 96.47 | 28.36 | 28.36 | 0.00 | 0.47 | 0.47 | 26.42 | 3.22 | 0.20 |
| F Value within models | | 9,722 | 10,400 | 11,777 | 37,985 | 17,099 | 17,099 | 579,002 | 17,099 | 17,099 | 11,777 | 37,985 | 579,002 |

**Table 41**
**Tukey's ranking for link (52,50) statistics at TP 16**

**Tukey's Studentized Range (HSD) Tests**

| VEHICLES IN | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 675 | A |
| A | 675 | $B_{25}$ |
| A | 675 | $B_{50}$ |
| A | 675 | $C_{25}$ |
| A | 675 | $C_{50}$ |
| A | 675 | $D_{25}$ |
| A | 675 | $D_{50}$ |
| B | 412 | F |
| B | 411 | $E_{50}$ |
| B | 411 | $E_{25}$ |

| TOTAL TIME (SEC/VEH) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 722.41 | $E_{50}$ |
| A | 722.34 | $E_{25}$ |
| A | 716.50 | F |
| B | 57.42 | $B_{50}$ |
| B | 57.42 | $D_{25}$ |
| B | 57.33 | $C_{25}$ |
| B | 57.32 | $D_{50}$ |
| B | 57.30 | $C_{50}$ |
| B | 57.29 | $B_{25}$ |
| B | 57.28 | A |

| DELAY TIME (VEH-MIN/VEH-MILE) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 11.12 | $E_{50}$ |
| A | 11.12 | $E_{25}$ |
| A | 11.02 | F |
| B | 0.03 | $B_{50}$ |
| B | 0.03 | $D_{25}$ |
| B | 0.03 | $C_{25}$ |
| B | 0.03 | $D_{50}$ |
| B | 0.03 | $C_{50}$ |
| B | 0.03 | $B_{25}$ |
| B | 0.03 | A |

| VEHICLES OUT | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 675 | A |
| A | 675 | $B_{25}$ |
| A | 675 | $C_{25}$ |
| A | 675 | $B_{50}$ |
| A | 675 | $C_{50}$ |
| A | 675 | $D_{50}$ |
| A | 675 | $D_{25}$ |
| B | 414 | F |
| B | 413 | $E_{50}$ |
| B | 411 | $E_{25}$ |

| DELAY TIME (SEC/VEH) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 667.02 | $E_{50}$ |
| A | 666.96 | $E_{25}$ |
| A | 661.12 | F |
| B | 2.03 | $B_{50}$ |
| B | 2.03 | $D_{25}$ |
| B | 1.94 | $C_{25}$ |
| B | 1.94 | $D_{50}$ |
| B | 1.92 | $C_{50}$ |
| B | 1.90 | $B_{25}$ |
| B | 1.90 | A |

| VOLUME (VEH/LN/HR) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 1,357 | $C_{50}$ |
| A | 1,357 | A |
| A | 1,357 | $B_{50}$ |
| A | 1,357 | $B_{25}$ |
| A | 1,357 | $C_{25}$ |
| A | 1,357 | $D_{25}$ |
| A | 1,357 | $D_{50}$ |
| B | 825 | F |
| B | 823 | $E_{50}$ |
| B | 820 | $E_{25}$ |

| VEH-MILES | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 678.66 | $C_{50}$ |
| A | 678.66 | A |
| A | 678.54 | $B_{50}$ |
| A | 678.46 | $B_{25}$ |
| A | 678.46 | $C_{25}$ |
| A | 678.43 | $D_{25}$ |
| A | 678.38 | $D_{50}$ |
| B | 412.25 | F |
| B | 411.32 | $E_{50}$ |
| B | 410.10 | $E_{25}$ |

| M/T RATIO | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 0.97 | A |
| A | 0.97 | $B_{25}$ |
| A | 0.97 | $C_{50}$ |
| A | 0.97 | $D_{50}$ |
| A | 0.97 | $C_{25}$ |
| A | 0.96 | $D_{25}$ |
| A | 0.96 | $B_{50}$ |
| B | 0.08 | F |
| B | 0.08 | $E_{50}$ |
| B | 0.08 | $E_{25}$ |

| DENSITY (VEH/LN-MILE) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 164.98 | $E_{50}$ |
| A | 164.49 | $E_{25}$ |
| A | 163.92 | F |
| B | 21.64 | $B_{50}$ |
| B | 21.64 | $D_{25}$ |
| B | 21.61 | $C_{25}$ |
| B | 21.60 | $D_{50}$ |
| B | 21.60 | $C_{50}$ |
| B | 21.60 | A |
| B | 21.59 | $B_{25}$ |

| VEH-MIN | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 4,949.25 | $E_{50}$ |
| A | 4,934.62 | $E_{25}$ |
| A | 4,917.73 | F |
| B | 649.34 | $B_{50}$ |
| B | 649.23 | $D_{25}$ |
| B | 648.23 | $C_{25}$ |
| B | 648.12 | $D_{50}$ |
| B | 648.11 | $C_{50}$ |
| B | 647.92 | A |
| B | 647.80 | $B_{25}$ |

| TOTAL TIME (VEH-MIN/VEH-MILE) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 12.04 | $E_{50}$ |
| A | 12.04 | $E_{25}$ |
| A | 11.94 | F |
| B | 0.96 | $B_{50}$ |
| B | 0.96 | $D_{25}$ |
| B | 0.96 | $C_{25}$ |
| B | 0.96 | $D_{50}$ |
| B | 0.95 | $C_{50}$ |
| B | 0.95 | $B_{25}$ |
| B | 0.95 | A |

| SPEED (MILE/HR) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 62.85 | A |
| A | 62.84 | $B_{25}$ |
| A | 62.83 | $C_{50}$ |
| A | 62.80 | $D_{50}$ |
| A | 62.80 | $C_{25}$ |
| A | 62.70 | $D_{25}$ |
| A | 62.70 | $B_{50}$ |
| B | 5.03 | F |
| B | 4.99 | $E_{50}$ |
| B | 4.99 | $E_{25}$ |

Note: Means with the same letter are not significantly different.

**Output Results of Entrance Link (53,51) Comparison**

Link (53, 51) was an entrance link on the normal flow direction with a length of 5,280 ft. and a 65 mph speed limit. The CORSIM output results showed that Type B, D, $E_{25}$ and F models had queued vehicles before this link; in contrast, Type A, C and $E_{50}$ models did not have queued vehicles before this link. Figure 106 shows the statistics and F-value of the link at TP16. Since all the F-values were larger than the $F_{critical}$ value of 1.912, the null hypothesis was rejected and stated that at least one of the operational MOEs means of the models was significantly different. Figure 106 shows the Tukey ranking for the link.

