

**CONTRAFLOW EVACUATION ON THE WESTBOUND I-10 OUT OF THE CITY  
OF NEW ORLEANS**

A Thesis

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## **Abstract**

In this study, CORSIM 5.0 simulation model results were used to evaluate the effectiveness of the contraflow segment on westbound I-10 out of the City of New Orleans. The Louisiana State Police plan for the contraflow segment was used to construct the CORSIM network. Alternative plans were also developed in this study to compare the effectiveness of the contraflow operation.

With the use of CORSIM, traffic flow on the contraflow segment was determined based on the amount of evacuating vehicles leaving the exit nodes. In addition the time and speed to travel the contraflow segment was estimated.

The results showed that the use of contraflow lanes could increase the traffic flow significantly. In addition, from the comparison of the alternatives plans it was found that the plan that used multiple entry nodes in the segment had the largest traffic flow. This was because that plan used the available roadway more effectively.

# **Chapter 1 Introduction**

## **1.1 General**

In the Atlantic and Northeast Pacific basins, tropical storms with winds in excess of 74 miles per hour (mph) are called hurricanes. Hurricanes are rated in intensity by the Saffir-Simpson Hurricane scale from category one to category five. This scale rates hurricanes in terms of their wind speed, barometric pressure, storm surge height, and damage potential. Major hurricanes are those in categories of three, four, and five with winds stronger than 110 mph, with storm surges higher than nine feet, and the potential to cause extensive damage to buildings (FEMA, 2000). Due to these potential threats, major hurricanes can cause loss of life and can impact the economy of a region. In 1900, the island of Galveston, Texas was hit by a hurricane that resulted in the deaths of more than 6,000 people (NOAA, 1994).

Since there are no practical methods to lessen the destructive power of hurricanes, people may have to evacuate their homes to protect their lives. In the United States (US) there are 18 mainland coastal states that are particularly susceptible to hurricane impacts. One of these states is Louisiana, home of one of the most vulnerable cities from hurricanes, New Orleans. The topography of the city averages two feet below sea level. In addition to that, New Orleans has a population of 1.4 million, a limited number of freeways, surrounded by water, and a limited number of shelters (Wolshon, 2001). Thus it is possible that a major hurricane could flood vast portions of the city, resulting in massive loss of life.

To reduce the potential loss of life that hurricanes can bring to the City of New Orleans; officials plan to evacuate a significant percentage of the population under the threat

of hurricanes. The prediction of the landfall location with sufficient advance warning can be considered one of the important requirements for a rapid evacuation. However, even with the development and deployment of weather satellites, the advanced prediction of a hurricane landfall currently remains less than suitably accurate. Currently, for a 24-hour forecast before hurricane landfall, the predicted error of strike location is about 100 miles based on the National Hurricane Center (NHC, 1999). It has been estimated that New Orleans requires a minimum of a 72-hour advance notification for a full evacuation during a major hurricane (FEMA 2000).

An early evacuation order would be one way to address this problem by giving more time to evacuate. However, there is always the possibility that the hurricane could change course before its landfall, resulting in unnecessary evacuations and leading evacuees to potentially more dangerous locations.

Following a recent series of hurricanes in the late 1990's (George 1998, Floyd 1999), there has been a call from public officials for the use of contraflow operation during hurricane evacuation. Contraflow, or reverse laning, involves reversal of traffic flow of one or more inbound lanes for outbound traffic with the goal of increasing capacity. During Hurricane Floyd, Georgia officials attempted to lessen traffic congestion through the application of contraflow operation.

The use of contraflow operation is also planned for the evacuation of New Orleans. Since the City has a limited number of evacuation routes, officials plan to use both inbound lanes of Interstate 10 for moving outbound traffic both eastbound and westbound out of the city. Plans for the use of contraflow on eastbound I-10 are currently under development. The preliminary plans call for it to continue into the State of Mississippi. However, the

Mississippi Department of Transportation remains somewhat reluctant to continue the Louisiana contraflow operation into their state.

For the planned contraflow on westbound I-10, officials plan to split the traffic on the west side of Loyola Avenue in the City of Kenner, using a two-lane paved median crossover located prior to the I-10/I-310 interchange. The left and center lanes of westbound I-10 will be diverted to the inbound lanes of the interstate through the median crossover. The normal outbound lanes will be forced to exit to northbound I-55, some 20 miles after Kenner crossover. After the interchange, the contraflow traffic will cross back into the normal outbound lanes in the City of LaPlace (LSP, 2000). Although the length of the New Orleans contraflow segment is short compared to other locations, it is expected to be efficient because there are no traffic merge points at its termination. It is also unique because there are no entrance or exit ramps along its entire length. These elements are expected to facilitate a rapid evacuation by significantly increasing the capacity of westbound I-10 out of the City.

However, since hurricanes are not frequent events, especially ones at a level of category three or above, no actual data of the traffic flow on the contraflow segment have ever been collected during a full evacuation of the city. Thus, the costs and benefits of contraflow in terms of freeway capacity improvements, safety, and manpower within the City of New Orleans remain unknown.

One of the ways to evaluate the effectiveness of contraflow operations is with the use of computer simulation models. Simulation models are used extensively by transportation agencies for analyzing traffic operations. Although these simulation programs have been developed to analyze traffic scenarios in normal operation conditions, it has been

hypothesized that they can also be applied to model the traffic situation under hurricane evacuation. The use of these models for the evacuation of the City of New Orleans, in particular, may help evaluate the expected characteristics and benefits of contraflow operation, including the time needed to clear the evacuation route before the hurricane landfall (clearance time), and evaluating alternative evacuation plans.

## **1.2 Goal**

The goal of this study was to improve the understanding of a contraflow evacuation on limited access highway segments. To achieve this goal, a research study was conducted using a computer simulation model to assess various capacity, delay, and travel time parameters of the planned contraflow evacuation on westbound I-10 out of New Orleans.

The specific objectives of this research study included:

1. The estimate of the flow rate and average speed of traffic on the westbound I-10 contraflow segment out of New Orleans during an evacuation.
2. The estimate of the amount of time that would be required to discharge a stopped queue from this segment prior to the landfall of storm conditions.
3. The estimate of the density and delay time of this segment under evacuation conditions.

In this research, the flow rate was based on the total number of vehicles exiting the contraflow segment. One exit, where flow rate was determined, was on northbound I-55 and the other on I-10 after the I-10/I-55 interchange. In this study the delay time was based on the estimated total travel time and actual travel time during normal operations. Density was based on the number of vehicles per mile on the contraflow segment.

## **Chapter 2 Literature Review**

In order to achieve the objectives of this research a literature review was conducted. The literature included information on contraflow operations, computer simulation models, and input data that served as a guideline to accomplish the objectives and furthermore to reach the goal of this research study.

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 (FEMA, 1984), and some others cities for hurricane evacuation. 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 anticipated 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 are thought to be able to help evaluate the contraflow traffic flow.

For a good 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 initiate and terminate 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 the use of 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 that are 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 (PBS&J, 2001) based on the category of the hurricane. In addition, a human behavioral analysis was conducted by Baker (1991, 2000) for human response during hurricane evacuation. These data helped to take the appropriate assumptions into the model, like the percentage of trucks from the total volume.

## 2.1 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 week day. 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 Figure 2-1. Making more efficient use of the available roadway, contraflow reduced the congestion on the expressway saving up to ten minutes during drivers commute (SE Expressway I-93, 1994).



**Figure 2-1 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. The capacity of this joining of three freeways 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 Figure 2-2. The tidal flow system is controlled in the TCC by two people and can switch to and from contraflow operation within 15 minutes (VISUM-online, 2000).



**Figure 2-2 A tidal flow operation on the urban freeway including interchanges and it switched twice a day (VISUM-online, 2000).**

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

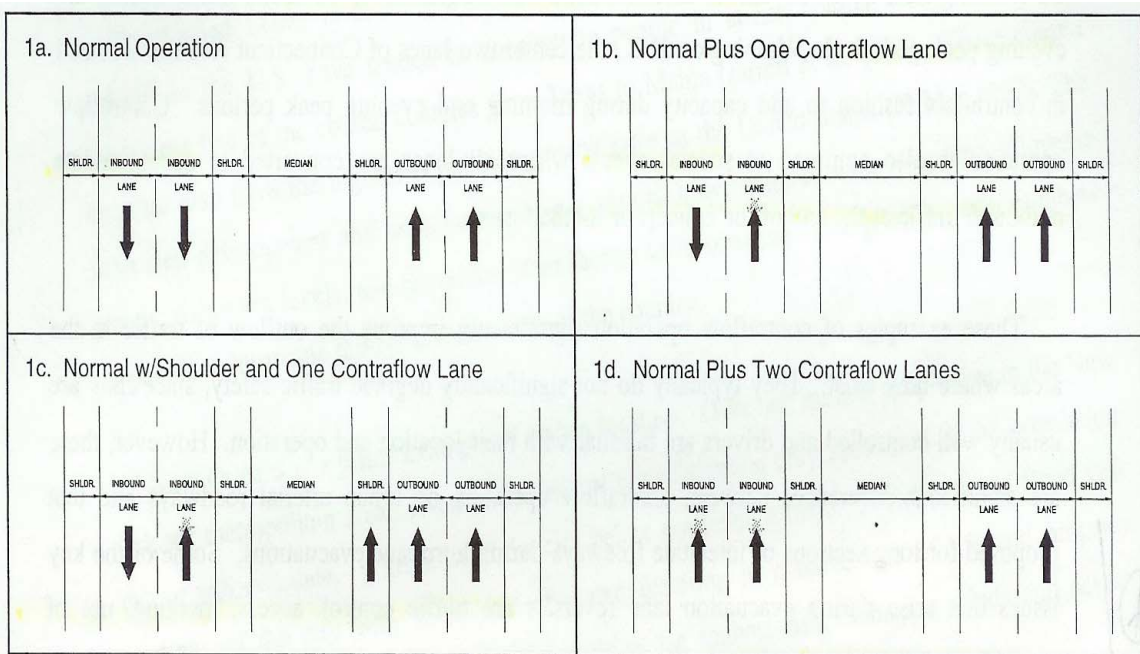
also used in Baton Rouge, Louisiana, after Louisiana State University (LSU) football games to help in the egress of greater than 90,000 people from the stadium.

However, there are significant differences between contraflow operation on urban arterial roadways and for 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, it is difficult to accurately predict how evacuees will react to a contraflow evacuation scenario; therefore it is still unknown how effective a contraflow evacuation operation will be.

Experiences in both Hurricane Floyd in 1999 and Hurricane George in 1998 (FEMA, 2000), 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 US history. Approximately three million people were evacuated from their homes (FEMA, 2000). Hurricane Floyd mainly threatened the eastern coastline of the US, 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 (Urbina E, 2001).

Currently, there are several forms of contraflow operations for hurricane evacuations. Figure 2-3 illustrates several contraflow operation configurations for four-lane freeway segments.



**Figure 2-3 Contraflow configurations of freeway lanes (Wolshon, 2001)**

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 Figure 2-3, 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 2-3, 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 in 1c of Figure 2-3, 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 because 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 2-3, 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 (FEMA, 2000).

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.

## **2.2 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, as well as 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 that are called macroscopic and microscopic.

### **2.2.1 Macroscopic**

Macroscopic models are based on the deterministic relationships between roadway and intersection characteristics with traffic flow. They consider the traffic flow as composed of platoons of vehicles. Macroscopic models can be easily applied to test operational strategies for hurricane evacuations in large segments of roads. 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 (ORNL, 1995). 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 (PBS&J, 2000a).

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 successfulness of macroscopic simulation models.

### **2.2.2 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 signs. 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 (Micro/Macro Simulation, 2000).

### 2.2.3 CORSIM

Prior studies based on Texas Department of Public Safety (TXDPS, 2000) 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).

CORSIM INPUT: There is 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.

CORSIM OUTPUT: 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.

## **2.3 Input Data**

Input data for a simulation model is just as important as the foundations for 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. The consulting firm PBS&J in 2001 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.

### **2.3.1 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 (LSP, 2000).

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"-:

1. 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. (Appendix-1)
2. Entrance ramp from LA 641 to I-10 East, Gramercy/Lutcher, will be closed and diverted to I-10 West or US 61. (Appendix-2)
3. Entrance ramp from LA 3188 to I-10 East, LaPlace, will be closed and diverted to I-10 West or back to US 61. (Appendix-3)
4. Entrance ramp from US 51 to I-10 East, LaPlace, will be closed and diverted to I-55 North or back to US 61. (Appendix-4)
5. Entrance ramp from US 51 to I-10 West, LaPlace, will be closed and diverted to I-55 North or back to US 61. (Appendix-4)
6. I-55 will be closed at Exit 1 LaPlace, and traffic will be diverted to US 51 South through the Exit 1. (Appendix-4)
7. 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. (Appendix-5)
8. 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. (Appendix-5)

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):

1. 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. (Appendix-6)
2. 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. (Appendix-4)
3. 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).