As shown in figure 106, all models had average volumes around 1,650 vphpl from TP1 to TP5. After TP6, the average volumes for Type B and F models started to drop and reached around 815 vphpl at TP16. Type $D_{25}$ and $E_{25}$ models started to drop from TP10 and reached around 1,095 vphpl at TP16. Type $D_{50}$ and $E_{50}$ started to drop in average volume after TP12 and reached around 1,625 vphpl. Type A and C models were around 1,656 vphpl constantly throughout 16 time periods. This showed that other than Type A and C models did have congested traffic, all models experienced different degrees of traffic congestion. Obviously, when the traffic congestion appeared on the link, the average volume started to drop.

Figure 107 and Figure 108 show the average speed and density throughout 4 hours of simulation. Type A and C models have constant speed at 63 mph with 27 vpmpl throughout 4 hours simulation. The average speed of Type $D_{50}$ and $E_{50}$ models appeared to drop after TP11 and reached 40 mph at 52 vpmpl at the end of TP16. These models were expected to increase in density and decrease in speed if the simulation time was extended. This was because the downstream traffic tended to create queued vehicles that affected the normal operation at the upstream exit-ramp location. The average speed for Type $D_{25}$ and $E_{25}$ models are around 8 mph at 140 vpmpl constantly after TP14. These models maintained higher average speed because there was 25 percent traffic exiting the available at the downstream exit-ramps. Type B and F models reached congested 164 vpmpl at 5 mph after TP8.

Figure 109

Average delay time on normal direction entrance link comparison - link (53, 51)

Figure 109 shows that the average delay times for Type B and F models were more than 667 sec/veh at the end of TP16. The delay time for Type $D_{25}$ and $E_{25}$ models increased after TP10 and reached 406 sec/veh at the end of TP16. The delay time for Type $D_{50}$ and $E_{50}$ models tended to increase after TP11, and it was expected to increase as the simulation time was extended. Figure 110 shows that the M/T ratios for congested models were less than 0.15. These results showed that the congested models wasted more than 85 percent of the total travel time on this link. As expected, exiting more vehicles at the available exit-ramps increased the average speed and decreased the travel time. Compared to link (18, 17), (34, 32), (35, 33) and (52,50), the highest congested density reached around 160 vpmpl at around 5mph in average speed.

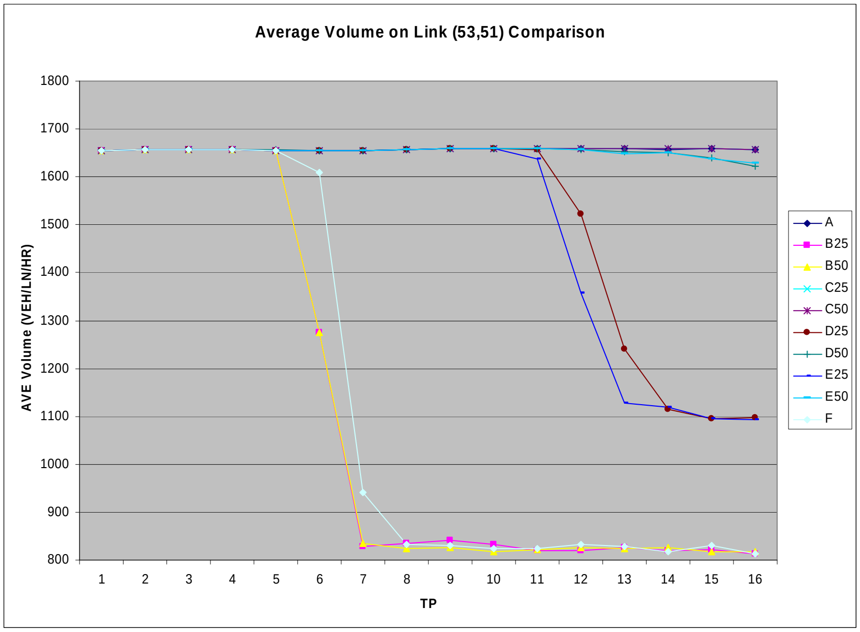


**Figure 106**
**Average volume on normal direction entrance link comparison - link (53, 51)**

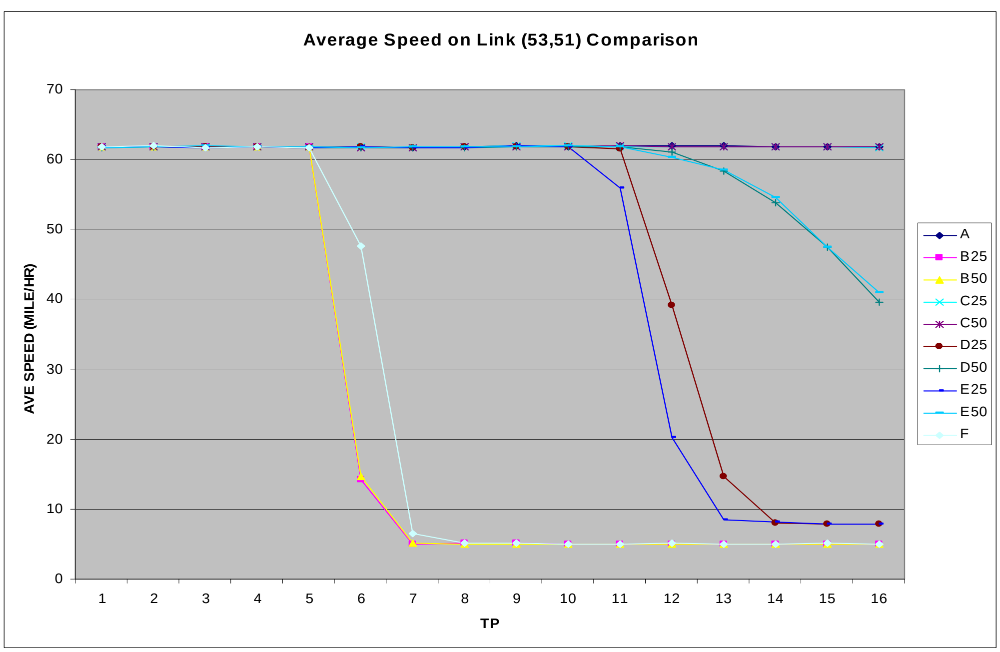

Figure 107
Average speed on normal direction entrance link comparison - link (53, 51)

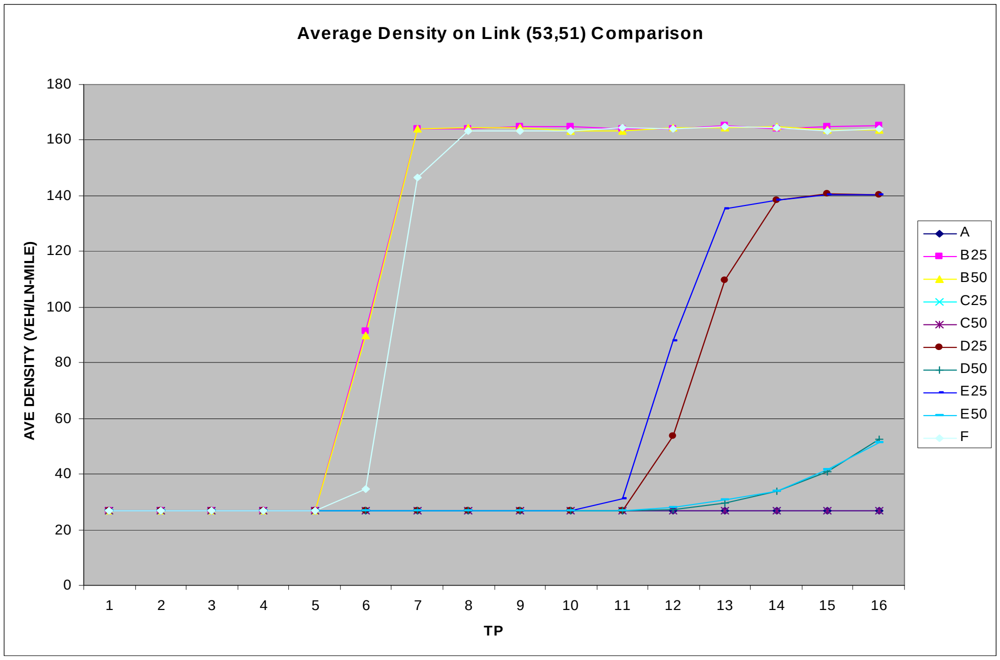


Figure 108
Average density on normal direction entrance link comparison - link (53, 51)