### **2.3.2 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” website provided by LSU ([www.atlas.lsu.edu](http://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 across the top by over four and a half miles on the side. 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.

### **2.3.3 Number of Evacuees**

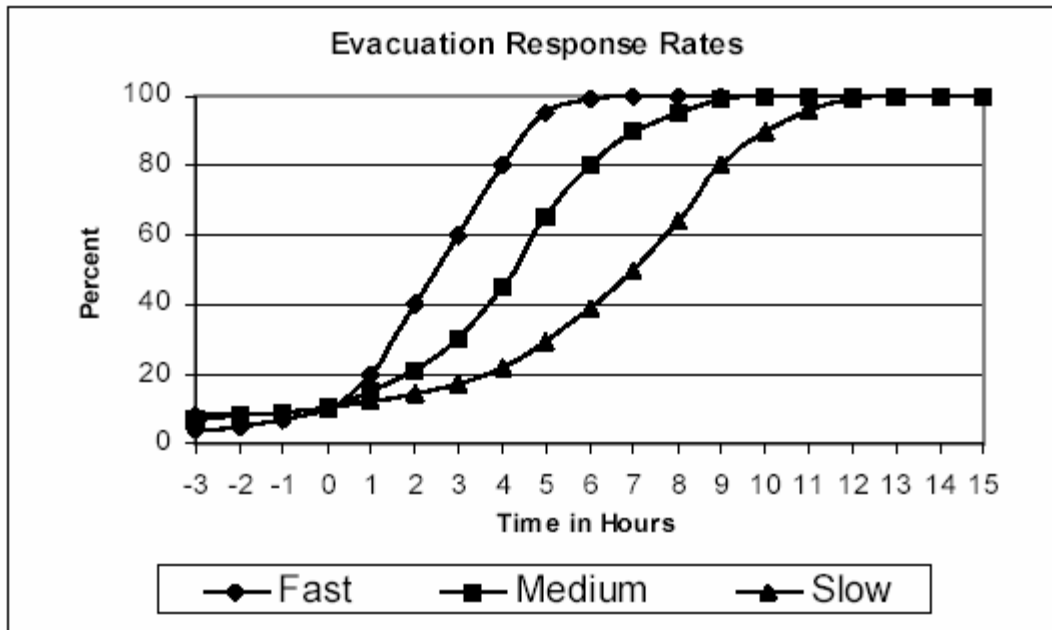
The New Orleans District of the US Army Corps of Engineers recognized the urgency of giving to the emergency management community some transportation guidance concerning the evacuation of the city. Therefore, they hired PBS&J to produce a transportation model tool that reflects previously developed evacuation 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 Table 2-1.

**Table 2-1 Amount of evacuation vehicles based on the category of the hurricane and the evacuation route from PBS&J survey.**

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	Cat 1/Fast	Cat 2	Slow Cat 2/Fast	Cat 3	Slow Cat 2/Fast	Cat 3	Fast Cat 3-4	Fast Cat 3-4	Slow Cat 3-4/Cat 5	Slow 3-4/Cat 5
		Evac Veh Low Occ	Evac Veh High Occ	Evac Veh Low Occ	Evac Veh High Occ	Evac Veh Low Occ	Evac Veh High Occ	Evac Veh Low Occ	Evac Veh High Occ	Evac Veh Low Occ	Evac Veh High Occ	Evac Veh Low Occ	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 Ponchartra	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				
Louisiana Highway 1	1,000	8,783	9,510	17,750	18,564	18,402	19,241	28,692	29,528				

### 2.3.4 Human Behavior

Hurricane evacuation behavior is an area that has interested researchers since at least the mid 1950s (Baker 1991). 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. US Army Corps of Engineers in 2000 proposed three different response curves, for slow, medium, and rapid responses respectively, based on behavioral analysis of past storms as shown in Figure 2-4. 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 2-4 Behavioral response curves (US Army Corps of Engineers, 2000)**

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 to that, 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 (TxDOT, 2000).

## 2.4 Summary

Despite the fact that contraflow operation has not yet been used for the evacuation of New Orleans, it is nonetheless viewed as an effective method to increase outbound flow during evacuations of the City.

To improve the understanding of contraflow evacuation on a highway segment, computer simulation models have been used in the past. Simulations cannot predict exactly how the contraflow flow will operate during an evacuation of the City of New Orleans, but they could be used to model traffic flow on contraflow segments. Since a contraflow segment typically covers a small area, it is appropriate to use microscopic simulations. Microscopic simulations have the ability to simulate the movement of individual vehicles through a research-based evacuation plan and allow operators to experiment with human factors under various environmental conditions. Based on human behavior, a reduction of speed must be implemented on the contraflow segment. As evacuees have a tendency to take a lot of their belongings, such as second cars, boats, etc, they may need longer evacuation time. Microscopic models enable operators to characterize these vehicles as trucks since they have similar driving behaviors. Since microscopic simulation models cannot account for the location, speed and direction of the least aggressive driver, multiple runs of the simulation with different seed numbers can offer a larger range of values regarding the traffic characteristics. In conclusion, this allows better evaluations for the effectiveness of the contraflow operation.

## **Chapter 3 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.

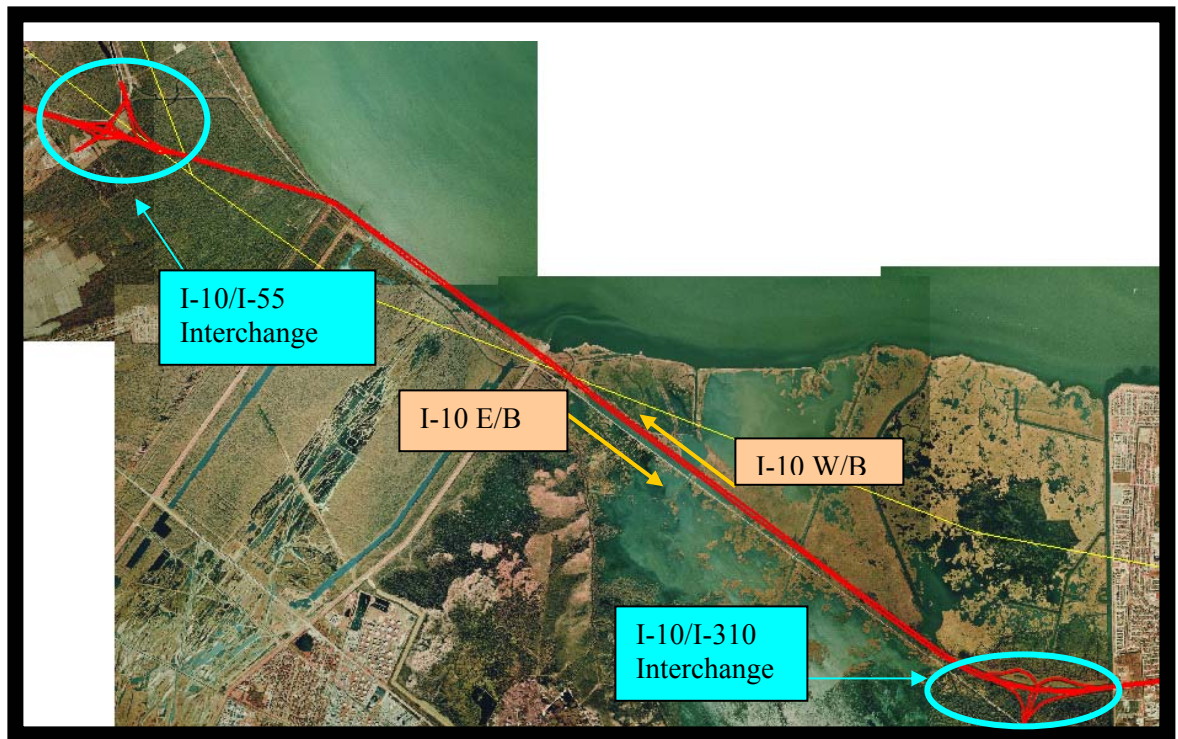
### **3.1 Network Construction**

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.

#### **3.1.1 Aerial Photos**

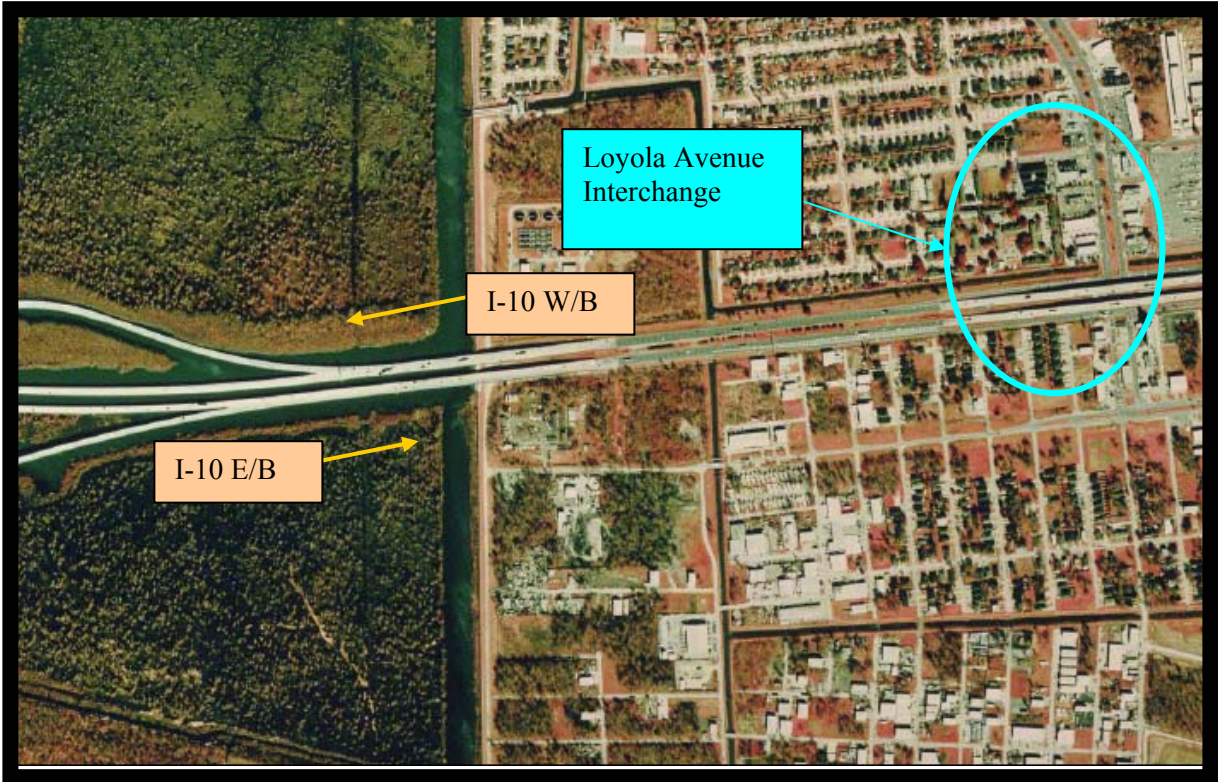
To construct the model, a number of aerial photos of the contraflow segment were obtained using the Geographic Information System (GIS) and inserted as bitmap images into TRAFED. These bitmap images were sufficient to be used as a guide for laying out the link

node diagram as shown in Figure 3-1. In this figure the red line represents the contraflow segment and the turquoise circles shows the I-10/I-55 and I-10/I-310 Interchange.