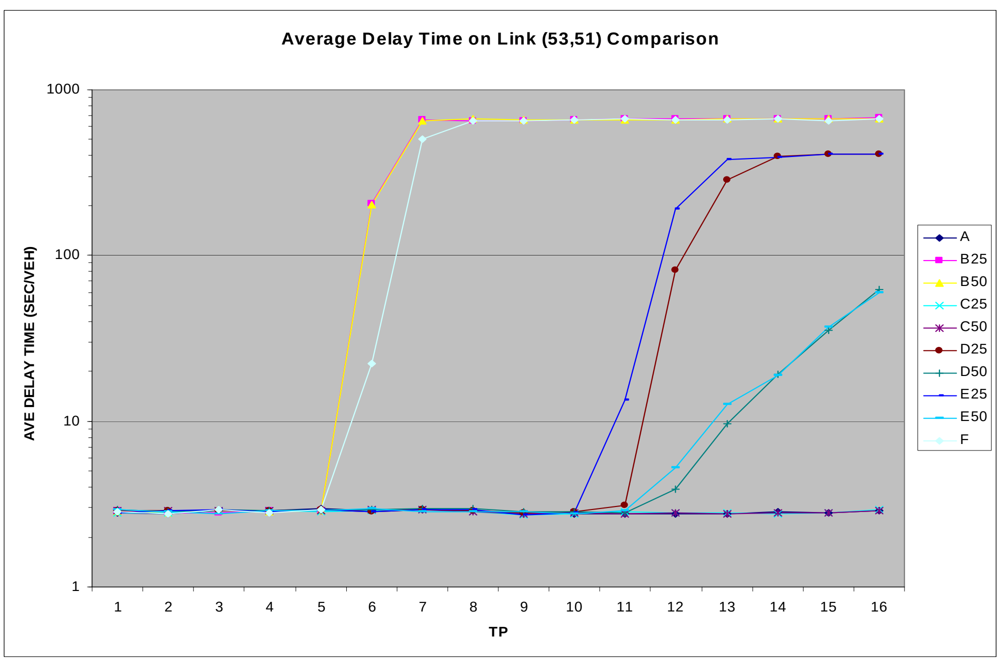

**Figure 109**
**Average delay time on normal direction entrance link comparison - link (53, 51)**

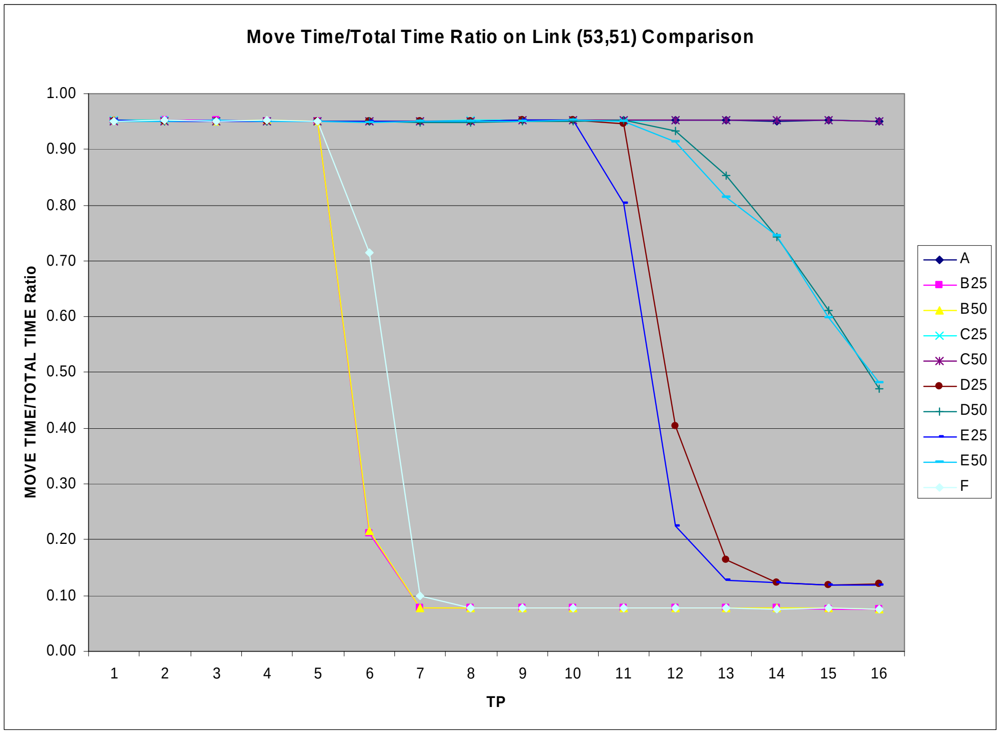


**Figure 110**
**Move time/total time ratio on normal direction entrance link comparison - link (53, 51)**

## Table 42
## Link (53,51) statistics at TP 16 for MIN, MAX, AVE, STDEV and F-value comparison

| TYPE | | VEHICLES IN | VEHICLES OUT | VEH-MILES | VEH-MIN | TOTAL TIME (SEC/VEH) | DELAY TIME (SEC/VEH) | M/T | TOTAL TIME (VEH-MIN/VEH-MILE) | DELAY TIME (VEH-MIN/VEH-MILE) | VOLUME (VEH/LN/HR) | DENSITY (VEH/LN-MILE) | SPEED (MILE/HR) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | MIN | 825.00 | 820.00 | 826.80 | 799.70 | 57.91 | 2.52 | 0.94 | 0.97 | 0.04 | 1,653.60 | 26.66 | 61.26 |
| | MAX | 825.00 | 830.00 | 829.80 | 810.80 | 58.77 | 3.38 | 0.96 | 0.98 | 0.06 | 1,659.60 | 27.03 | 62.17 |
| | MEAN | 825.00 | 825.83 | 828.01 | 804.28 | 58.28 | 2.90 | 0.95 | 0.97 | 0.05 | 1,656.01 | 26.81 | 61.77 |
| | STDEV | - | 2.53 | 0.77 | 2.67 | 0.20 | 0.20 | 0.00 | 0.00 | 0.00 | 1.53 | 0.09 | 0.22 |
| $B_{25}$ | MIN | 385.00 | 388.00 | 386.20 | 4,683.50 | 689.60 | 634.21 | 0.07 | 11.49 | 10.57 | 772.40 | 156.12 | 4.69 |
| | MAX | 433.00 | 430.00 | 429.80 | 5,153.90 | 766.80 | 711.41 | 0.08 | 12.78 | 11.86 | 859.60 | 171.80 | 5.22 |
| | MEAN | 410.10 | 407.60 | 406.98 | 4,955.80 | 731.06 | 675.67 | 0.08 | 12.18 | 11.26 | 813.95 | 165.19 | 4.93 |
| | STDEV | 13.54 | 11.19 | 11.06 | 109.65 | 22.76 | 22.76 | 0.00 | 0.38 | 0.38 | 22.11 | 3.66 | 0.15 |
| $B_{50}$ | MIN | 388.00 | 388.00 | 390.00 | 4,679.30 | 662.73 | 607.34 | 0.07 | 11.05 | 10.12 | 780.00 | 155.98 | 4.67 |
| | MAX | 438.00 | 428.00 | 431.40 | 5,172.80 | 771.13 | 715.75 | 0.08 | 12.85 | 11.93 | 862.80 | 172.43 | 5.43 |
| | MEAN | 410.60 | 409.03 | 408.56 | 4,915.32 | 722.40 | 667.01 | 0.08 | 12.04 | 11.12 | 817.13 | 163.84 | 4.99 |
| | STDEV | 12.30 | 10.56 | 11.87 | 111.37 | 25.55 | 25.55 | 0.00 | 0.43 | 0.43 | 23.75 | 3.71 | 0.18 |
| $C_{25}$ | MIN | 825.00 | 819.00 | 826.80 | 798.30 | 57.73 | 2.34 | 0.94 | 0.96 | 0.04 | 1,653.60 | 26.61 | 61.31 |
| | MAX | 825.00 | 829.00 | 829.70 | 810.30 | 58.72 | 3.33 | 0.96 | 0.98 | 0.06 | 1,659.40 | 27.01 | 62.36 |
| | MEAN | 825.00 | 824.67 | 827.99 | 804.55 | 58.30 | 2.92 | 0.95 | 0.97 | 0.05 | 1,655.97 | 26.82 | 61.75 |
| | STDEV | - | 2.45 | 0.67 | 3.12 | 0.24 | 0.24 | 0.00 | 0.00 | 0.00 | 1.34 | 0.10 | 0.26 |
| $C_{50}$ | MIN | 825.00 | 819.00 | 826.30 | 800.70 | 57.96 | 2.57 | 0.94 | 0.97 | 0.04 | 1,652.60 | 26.69 | 61.25 |
| | MAX | 825.00 | 831.00 | 829.40 | 809.50 | 58.78 | 3.40 | 0.96 | 0.98 | 0.06 | 1,658.80 | 26.98 | 62.11 |
| | MEAN | 825.00 | 824.90 | 828.12 | 804.17 | 58.27 | 2.88 | 0.95 | 0.97 | 0.05 | 1,656.23 | 26.81 | 61.79 |
| | STDEV | - | 2.59 | 0.80 | 2.52 | 0.19 | 0.19 | 0.00 | 0.00 | 0.00 | 1.60 | 0.08 | 0.20 |
| $D_{25}$ | MIN | 498.00 | 481.00 | 502.80 | 3,935.50 | 390.94 | 335.56 | 0.11 | 6.52 | 5.59 | 1,005.60 | 131.18 | 6.85 |
| | MAX | 602.00 | 603.00 | 604.00 | 4,460.20 | 525.87 | 470.49 | 0.14 | 8.76 | 7.84 | 1,208.00 | 148.67 | 9.21 |
| | MEAN | 550.20 | 546.90 | 548.49 | 4,208.65 | 461.46 | 406.08 | 0.12 | 7.69 | 6.77 | 1,096.97 | 140.29 | 7.83 |
| | STDEV | 22.98 | 25.08 | 21.94 | 120.40 | 29.12 | 29.12 | 0.01 | 0.49 | 0.49 | 43.88 | 4.01 | 0.51 |
| $D_{50}$ | MIN | 760.00 | 745.00 | 758.80 | 801.00 | 57.99 | 2.60 | 0.24 | 0.97 | 0.04 | 1,517.60 | 26.70 | 15.61 |
| | MAX | 825.00 | 858.00 | 848.40 | 2,981.80 | 230.61 | 175.23 | 0.96 | 3.84 | 2.92 | 1,696.80 | 99.39 | 62.08 |
| | MEAN | 818.67 | 799.90 | 811.51 | 1,569.93 | 117.60 | 62.21 | 0.61 | 1.96 | 1.04 | 1,623.01 | 52.33 | 39.61 |
| | STDEV | 15.13 | 29.77 | 23.16 | 788.31 | 62.41 | 62.41 | 0.29 | 1.04 | 1.04 | 46.32 | 26.28 | 18.56 |
| $E_{25}$ | MIN | 508.00 | 503.00 | 517.80 | 4,044.90 | 428.24 | 372.86 | 0.11 | 7.14 | 6.21 | 1,035.60 | 134.83 | 7.33 |
| | MAX | 609.00 | 593.00 | 576.50 | 4,367.60 | 491.06 | 435.68 | 0.13 | 8.18 | 7.26 | 1,153.00 | 145.59 | 8.41 |
| | MEAN | 548.10 | 545.80 | 546.79 | 4,213.11 | 462.72 | 407.33 | 0.12 | 7.71 | 6.79 | 1,093.57 | 140.44 | 7.79 |
| | STDEV | 21.97 | 20.90 | 14.74 | 89.63 | 18.11 | 18.11 | 0.00 | 0.30 | 0.30 | 29.47 | 2.99 | 0.31 |
| $E_{50}$ | MIN | 778.00 | 722.00 | 761.80 | 798.80 | 57.80 | 2.42 | 0.24 | 0.96 | 0.04 | 1,523.60 | 26.63 | 15.61 |
| | MAX | 825.00 | 830.00 | 829.40 | 3,025.10 | 230.57 | 175.19 | 0.96 | 3.84 | 2.92 | 1,658.80 | 100.84 | 62.28 |
| | MEAN | 820.80 | 802.17 | 814.25 | 1,543.49 | 114.89 | 59.50 | 0.63 | 1.91 | 0.99 | 1,628.50 | 51.45 | 40.99 |
| | STDEV | 11.85 | 26.20 | 17.74 | 795.24 | 61.48 | 61.48 | 0.30 | 1.02 | 1.02 | 35.48 | 26.51 | 19.58 |
| F | MIN | 391.00 | 378.00 | 384.90 | 4,763.00 | 672.32 | 616.93 | 0.07 | 11.21 | 10.28 | 769.80 | 158.77 | 4.69 |
| | MAX | 436.00 | 442.00 | 437.00 | 5,142.30 | 767.10 | 711.72 | 0.08 | 12.79 | 11.86 | 874.00 | 171.41 | 5.35 |
| | MEAN | 410.30 | 406.87 | 407.00 | 4,918.46 | 725.62 | 670.23 | 0.08 | 12.09 | 11.17 | 814.00 | 163.95 | 4.97 |
| | STDEV | 11.26 | 13.51 | 12.18 | 85.88 | 22.25 | 22.25 | 0.00 | 0.37 | 0.37 | 24.36 | 2.86 | 0.15 |
| F Value within models | | 6,187 | 3,617 | 5,859 | 830 | 2,582 | 2,582 | 279 | 2,582 | 2,582 | 5,859 | 830 | 279 |