**Figure 3-1 Aerial photo of the contraflow segment**

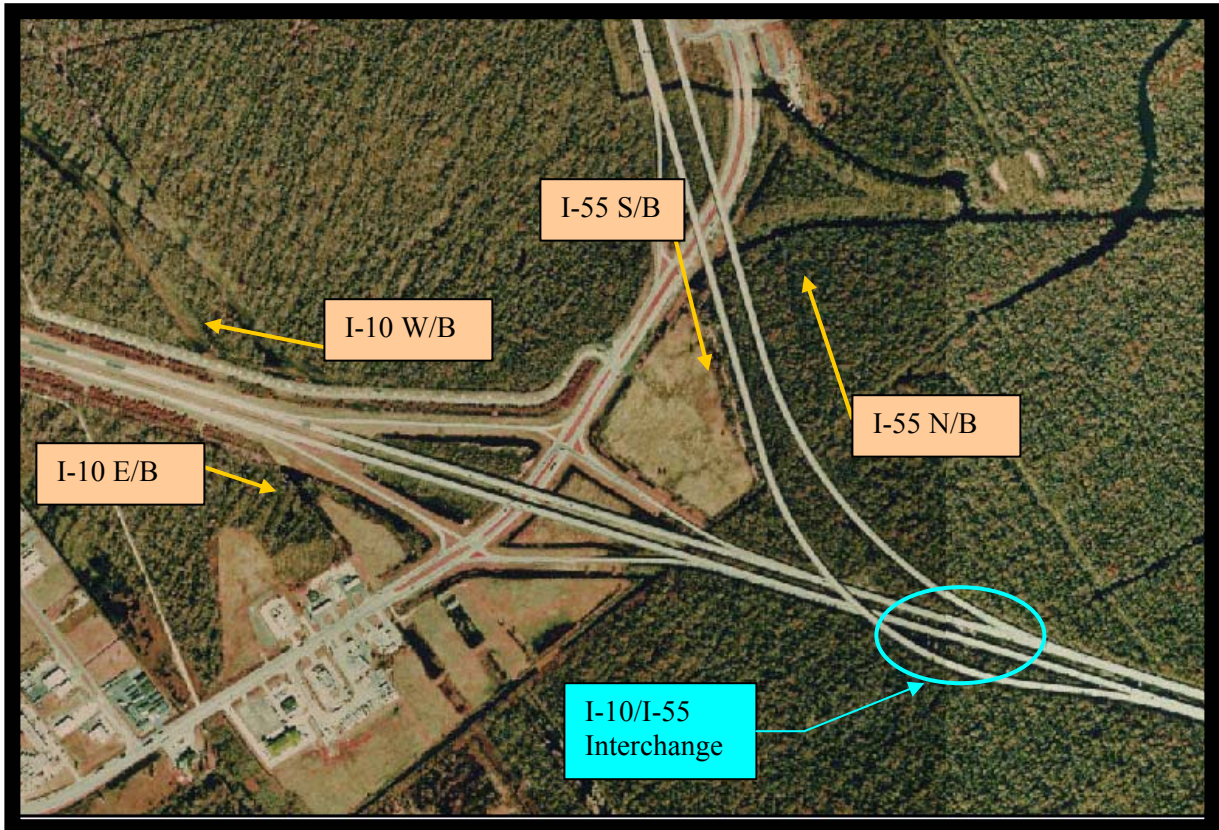
However, Figure 3-1 did not provide sufficient details for the Interchanges of the segment. To address this problem, three aerial photos of one meter resolution were used for the construction of the model. The first photo was of Loyola Avenue Interchange, east of the Kenner crossover as shown in Figure 3-2. The second was of the I-10/I-310 Interchange as shown in Figure 3-3, and the third was of the I-10/I-55 Interchange as shown in Figure 3-4.



**Figure 3-2 Loyola Entrance Ramp in westbound I-10**



**Figure 3-3 I-10/I-310 Interchange**



**Figure 3-4 I-10/I-55 Interchange**

### **3.1.2 Geometric Layout**

Although the aerial photos in Figures 3-1 to 3-4 had an accuracy of one meter, they were not sufficiently 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 Department of Transportation in Florida, Alabama, and Georgia.

### **3.1.3 Behavioral Input Information**

The “Southeast Louisiana Hurricane Evacuation Study”, prepared by the consulting firm Post, Buckley, Schuh, and Jernigan (PBS&J, 2001), was used to determine the amount of evacuation traffic from the City of New Orleans used in this study. The PBS&J data were developed based on varying categories of the hurricane and tourist occupancy. In this study, evacuation traffic volumes from category 5 hurricane were used as a worst-case scenario. These volumes, as well the volumes associated with other storm scenarios are shown in Table 2-1. In the PBS&J 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 2-4, 10 percent of evacuees would leave home before the order to evacuate. Therefore, an amount of 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 (2000) and Baker (1991 & 2000), 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.

### **3.2 Addressing the Limitations of CORSIM**

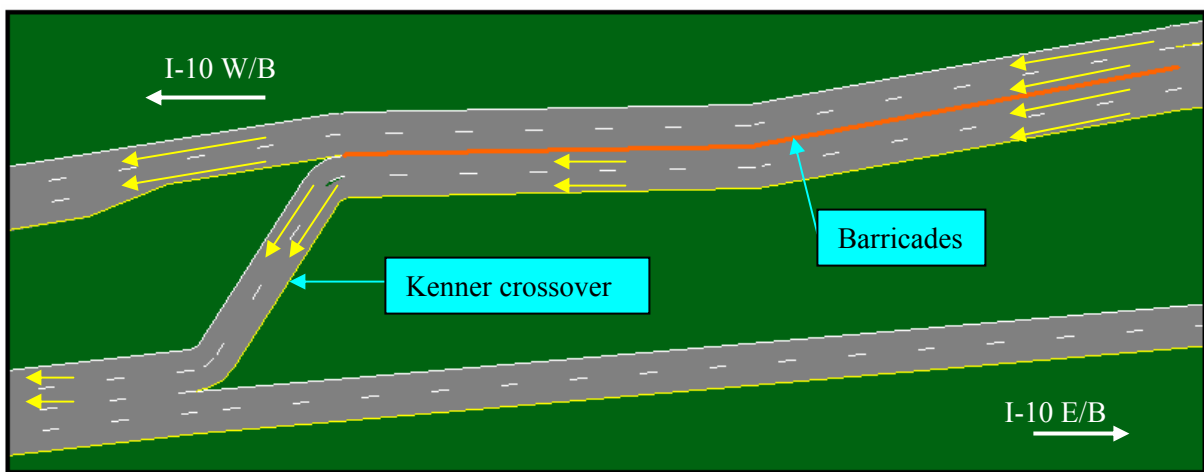
In this study efforts were made to reproduce contraflow operations in the simulation model. Some of the main limitations of CORSIM in modeling reverse lanes and coding the termination point are described in the following paragraphs.

#### **3.2.1 Reverse Lanes**

One primary limitation of CORSIM is that it was not possible to simulate flow 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” (Baker, E. 1991) and “Hurricane Evacuations in the United States” (Baker, E. 2000), establish that a driver’s tendency in these situation is to reduce their speed. Thus, in the CORSIM model the operational free flow speed was reduced from 65 to 55 mph for the reverse lanes.

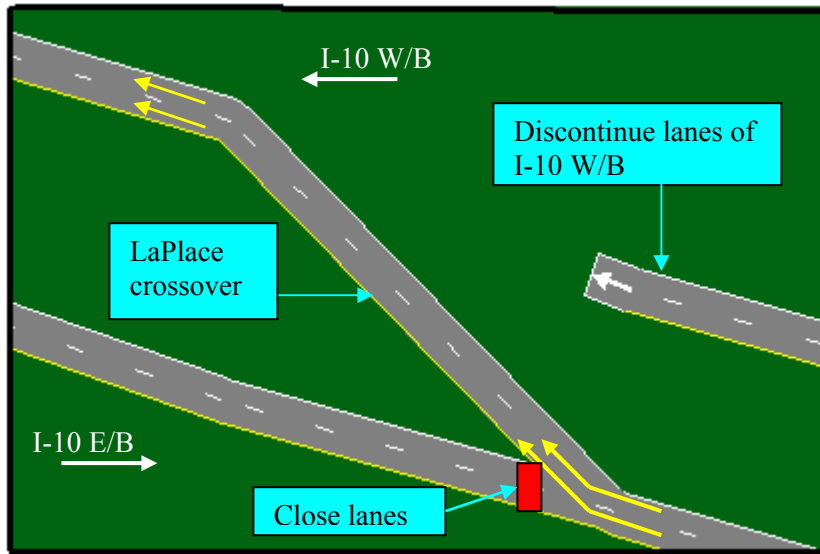
The LSP plan calls for police cars to be used, to force traffic in the left and center lanes of westbound I-10 continue on the contraflow lanes through the Kenner crossover as shown in Appendix 6. To code this in CORSIM barricades were used between the center and rightmost lane of westbound I-10, just east of Loyola Avenue to force vehicles in the

left and center lanes to divert through the crossover to the contraflow lanes as shown in Figure 3-5. 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 in 150 ft and 250 ft, respectively, after the Kenner crossover as shown in Figure 3-5 to form the four-lane freeway on westbound I-10 West based on LSP plan.



**Figure 3-5 Representation of the Kenner crossover in the CORSIM model**

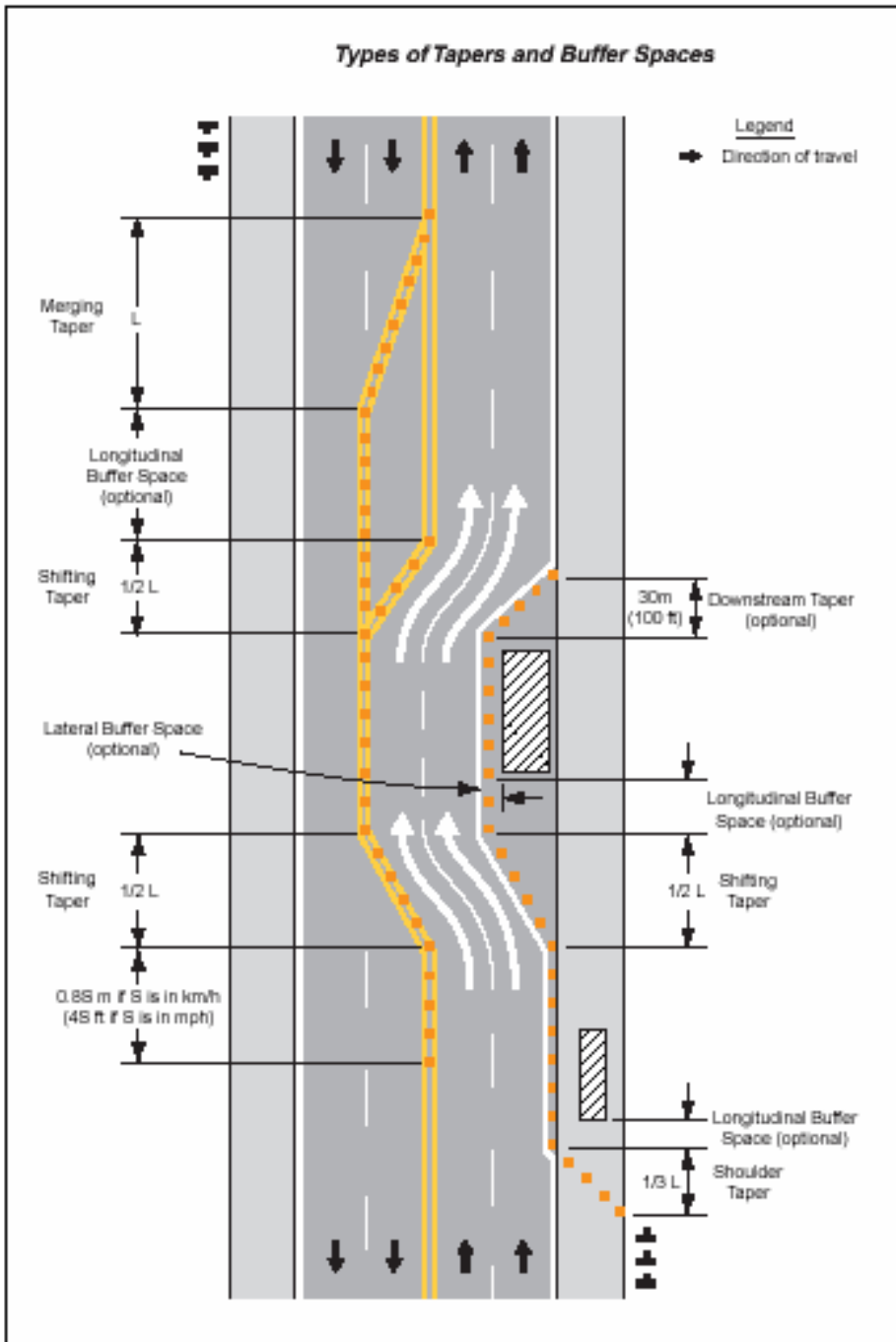
At the I-10/I-310 Interchange, the entrance ramp is planned to be blocked by the LSP to prevent “wrong way” exiting as shown in Appendix 7. To code this in the CORSIM, northbound I-310 was not joined with eastbound I-10. At the La Place crossover, just west of US 51, the westbound contraflow traffic 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 flow 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 3-6.