**Table 43**
**Tukey's ranking for link (53, 51) statistics at TP 16**

Tukey's Studentized Range (HSD) Tests

| VEHICLES IN | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 825 | A |
| A | 825 | $C_{25}$ |
| A | 825 | $C_{60}$ |
| A | 821 | $E_{50}$ |
| A | 819 | $D_{50}$ |
| B | 550 | $D_{25}$ |
| B | 548 | $E_{25}$ |
| C | 411 | $B_{60}$ |
| C | 410 | F |
| C | 410 | $B_{25}$ |

| TOTAL TIME (SEC/VEH) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 731.06 | $B_{25}$ |
| A | 725.62 | F |
| A | 722.40 | $B_{60}$ |
| B | 462.72 | $E_{25}$ |
| B | 461.46 | $D_{25}$ |
| C | 117.60 | $D_{50}$ |
| C | 114.89 | $E_{50}$ |
| D | 58.30 | $C_{25}$ |
| D | 58.28 | A |
| D | 58.27 | $C_{60}$ |

| DELAY TIME (VEH-MIN/VEH-MILE) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 11.26 | $B_{25}$ |
| A | 11.17 | F |
| A | 11.12 | $B_{60}$ |
| B | 6.79 | $E_{25}$ |
| B | 6.77 | $D_{25}$ |
| C | 1.04 | $D_{50}$ |
| C | 0.99 | $E_{50}$ |
| D | 0.05 | $C_{25}$ |
| D | 0.05 | A |
| D | 0.05 | $C_{60}$ |

| VEHICLES OUT | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 826 | A |
| A | 825 | $C_{60}$ |
| A | 825 | $C_{25}$ |
| B | 802 | $E_{50}$ |
| B | 800 | $D_{50}$ |
| C | 547 | $D_{25}$ |
| C | 546 | $E_{25}$ |
| D | 409 | $B_{60}$ |
| D | 408 | $B_{25}$ |
| D | 407 | F |

| DELAY TIME (SEC/VEH) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 675.67 | $B_{25}$ |
| A | 670.23 | F |
| A | 667.01 | $B_{60}$ |
| B | 407.33 | $E_{25}$ |
| B | 406.08 | $D_{25}$ |
| C | 62.21 | $D_{50}$ |
| C | 59.50 | $E_{50}$ |
| D | 2.92 | $C_{25}$ |
| D | 2.90 | A |
| D | 2.88 | $C_{60}$ |

| VOLUME (VEH/LN/HR) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 1,656 | $C_{60}$ |
| A | 1,656 | A |
| A | 1,656 | $C_{25}$ |
| B | 1,629 | $E_{50}$ |
| B | 1,623 | $D_{50}$ |
| C | 1,097 | $D_{25}$ |
| C | 1,094 | $E_{25}$ |
| D | 817 | $B_{60}$ |
| D | 814 | F |
| D | 814 | $B_{25}$ |

| VEH-MILES | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 828.12 | $C_{60}$ |
| A | 828.01 | A |
| A | 827.99 | $C_{25}$ |
| B | 814.25 | $E_{50}$ |
| B | 811.51 | $D_{50}$ |
| C | 548.49 | $D_{25}$ |
| C | 546.79 | $E_{25}$ |
| D | 408.56 | $B_{60}$ |
| D | 407.00 | F |
| D | 406.98 | $B_{25}$ |

| M/T RATIO | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 0.95 | $C_{60}$ |
| A | 0.95 | A |
| A | 0.95 | $C_{25}$ |
| B | 0.63 | $E_{50}$ |
| B | 0.61 | $D_{50}$ |
| C | 0.12 | $D_{25}$ |
| C | 0.12 | $E_{25}$ |
| C | 0.08 | $B_{60}$ |
| C | 0.08 | F |
| C | 0.08 | $B_{25}$ |

| DENSITY (VEH/LN-MILE) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 165.19 | $B_{25}$ |
| A | 163.95 | F |
| A | 163.84 | $B_{60}$ |
| B | 140.44 | $E_{25}$ |
| B | 140.29 | $D_{25}$ |
| C | 52.33 | $D_{50}$ |
| C | 51.45 | $E_{50}$ |
| D | 26.82 | $C_{25}$ |
| D | 26.81 | A |
| D | 26.81 | $C_{60}$ |

| VEH-MIN | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 4,955.80 | $B_{25}$ |
| A | 4,918.46 | F |
| A | 4,915.32 | $B_{60}$ |
| B | 4,213.11 | $E_{25}$ |
| B | 4,208.65 | $D_{25}$ |
| C | 1,569.93 | $D_{50}$ |
| C | 1,543.49 | $E_{50}$ |
| D | 804.55 | $C_{25}$ |
| D | 804.28 | A |
| D | 804.17 | $C_{60}$ |

| TOTAL TIME (VEH-MIN/VEH-MILE) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 12.18 | $B_{25}$ |
| A | 12.09 | F |
| A | 12.04 | $B_{60}$ |
| B | 7.71 | $E_{25}$ |
| B | 7.69 | $D_{25}$ |
| C | 1.96 | $D_{50}$ |
| C | 1.91 | $E_{50}$ |
| D | 0.97 | $C_{25}$ |
| D | 0.97 | A |
| D | 0.97 | $C_{60}$ |

| SPEED (MILE/HR) | | |
|---|---|---|
| TUKEY RANKING | MEAN | TYPE |
| A | 61.79 | $C_{60}$ |
| A | 61.77 | A |
| A | 61.75 | $C_{25}$ |
| B | 40.99 | $E_{50}$ |
| B | 39.61 | $D_{50}$ |
| C | 7.83 | $D_{25}$ |
| C | 7.79 | $E_{25}$ |
| C | 4.99 | $B_{60}$ |
| C | 4.97 | F |
| C | 4.93 | $B_{25}$ |