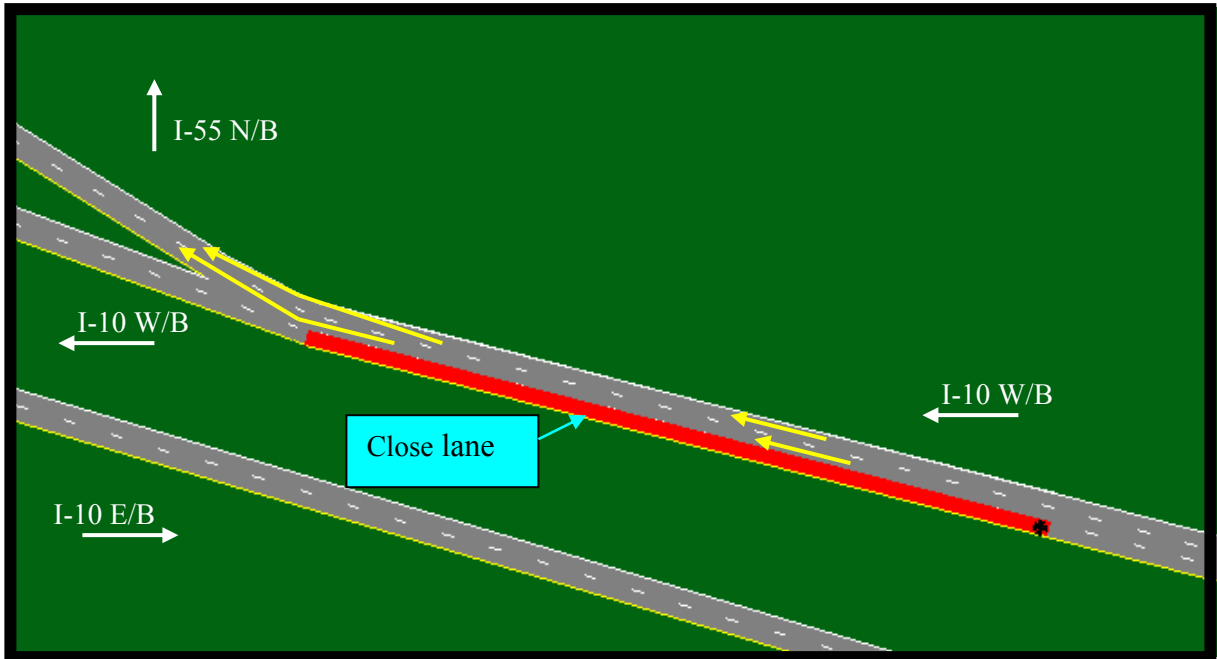
**Figure 3-6 Representation of LaPlace crossover in the CORSIM model**

### **3.2.2 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 as shown in Appendix 4. To build this in CORSIM 5.0 a condition analogous to a construction zone was assumed (MUTCD 2000). 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 3-7. 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 MUTCD-2000. Moreover, incidents were set on the closed lanes at LaPlace crossover as shown in Figure 3-6 and at I-10/I-55 Interchange as shown in Figure 3-8, to represent the closed lanes in the LSP plan.



**Figure 3-7 Transition area in a construction zone**



**Figure 3-8 Representation of the closed lane at I-10/I-55 Interchange by police in CORSIM**

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 3-8.

### 3.2.3 Capacity Limitations

In CORSIM the entry node for vehicles cannot exceed the capacity of the road. Based on the HCM, for 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.

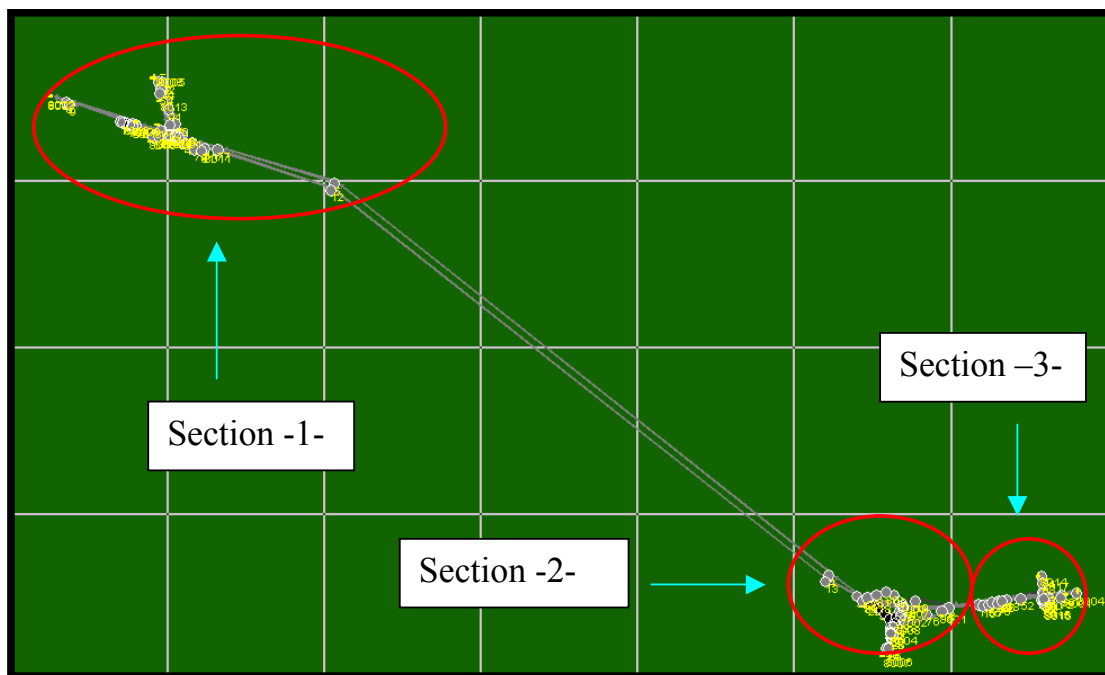
Using the fast response behavioral curve of Figure 2-4, it is assumed that 10 percent of the total evacuation volume would depart prior to an order being issued. This would result in a demand of nearly 12,000 vehicles prior to the start of the simulation period. Thus, 111,901 vehicles were generated 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 periods of one hour 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 due in part 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 two one-hour periods had zero volume to estimate the clearance time.

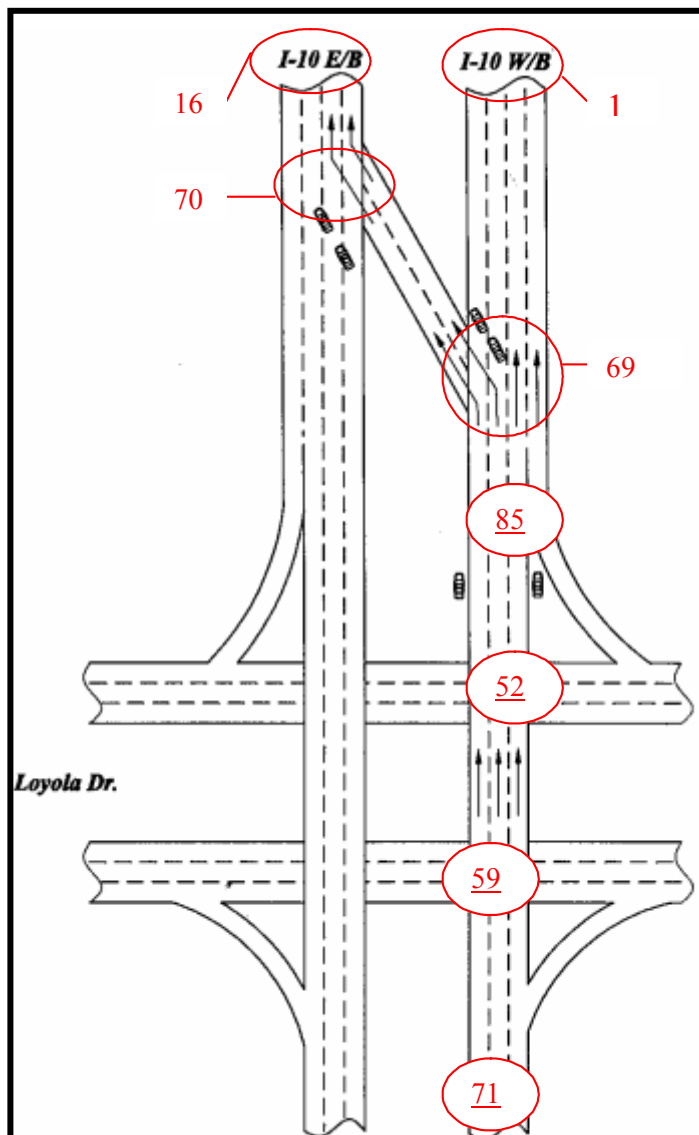
## Chapter 4 Analysis and Results

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 two hours to execute on a Pentium IV-1700 MHz PC; therefore approximately 60 hours of processing time were 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 4-1 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 4-1 Link node diagram of the contraflow segment**

Section one represents the initiation point of the segment as shown in Figure 4-2. Section two represents the link node diagram on I-10/I310 Interchange as shown in Figure 4-3, and finally, section three represents the termination point of the segment as shown in Figure 4-4. For Figures 4-2 to 4-4, plans from LSP were used. The numbers in the circles in figures 4-2 to 4-4 represent node numbers of the CORSIM network.