Note: Means with the same letter are not significantly different.

### Speed-Density, Flow-Density and Speed-Flow Relationships

Relationships between flow, speed, and density obtained from the contraflow and normal flow routes are shown in
Figure 111. These data were obtained from eight links of the ten contraflow termination design models. These eight links, which were Link (28,26), (34,32), (29,27), (35,33), (46,44), (52,50), (47,45), and (53,51), were selected to show the relationship throughout 4 hours of simulation time. Measurements of data were averaged over each time-period (i.e., 15 minutes). The first four links were located prior to the one-lane closure area and at least one-half mile ahead of the available exit-ramps. The latter four links were located at least one mile ahead from the available exit-ramps.

The speed-density plot for the contraflow route shows a consistent data point pattern, except for the infrequent observations in the density ranged 40 vpmpl to 90 vpmpl. This variation appeared to result from two distinctly different operation modes. In one operation mode, the link was unaffected by the downstream links and free-flow conditions existed (i.e. the densities below 40 vpmpl); the other occurred when the downstream queued vehicles affected the link and congested conditions appeared (i.e. when the densities higher than 90 vpmpl). The free-flow speeds were around 60 mph, and the highest congested densities were around 160 vpmpl. The data point pattern exhibited a continuous decreasing slope with increased densities. The flow-density plot exhibited two distinctive groups of data. The first data points had higher flow around 1,350 vphpl at the free-flow portion, and the congested portion was relatively a flat slope and reached around 820 vphpl. The second data points were having lower flow slightly above 1,000 vphpl at the free-flow portion. Similarly, the congested portion was a flat slope to the right and reached the same 820 vphpl. The maximum flow appeared to be around 1,350 vphpl, and the optimum density was less than 40 vpmpl.

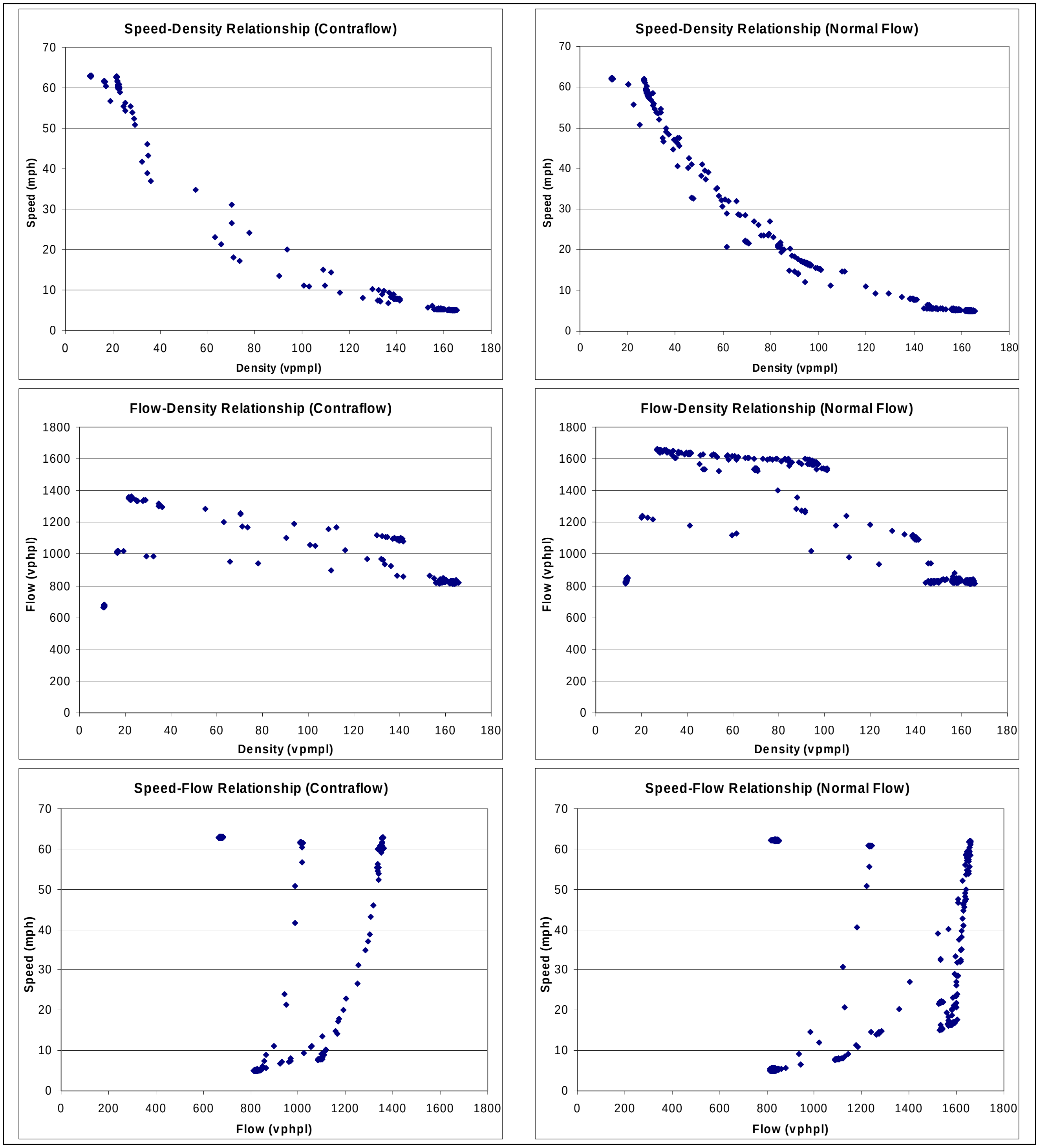


**Figure 111**
**Links data prior to lane-drop area**

As expected, the speed-flow plot shows two groups of data points. One group was the maximum flow with 1,350 vphpl and a continuous decrease in flow with speed decrease, and the other group was the uncongested group. It appeared that the optimum speed was above 30 mph to maintain a flow of above 1,300 vphpl and the most congested speeds were around 5 mph.