**Figure 4-2 Link node diagram in Section 1**

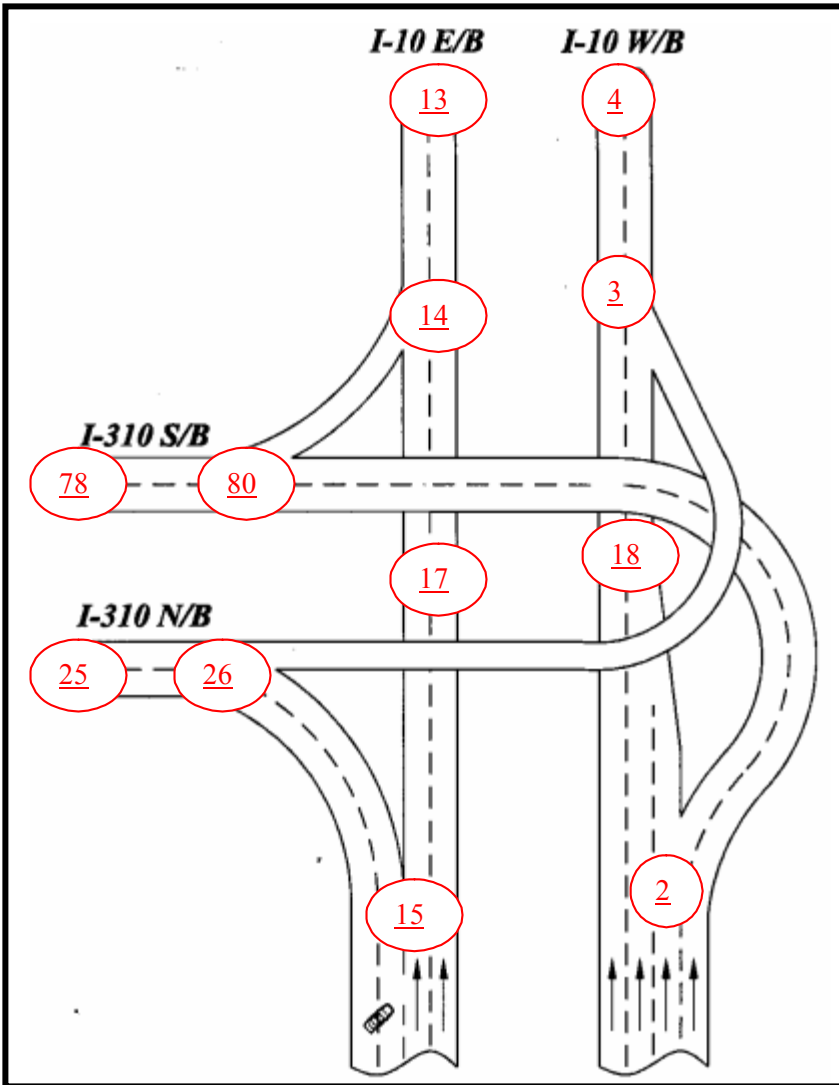


Figure 4-3 Link node diagram in Section 2

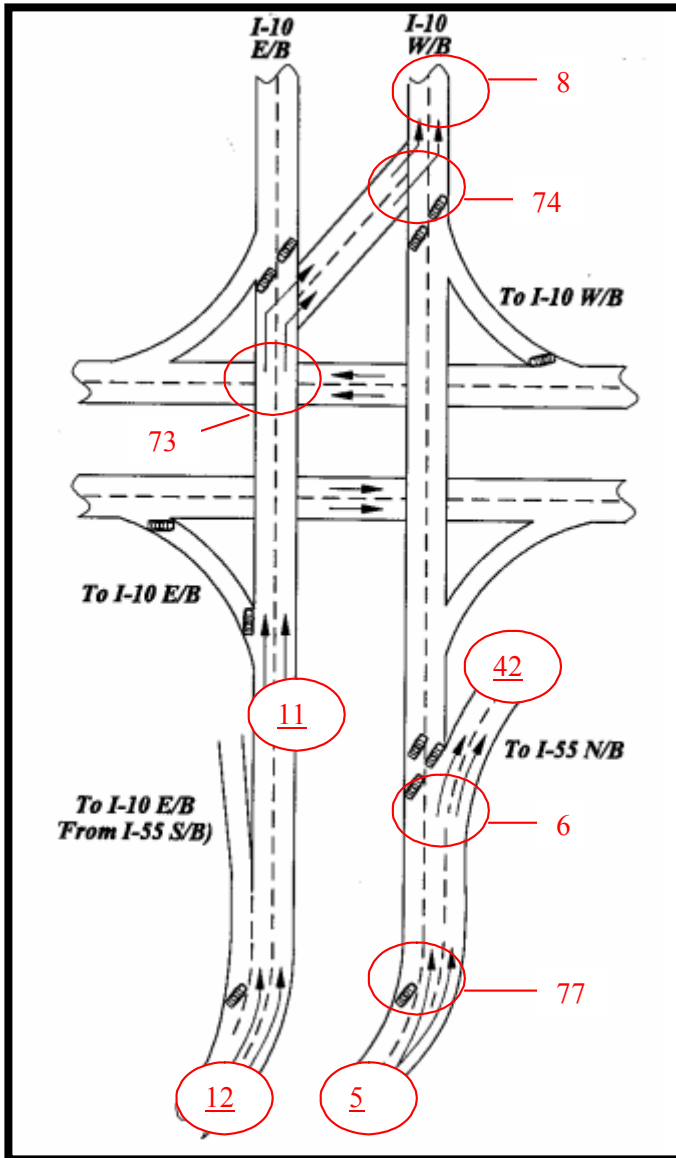


Figure 4-4 Link node diagram in Section 3

#### 4.1 CORSIM Output

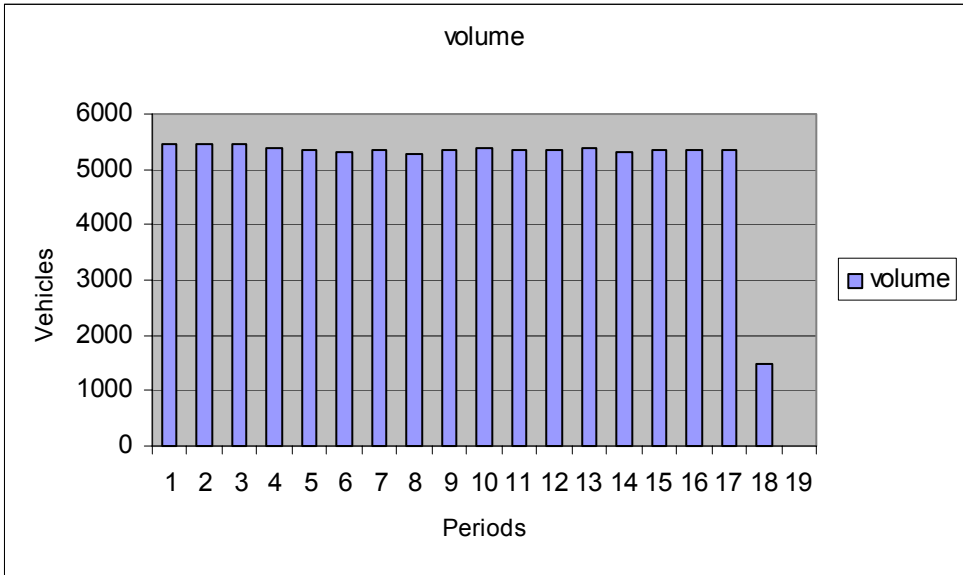
The CORSIM model produced a lot of unnecessary data for this study. Data such as vehicles emission and fuel consumption made it hard to estimate the objectives of this study. To address this problem, with the use of a macro-function in excel, only the data based on volume and speed were imported into 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 one hour, the calculated speed was multiplied by 60 to have the speed in miles per hour.

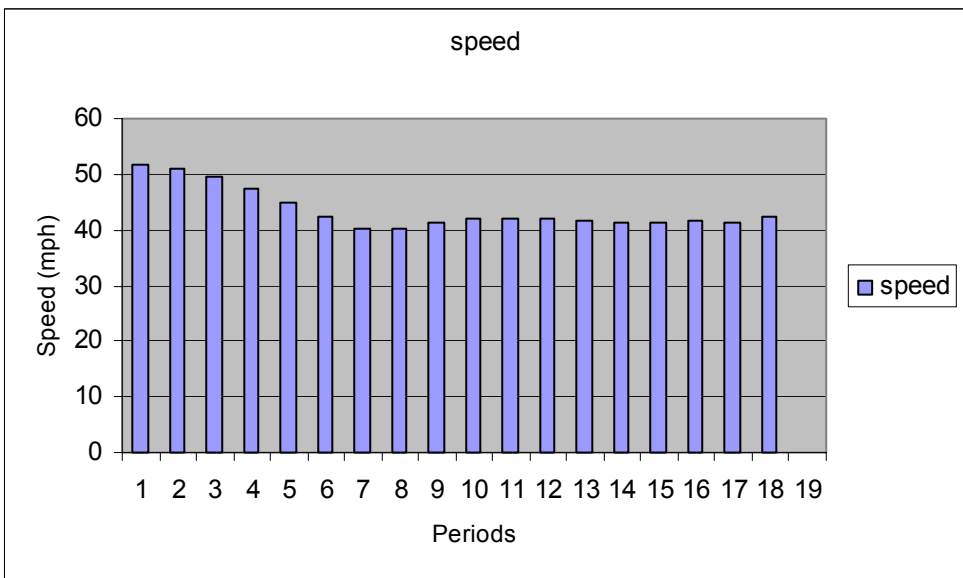
Volume (10:00am) = Number of vehicles at 10am - Number of vehicles at 9:00 am (Equation 1)

Speed (10:00am) =  $\frac{(Vehicles - miles \_ at10am) - (Vehicles - miles \_ at9am)}{(Vehicles - min \_ at10am) - (Vehicles - min \_ at9am)} \times 60$  (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 Figure 4-5, and Figure 4-6.



**Figure 4-5 Average volume in vehicles per hour for each period**



**Figure 4-6 Average speed in miles per hour for each period**

Based on the volume-graph shown in Figure 4-5, the volume in the network was approximately the same for periods one 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 next morning. The rest 1,468 vehicles got in the network during period 18.

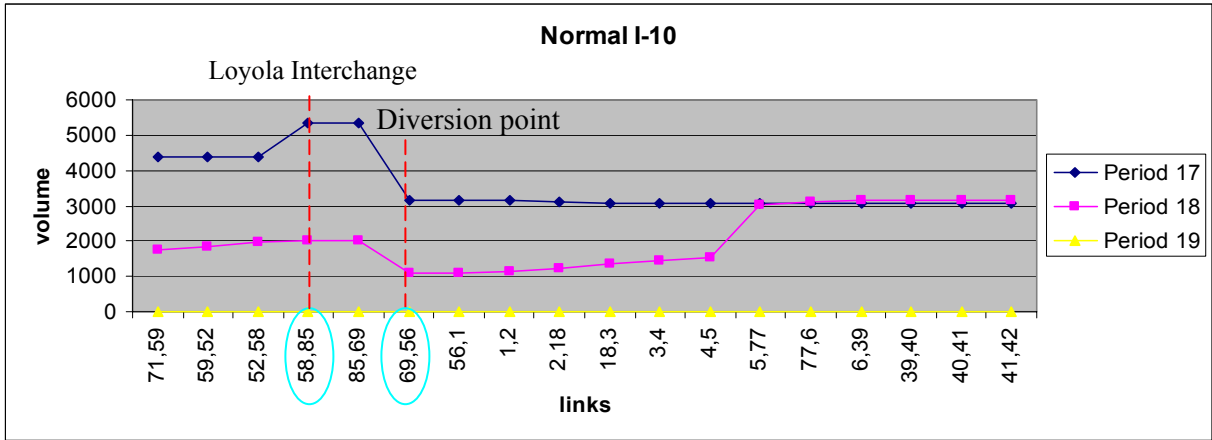
The speed-graph in Figure 4-6 shows a decrease of average speed in the network until period six. This probably has to do with the adjustment of speed based on the traffic flow and capacity of the road. For example, if during the first period, 10 vehicles did not exit the network from an amount of vehicles 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 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.

## 4.2 Volume

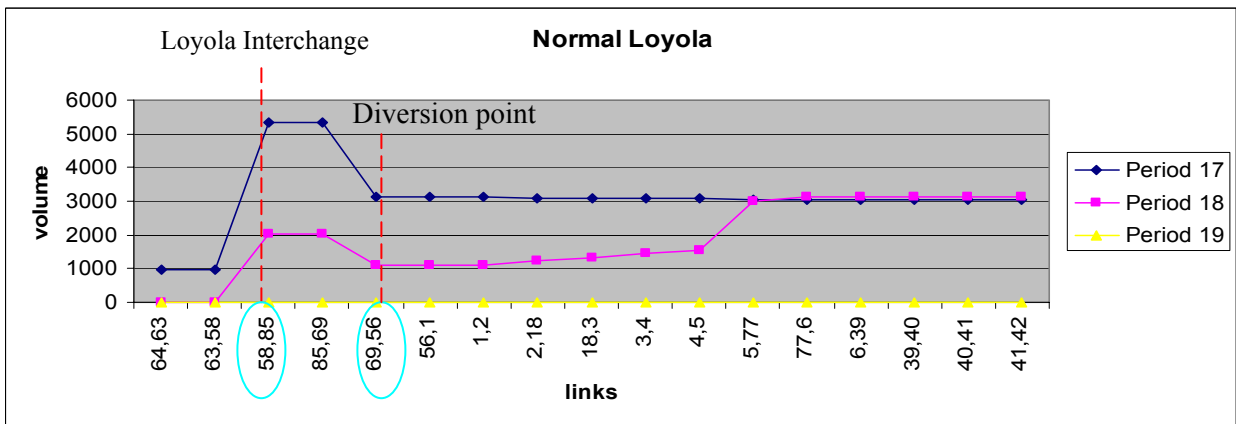
The volume-graph in Figure 4-5 showed that the volumes through period 17 were constant. Therefore, only the last three periods (17, 18, and 19) were used for analysis. Given that the model was simulated 30 times, 30 values of volume were analyzed for the last three periods. The average, minimum, maximum and 95 percent confident interval of the volume was estimated for each link in the network using Equation 1.

Figure 4-7 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 an amount of evacuees used the reverse lanes through the crossover. After the diversion point the volume in the normal lanes of I-10 was constant. Figure 4-5 illustrates that the average volume of the network during period 18 was much less than period 17, and due to this reason, the number of vehicles per link during period 18 as shown in Figure 4-7 were 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 link during period 18. The volume during period 19 was zero because there were no vehicles getting in the network.



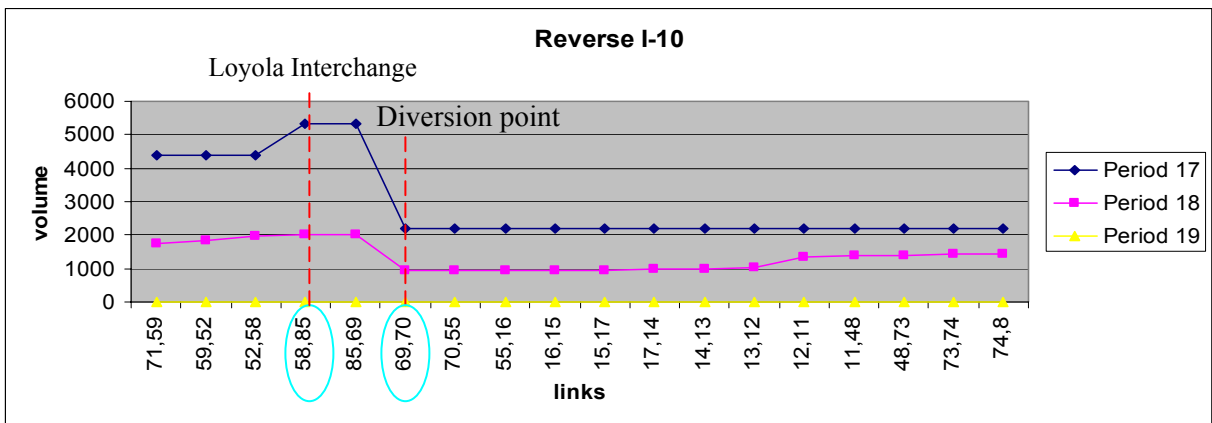
**Figure 4-7** Number of vehicles per hour using the normal I-10 to evacuate

Figure 4-8 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 4-7.



**Figure 4-8** Number of vehicles per hour starting from Loyola Avenue and continuing in the normal I-10

Last, the amount of vehicles in each link for the third route (Reverse I-10) is shown in Figure 4-9. 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 4-9 Number of vehicles per hour using the reverse lanes on I-10 to evacuate**

Since period 17 had the largest amount of vehicles among the last three periods, it was chosen to develop Table 4-1. 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 where 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 a 40 percent used the reverse lanes. This volume was the sum of traffic coming from Loyola Avenue and a 50 percent coming from the right most lane of westbound I-10.

**Table 4-1 Volume data based on entry, crossover and termination links at Period 17**

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

The percentage number of vehicles that used the normal and the reverse lanes shown in Table 4-1 was about the same as the theoretical assumptions that 60 percent of the traffic demand entering the contraflow segment would continue in the normal flow lanes since it has been hypothesized that evacuees would tend to stay on the normal travel lanes (TxDOT, 2000).

From cumulative volume data Table 4-2 was developed. This table shows how many vehicles entered and exited the network from period one through period 17. For example, based on the average data an approximately of 90,884 vehicles entered in the network and 88,224 vehicles exited. That means that for an amount of 88,224 evacuation vehicles, approximately 17 hours were needed to evacuate them from the contraflow segment.

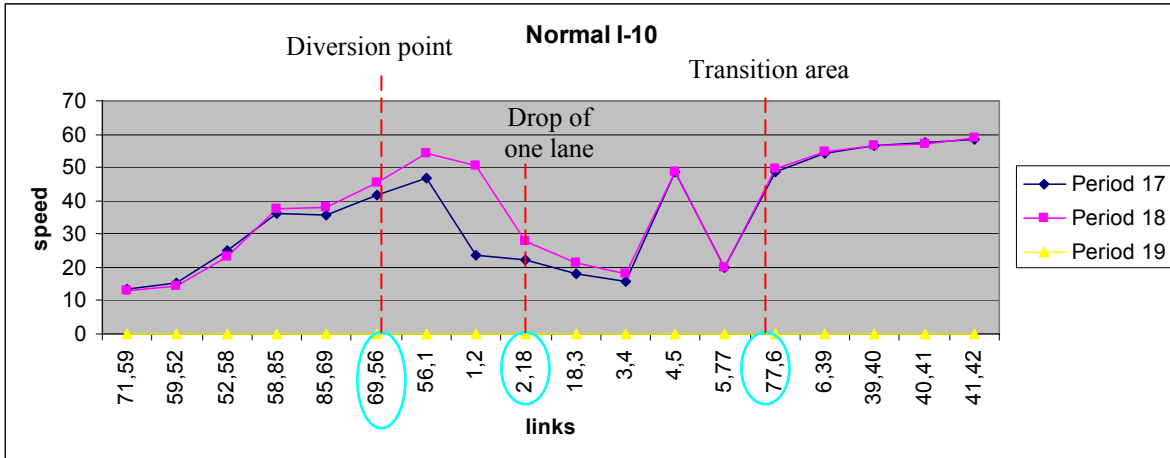
**Table 4-2 Cumulative volume data, based on entry and exit links until Period 17**

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

### 4.3 Speed

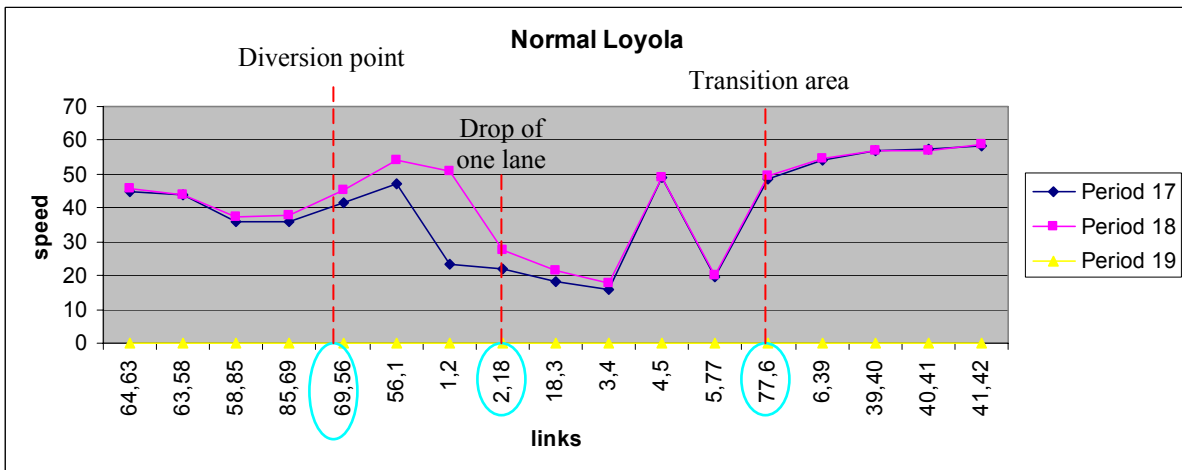
Data from time periods 17, 18, and 19 were also used to estimate the speed for each link. The average, minimum, maximum and 95 percent confident intervals of the speed were estimated for each link on the network from the 30-run simulation for these periods. Equation 2 was used to estimate the speed for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

From the link data, the speed in each route for period, 17, 18, and 19 were estimated. Figure 4-10 shows the average speed in each link for the first route (Normal I-10) during the last three periods. Since in the initial links of the segment the barricades and the Kenner median crossover reduced the capacity of that road 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 with period 17, and for period 19 the speed was zero since there were no vehicles.



**Figure 4-10 Average speed on each link in miles per hour using the normal I-10**

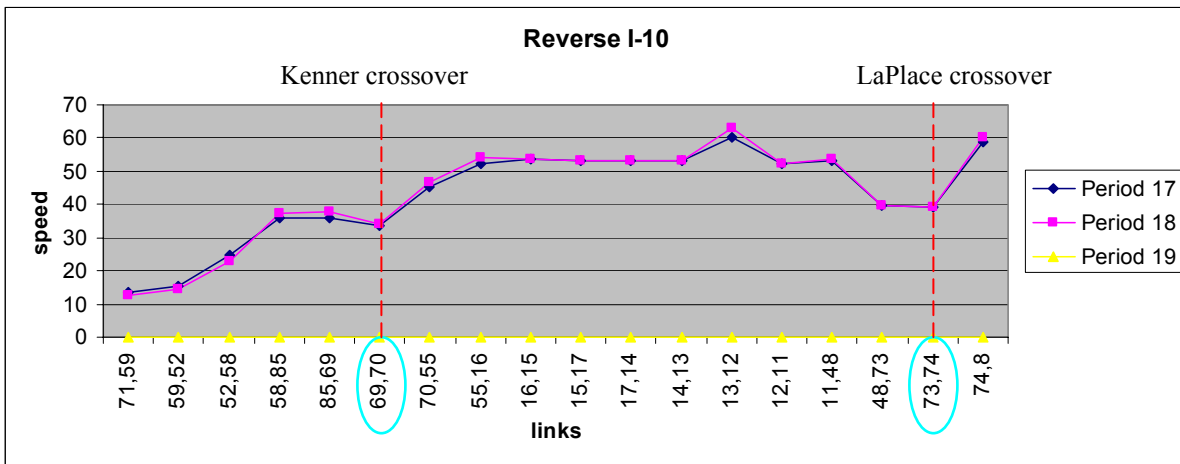
Figure 4-11 shows the speed in each link from the second route (Normal Loyola) during the last three periods. After link (63, 58), since vehicles merged into I-10, the speed characteristics were the same as in the normal lanes shown in Figure 4-10.



**Figure 4-11 Average speed on each link in miles per hour starting from Loyola Avenue and continuing in the normal I-10**

Last, the speed in each link for the third route (Reverse I-10) is shown in Figure 4-12. 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 there was an increase of speed until it reach the 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 up to free-flow speed.



**Figure 4-12 Average speed on each link in miles per hour using the reverse lanes**

From the graph in Figure 4-12 it can be concluded that the traffic in the reverse lanes operates with higher speed than in the normal lanes. Probably this has to do with the volume since fewer vehicles used the reverse lanes (around 40 percent of the total amount).

Table 4-3 was conducted to illustrate the travel time and mean speed on the three routes based on average speed and length of each link during the last three periods. Using the length of a link, divided by the speed of that link, the time to travel for that link was estimated. 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 that would be required to discharge this segment before a hurricane landfall.

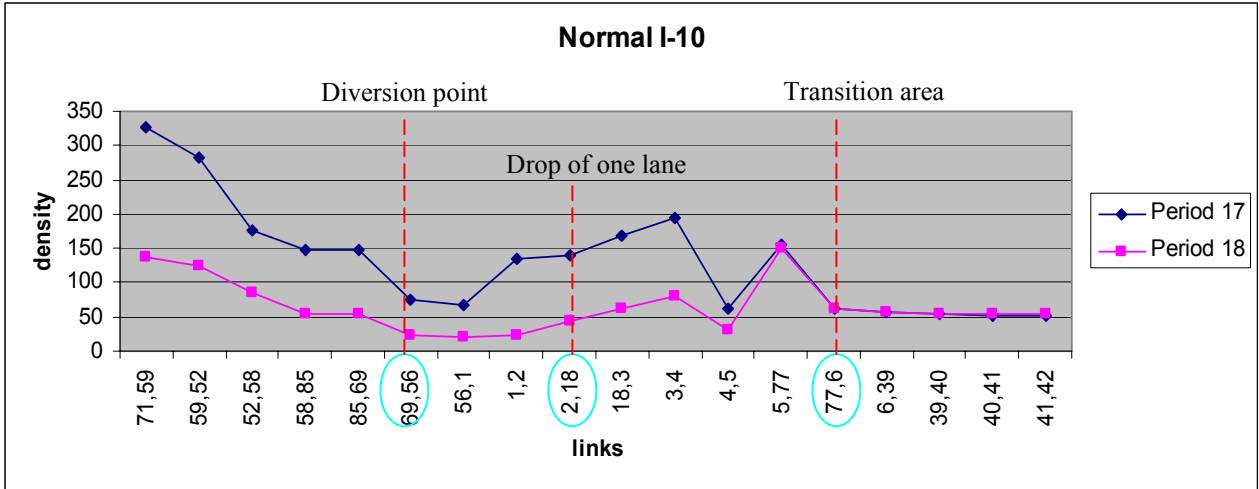
In this research study, it was found that an amount of about 25 minutes would be required to clear this segment based on the first route (Normal I-10).

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 4-3. The route that uses the normal I-10 through 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 4-3 Travel time and Mean speed on the three routes for the three last periods**

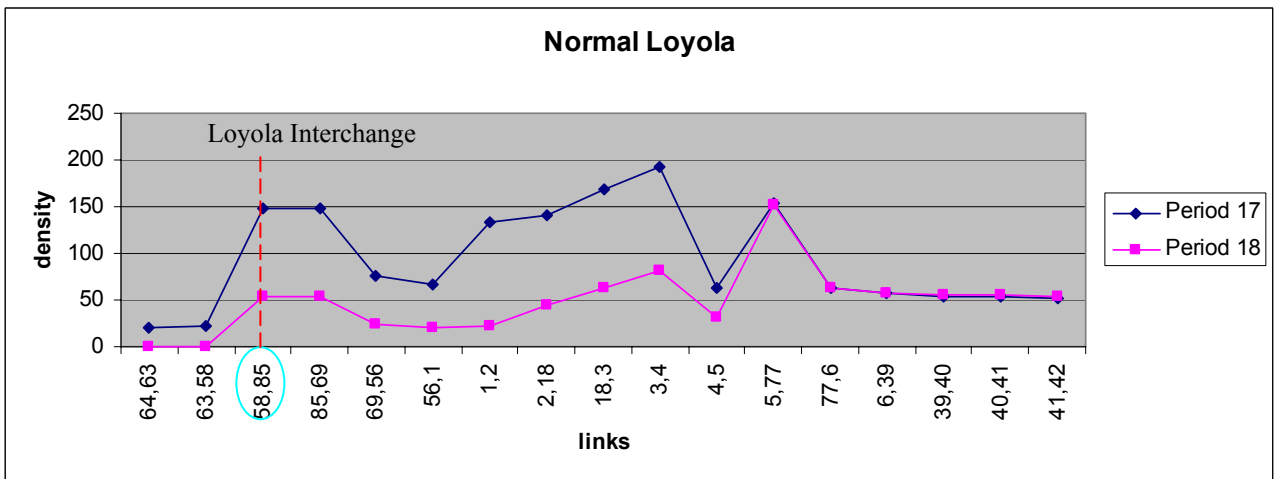
<b>Simulation Periods</b>		<b>Normal I-10 (First Route)</b>	<b>Normal Loyola (Second Route)</b>	<b>Reverse I-10 (Third Route)</b>
<b>Period 17</b>	<b>Travel Time (minutes)</b>	24.33	22.06	17.09
	<b>Mean Speed (mph)</b>	32.33	35.06	48.85
<b>Period 18</b>	<b>Travel Time (minutes)</b>	23.18	20.69	16.90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

The density per link was determined from the amount 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 4-13.



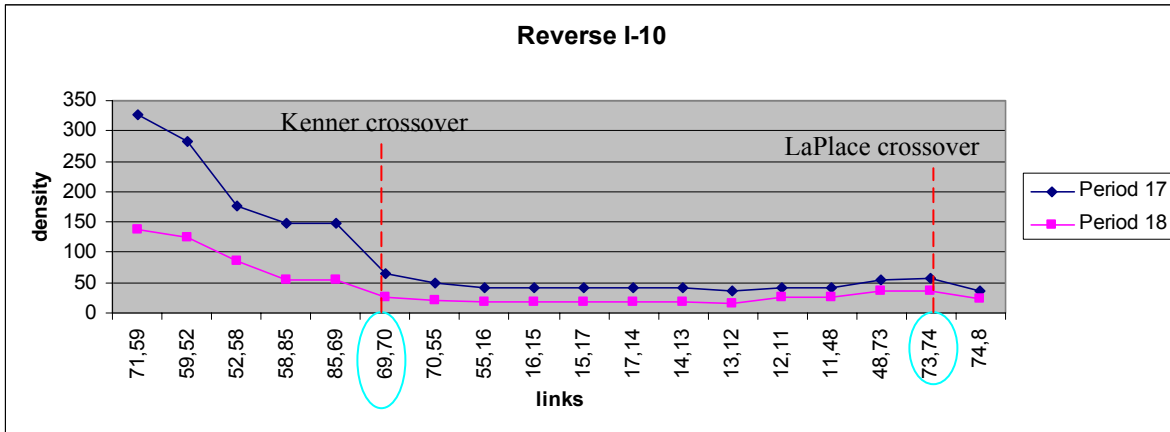
**Figure 4-13 Density in Vehicles per Mile per Lane for Normal I-10**

The second graph represents the density for the second route (Normal Loyola) as shown in Figure 4-14. After link (63, 58) since vehicles merged on I-10, the characteristics of density were the same as in the normal lanes of I-10 shown in Figure 4-13.