The speed-density plot for the normal flow route shows a consistent data point pattern with an exponential shape and a continuous decrease with increased densities. The free-flow speed appeared to be around 60 mph, and the maximum densities were around 160 vpmpl. The flow-density plot shows a continuous decreasing flat slope while densities increased ranged around 30 vpmpl to 100 vpmpl. On the congested portion, the flow reached around 820 vphpl at around 160 vpmpl. The maximum flow appeared to be about 1,650 vphpl and occurred at an optimum density of about 40 vpmpl. The speed-flow plot generally shows two different operation modes. The first was basically unaffected by the conditions, and the second was affected by the downstream queued vehicles. Obviously, the free-flow speeds were above 60 mph. The optimum speeds were above 30 mph to maintain a flow of 1,600 vphpl. As shown in the speed-flow plot, the congested speeds were around 5 mph at around 820 vphpl.

These results showed that the maximum congested densities were around 160 vpmpl at about 5 mph on both contraflow and normal flow routes (i.e., the congested flows on both routes were around 820 vphpl). One-lane closure operation created merging conflicts and queued vehicles backed into the upstream links. The speed-flow plots for the contraflow and normal flow show that the traffic flows tended to drop dramatically when the speeds were less than approximately 30 mph. On both routes, the critical density and critical speed were approximately 40 vpmpl and 30 mph, respectively. The traffic volume decreased whenever the density was higher than the critical density or lower than the critical speed. On the other hand, to maintain high traffic flow on the evacuation routes, the densities on the freeway should remain below 40 vpmpl and the average speeds should remain above 30 mph.

# CONCLUSIONS

The results of these studies revealed several interesting findings about the contraflow evacuation plans for the southeast United States. Among the most significant conclusion was that many of the current plans for evacuation initiation and termination points may likely restrict the ability of these segments to be used to their maximum effectiveness.

**Termination Points**

The evaluation of the proposed termination configurations provides strong evidence for two concepts. The first is that to work effectively, contraflow termination designs should incorporate split rather than merge designs. The research showed that congestion and delays are increased as much as ten-fold when four freeway lanes were merged in to two. While merges are possible under lower volume conditions, plans that spread traffic volume spatially throughout the available road infrastructure will likely be more successful. The second was the advantage that can be gained by systematically decreasing volume on contraflow evacuation routes. The research showed that volume decreases of 25 percent prior to the termination reduced the delay associated with the merge lane-drop by between 20 to 60 percent depending on the configuration type (this remains, however, a four to eight-fold increase over the split configuration delays). A 50 percent decrease in traffic volume reduced merge-associated delays by 80 percent (again, however, a two-fold increase over the delay versus the split design).

The focus of the termination point study was to assess the relative operational differences between each of the designs and the effect of varied volumes on them. Models A, $C_{50}$, and $D_{50}$ consistently out-performed the other models in nearly all performance measures, with $C_{50}$ the best performer in all categories except total time in the system. On average, the A, $C_{50}$, and $D_{50}$ models were able to maintain operating speeds at or above 32 mph and kept vehicles moving more than half the time. By contrast, models F, $E_{25}$, $E_{50}$, and $D_{25}$ each had average operating speeds below 10 mph and vehicle stoppages more than 70 percent of the time. These finding are not surprising and intuitively logical because the A, B, and C configurations minimize merging prior to the cross-over and, in the cases of $C_{50}$ and $D_{50}$, removed half of the traffic volume. Interestingly, however, the performance of models $B_{25}$ and $B_{50}$ were only marginally better than the D, E, and F group, even with a traffic decrease. This appeared to be due to the fact that merging maneuvers in the B configuration took place prior to the exit ramps, rather than after the exit ramps, as was the case in models C and D where densities were lower and merging opportunities greater. This pre-exit merge meant that traffic queued for some distance prior to the crossover.

The results of the “number of vehicles processed” measures were also consistent with the findings above. Again, the A, $C_{50}$, and $D_{50}$ models showed the best performance, with $C_{25}$

close behind. One of the more interesting results was that despite the fact that the A model maintained all lanes open, its average hourly flow rate of (1,441 vph) was just below the $C_{50}$ and $D_{50}$ models (1,463 vph and 1,462 vph, respectively). At the opposite end of the spectrum, the F model, with no exits and lane drop, merges on both the normal and contraflow lanes. It had average hourly flows of just more than half of these rates at 822 vph.

The gains that could be realized from decreasing the level of evacuating traffic volume arrives at the termination point. The results showed that when traffic volumes were decreased by 25 percent under the highest volume scenario, the travel delay associated with the lane-drop merge was reduced between 20 to 60 percent. The gains that were observed were also lane dependent, with average decreases of 115 minutes in the normal lanes and 67 minutes in the contraflow lanes. Although these delay reductions were significant, they nevertheless remain four to eight times higher than for similar volumes in the non-merge configurations. The delay effect of volume was even more pronounced at the 50 percent reduction level. When arriving volumes were cut in half, the delay associated with the lane-drop merge decreased by 80 percent. This is, however, still twice the of equivalent no-merge configurations. In practice, volume reduction could be accomplished in a number of ways. The most practical would be to allow vehicles to use exits along the intermediate segment of the evacuation route.

When the general relationship of traffic volume is plotted against its corresponding travel delay resulting from the lane drop merge, shown in Figure 112, it is evident that delays and travel times increase fairly rapidly once traffic volumes begin to exceed half of the maximum flow volumes. This would strongly suggest that the use of intermediate exits throughout the length of the segment to diminish traffic volumes at the termination of the contraflow evacuation segment would be advantageous.