**Figure 4-14 Density in Vehicles per Mile per Lane for Loyola**

The third graph represents the density for the last route (Reverse I-10) as shown in Figure 4-15. From this graph, it can be assumed that the level of service is not in the congestion level.



**Figure 4-15 Density in Vehicles per Mile per Lane for Reverse I-10**

To summarize, from these data analyses the objectives of these 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, it was guide interesting that the speed on I-10/I-55 Interchange (around 20mph) was lower that the speed on the LaPlace crossover (around 39mph). Even that the posted speed was higher on I-10/I-55 interchange, since the amount of evacuation vehicles on the normal lanes was more than the amount on the reverse lanes, the speed was less than the speed at LaPlace crossover.

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. From the data analyses, it was found 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.

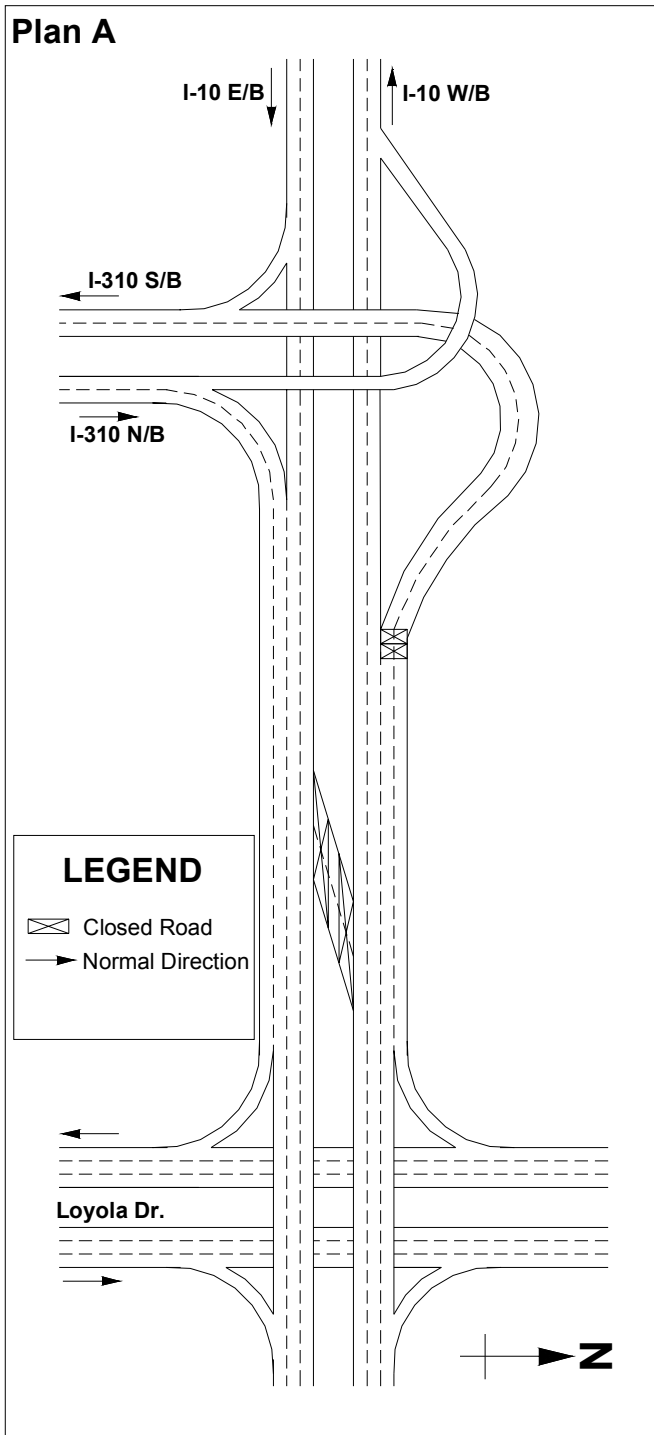
The last two objectives of this study, density and delay time were also reached. From the amount of vehicles and length of each link, the density characteristics of the segment were estimated. The delay time was estimated from the total travel time and the actual travel time during normal operations. Based on the posted speed of 65mph and the length of the segment (69,216 ft), an amount of 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.

To evaluate the effectiveness of the contraflow operation an experiment (Plan A) as shown in Figure 4-16, was conducted. Plan A used the same operational characteristics as the plan by LSP (Plan B) shown in Figure 4-17, except only the two normal outbound lanes on westbound I-10 were used for the evacuation of that segment.

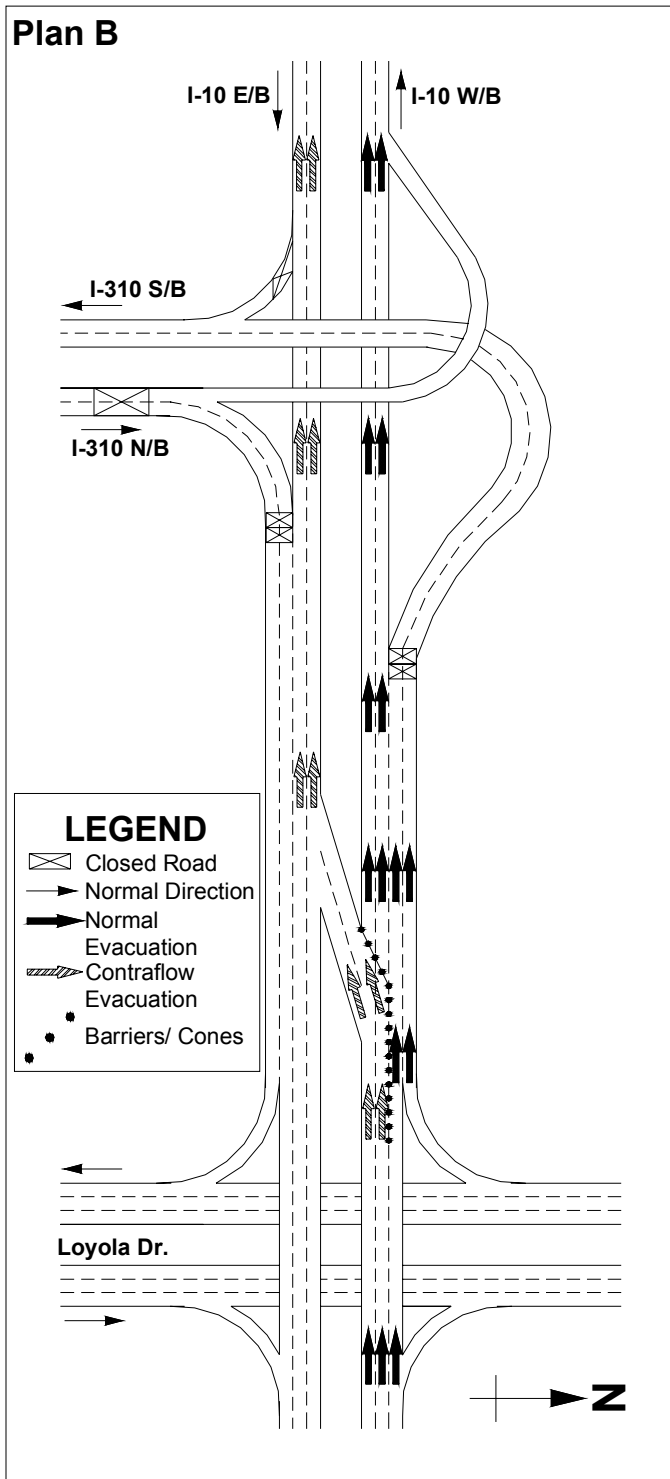
Furthermore, entering an additional volume on the segment did not look like a bad idea. Since the contraflow segment starts with three freeway lanes and ends with four, there no indications of stopped queues during the 19 one-hour periods of the simulation. Two alternative experimental plans were conducted allowing an additional flow from I-310. The

first experiment (Plan C) as shown in Figure 4-18 had the same operational characteristics as the plan from LSP, plus 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. In the second experiment (Plan D) as shown in Figure 4-19, the same operational characteristics as Plan B were used, but 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 had also 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 chose because from Plan B, the previous periods had almost the same volume characteristics as shown in Figure 4-5 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 experimnts.