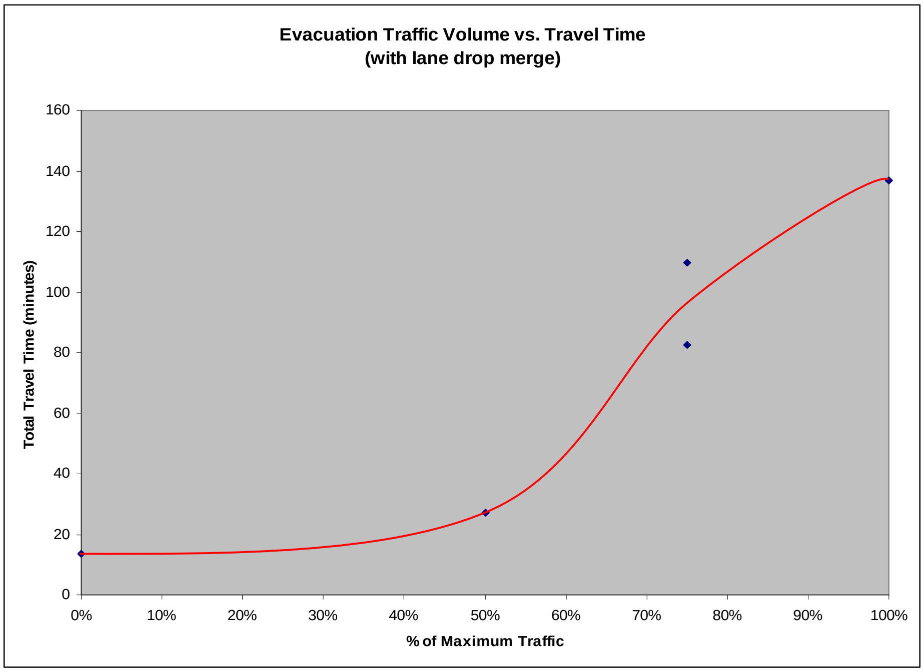


**Figure 112**
**Relationship of traffic volume and travel time on the test route**

**Initiation Point**

The evaluation of the New Orleans contraflow initiation point demonstrated several concepts relative to the loading on contraflow segments. The most important was the critical role played by the entry point in effectively utilizing the segment and reducing the duration of congestion prior to the contraflow lanes. Since the inception of contraflow evacuation, emphasis has been placed on the termination designs because it has been assumed that they would dictate the effectiveness of the segment. However, the research clearly demonstrated that the capacity of the segment can also be controlled to a great degree by the capacity of entry point. In fact, the research suggests that the New Orleans design, which is similar to the designs of many other states, will actually create a bottleneck that should lead to congested traffic conditions upstream of the cross-over. To more effectively utilize the segment it is suggested that traffic could be added at points after the cross over or, more desirably, loading schemes be reconfigured to spatially spread the loading of the segment over several ramps prior to a cross over.

As expected, the initiation point models clearly demonstrated the enormous benefits that can be gained from contraflow. More interesting, however, was the finding that single median cross over loading designs result in an underutilization of the contraflow segment.

In its current state, the LSP plan calls for the three outbound lanes of westbound I-10 to be divided into four lanes (two normal and two contraflow). This plan adds an additional 73 percent to the do-nothing (no-contraflow) outbound capacity. However, the simulations also showed that this configuration actually creates a bottleneck that reduces the ability of the roads to fill the segment to its capacity. This occurs because free flow speeds in the vicinity of the crossover are expected to drop by about 10 to 15 miles per hour, reducing the flow through the cross over area to about 1,000 vphpl and creating congested conditions that would extend for many miles upstream.

Simply put, this would result in a condition similar to those of the classic freeway lane drop scenario as diagrammed in Figure 113. In this scenario, traffic approaching the Loyola Avenue split would move through the crossover at flow rates at or near capacity, then at a near free-flow state throughout the remainder of the segment since there are no other downstream capacity limiting restrictions in the system. Thus, it would be expected that if no incidents occur, no congestion would be apparent within the remaining segment downstream of the initiation point.

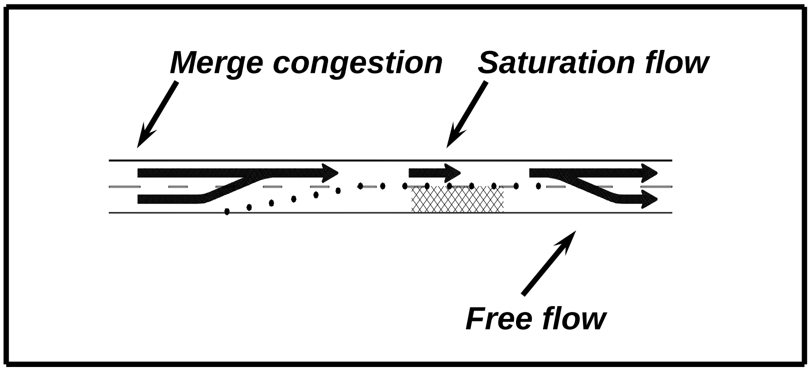


**Figure 113**
**Lane drop bottleneck diagram**

Plans C and D proposed to take advantage of the excess capacity that exists within the contraflow segment by adding traffic evacuating from the west bank of the Mississippi. As illustrated in Figure 114, the volume added from one or both I-310 ramps would increase the utilization of the contraflow segment adding volume that would permit it to operate nearer its capacity and, most importantly, significantly increase the total number of people that can evacuate the New Orleans region.

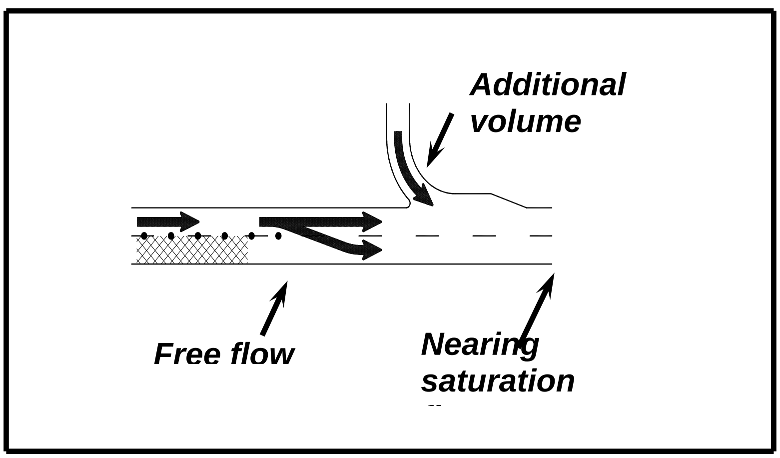


**Figure 114**
**Increased utilization of contraflow segment**

When compared to Plans A and B, the study clearly demonstrates that benefits could be realized using the C and D alternative loading scenarios. As Table 44's comparison of total exiting volume shows, the LSP contraflow plan increased the day-long evacuation volume through this segment by nearly 53 percent or a total of 30,538 vehicles over a non-contraflow use configuration. Similarly, the alternative scenarios of using I-310 to load additional vehicles into the segment would add another 10,000 to 26,000 vehicles over the current LSP plan and would nearly double the total exiting volume of a conventional (non-contraflow) configuration. These statistics become even more significant when it is recognized that the typical occupancy of vehicles during an evacuation has been estimated at about 3.5 passengers per vehicle.

**Table 44**
**Comparison of total exiting volume**

| | Plan A | Plan B | Plan C | Plan D |
|---|---|---|---|---|
| Exiting Volume (veh) | 57, 686 | 88,224 | 98,486 | 114,150 |
| Increase over Plan A (%) | -na- | 52.9 | 70.8 | 97.9 |
| Increase over Plan B (%) | -na- | -na- | 11.6 | 29.4 |

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