**Figure 4-16 PLAN A: Flow only from the normal outbound lanes on westbound I-10**



**Figure 4-17 PLAN B: Flow from the normal and contraflow lanes on westbound I-10**

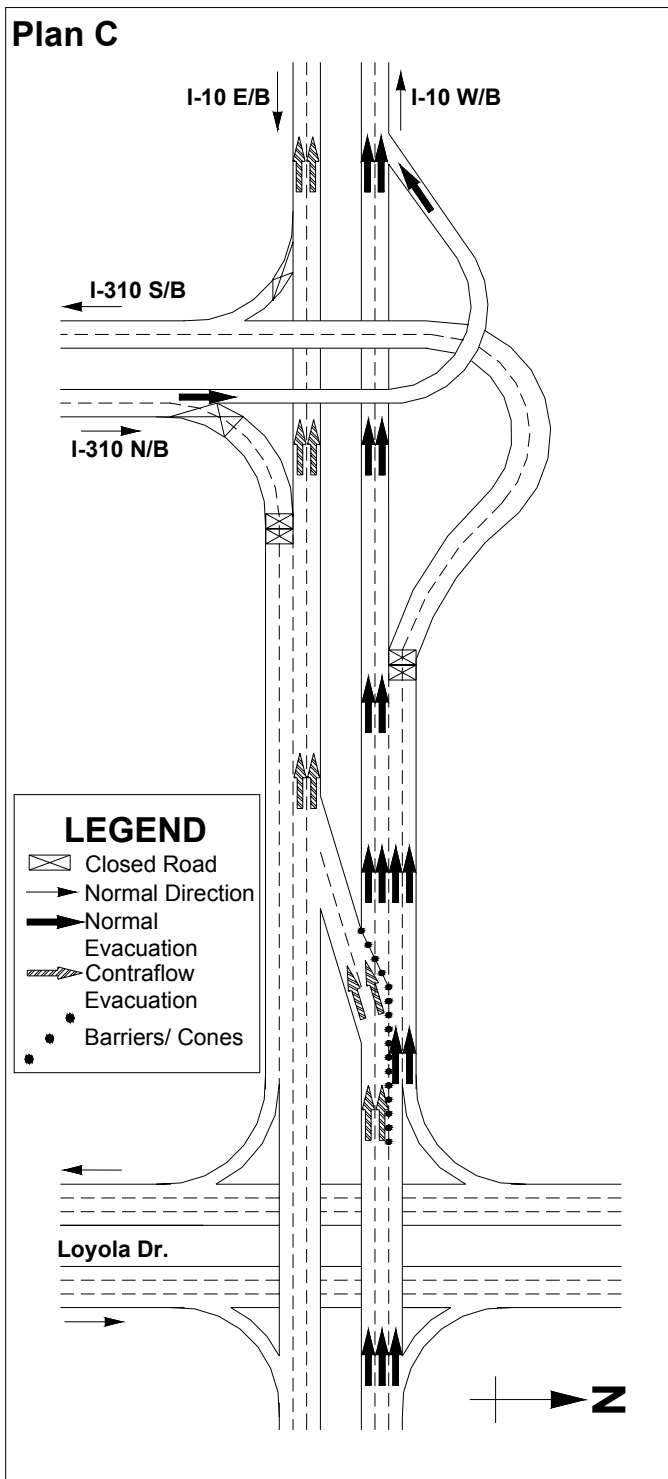


Figure 4-18 PLAN C: Allowing additional flow from Northbound I-310

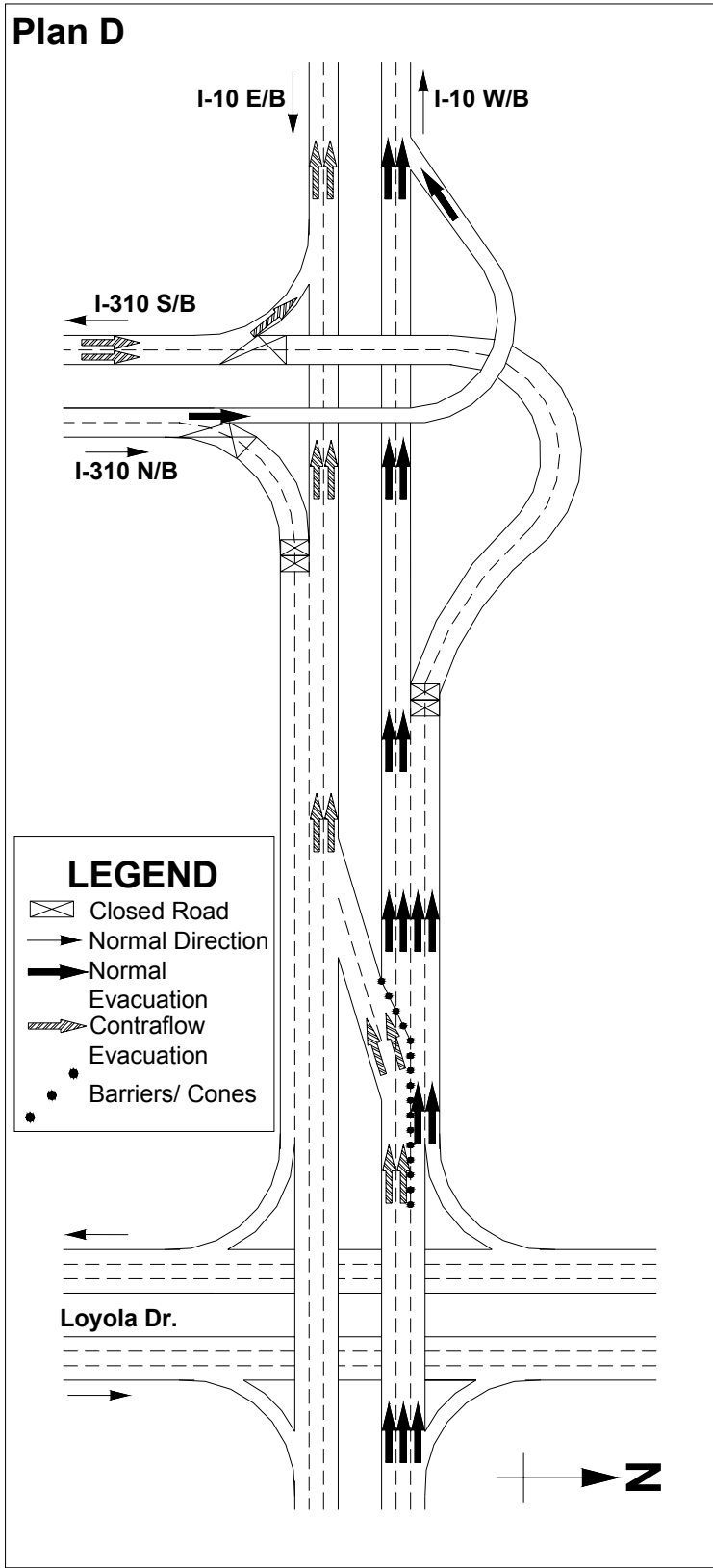


Figure 4-19 PLAN D: Allowing additional flow from Southbound and Northbound I-310

## **Chapter 5    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 there were significant differences between the means of the four plans. Based on the results of the statistical testing, conclusions were drawn and recommendations were made.

### **5.1    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.

#### **5.1.1    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 5-1 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 5-1 Volume data based on entry, exit links at period 17 and until period 17**

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

### 5.1.2 Speed

Table 5-2 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.

Using the length of a link, divided by the speed of that link, the time to travel that link was estimated. 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. In this research study, it was found that an amount of around 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 5-2, 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 5-2 Travel time and Mean speed on the four routes at Period 17 for Plan A**

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

## **5.2 Plan C**

From Figure 4-18 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 were conducted and listed in a table, using the same procedure as in Plan B.

### 5.2.1 Volume

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

Table 5-3 also shows the number of vehicles that used the normal and 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 and reverse lanes was estimated respectively. Based on the average volume values shown in Table 5-3, an approximately 44 percent continued on the normal I-10 after the Kenner crossover and a 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 5-4. This table shows how many vehicles entered and exited the network from 8:00am through 1:00am of the next day. For example, based on the average data an approximation of 101,736 vehicles entered the network and 98,486 vehicles exited.

**Table 5-4 Cumulative volume data, based on entry and exit links until period 17**

<b>Location</b>	<b>Link Segment</b>	<b>Minimum Volume (veh.)</b>	<b>Maximum Volume (veh.)</b>	<b>Average Volume (veh.)</b>	<b>C.I. Upper Bound Volume (veh.)</b>	<b>C.I. Lower Bound Volume (veh.)</b>
<b>Entry node on I-10</b>	(71,59)	69,165	70,072	69,440	69,508	69,372
<b>Entry node in Loyola</b>	(64,63)	16,148	16,148	16,148	16,148	16,148
<b>Entry node on I-310</b>	(25,26)	16,148	16,148	16,148	16,148	16,148
	<b>IN</b>	<b>101,461</b>	<b>102,368</b>	<b>101,736</b>	<b>101,804</b>	<b>101,668</b>
<b>Termination point on I-55</b>	(41,42)	52,457	54,470	52,855	52,981	52,730
<b>Termination point on I-10</b>	(74,8)	44,799	45,986	45,631	45,723	45,538
	<b>OUT</b>	<b>97,256</b>	<b>100,456</b>	<b>98,486</b>	<b>98,704</b>	<b>98,268</b>

Using Table 5-4, it can be concluded that for an amount of 98,486 evacuation vehicles, approximately 17 hours were needed to evacuate them from the contraflow segment.

### **5.2.2 Speed**

Table 5-5 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. In this research study, it was found that an amount of around 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 5-5, 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 5-5 Travel time and Mean speed on the four routes at Period 17 for Plan C**

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

### 5.3 Plan D

From Figure 4-19, it can be notice that 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.

#### 5.3.1 Volume

Table 5-6 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 three entry links were, 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 5-6 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 5-6.

**Table 5-6 Volume data based on entry, exit and splitting links at period 17**

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

Based on the average volume values of Table 5-6, an approximately 45 percent continued on the normal I-10 just after the Kenner crossover and a 55 percent continued on the reverse lanes. The 45 percent was from a 100 percent traffic coming from Loyola Drive and an about 32 percent coming from the right most lane of I-10.

From cumulative volume data, Table 5-7 was composed. 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 5-7 Cumulative volume data, based on entry and exit links until period 17**

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

### 5.3.2 Speed

Table 5-8 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 moreover to travel a route was estimated using the same procedure as in Plan C. From this table, it was determined that an amount of around 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 as shown in Table 5-8 based on the travel time and length of each route. 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 5-8 Travel time and Mean speed on the five routes at Period 17 for Plan D**

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

## **5.4 Comparison**

From the four plans (Plans A to D), tables and graphs were developed, and compared the plans 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 the evacuation of 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.

### **5.4.1 Volume**

Table 5-9 represents the average number of evacuation vehicles that exited the segment through Period 17 for the four plans. From the results in the table it can be concluded that Plan D was the most effective, and then Plan C, followed by Plan B and lastly Plan A. During the 17 hours of evacuation 25,926 more vehicles were passed through the segment using Plan D than Plan B.

Table 5-10 shows how many more vehicles were exited using the three types of contraflow operation (Plans B to D) than using only the normal outbound lanes based on the data illustrated in Table 5-9. The first column of Table 5-10 compare 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 of 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. From this table it can be concluded that Plan D with an increase of about 98 percent, was the most effective among the other three plans.

Furthermore,

Table 5-11 shows the differences between the three-contraflow plans with the normal outbound lanes during Period 17. From the last two tables (Tables 5-10 and 5-11) it can be concluded that the values of the percentage increase in Table 5-11 were similar with the percentage values in Table 5-10.

**Table 5-9 Amount of vehicles that exited the segment until Period 17**

<b>Cumulative volume through Period 17</b>	<b>Plan A</b>	<b>Plan B</b>	<b>Plan C</b>	<b>Plan D</b>
<b>Exited Volume (veh)</b>	57,686	88,224	98,486	114,150

**Table 5-10 Differences between the three contraflow plans and plan A until Period 17**

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

**Table 5-11 Differences between the three contraflow plans and plan A at Period 17.**

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

From the above tables it can be concluded 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 the plan D was better than plan C, and plan C was better than Plan B, an additional table and graph were constructed.

Table 5-12 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 Table 5-12. 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 4-18). 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 4-19).

Comparing Plan C with Plan B it can be concluded 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 the 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 4-15, there was an increase of 8,907 exiting vehicles from Route 2.

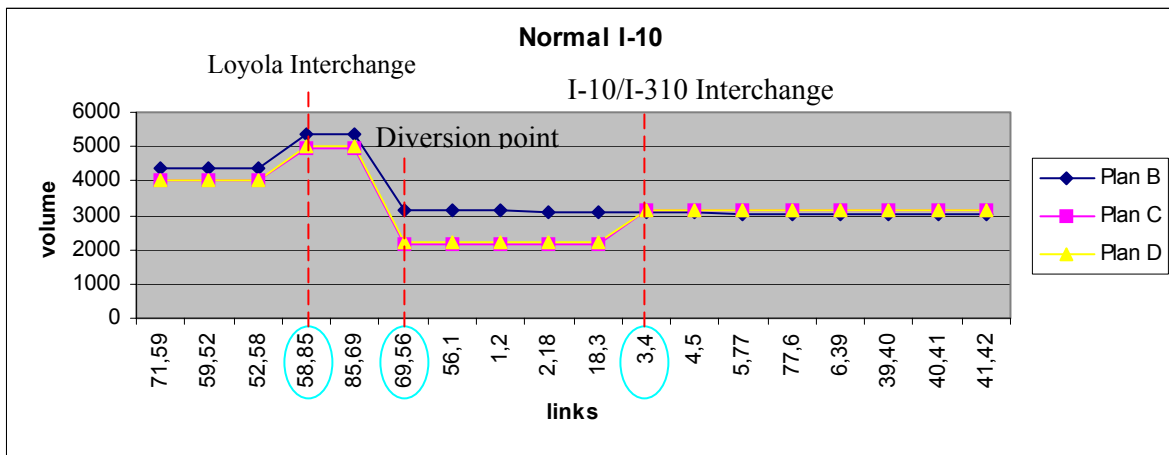
Comparing Plan D with the other two plans; it can be concluded that the additional flow from both normal and reverse lanes of I-310 made much more efficient use of the available roadway. The additional flow of 16,148 vehicles on Route 2 and the diversion of 54 percent of the total amount of vehicles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

**Table 5-12 Amount of vehicles that got in and out 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 5-1 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

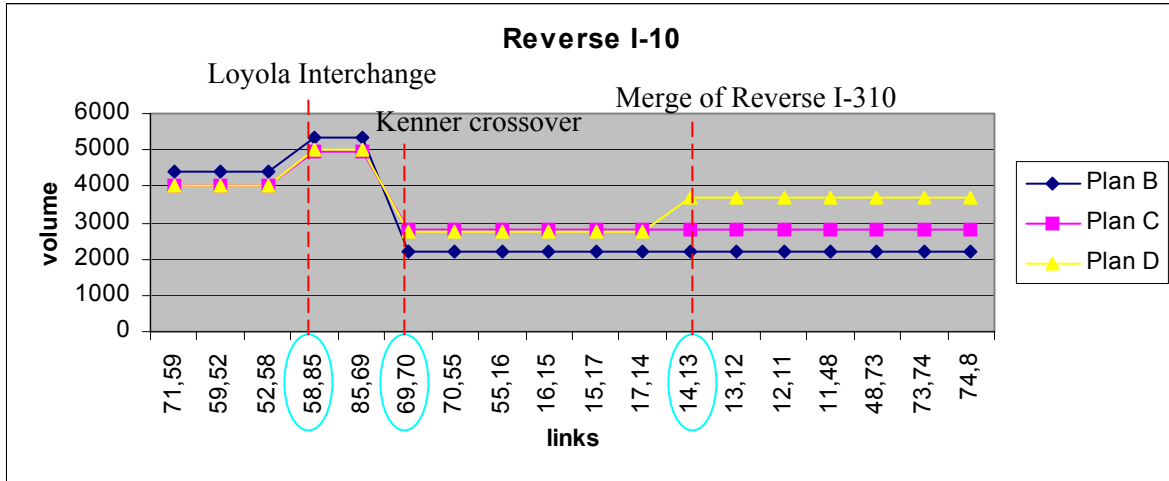
(69, 56), which represents the normal lanes after the Kenner crossover, through link (18, 3), Plan C and D had the lowest volume. This was the result of the reduction in the percentage of vehicles that used the normal lanes as shown in Table 5-12. From link (3, 4), which represents the I-10/I-310 Interchange; 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 5-1 Number of vehicles per hour using the normal I-10 to evacuate for the three plans at period 17**

Figure 5-2 illustrates the number of evacuation vehicles between the three contraflow plans (Plans B to D) per link for the reverse route (Reverse I-10). From the graph it can be demonstrated that the volume through link (85, 69) was quite 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 Table 5-12. 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 5-2 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 the 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:

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

(Equation 3)

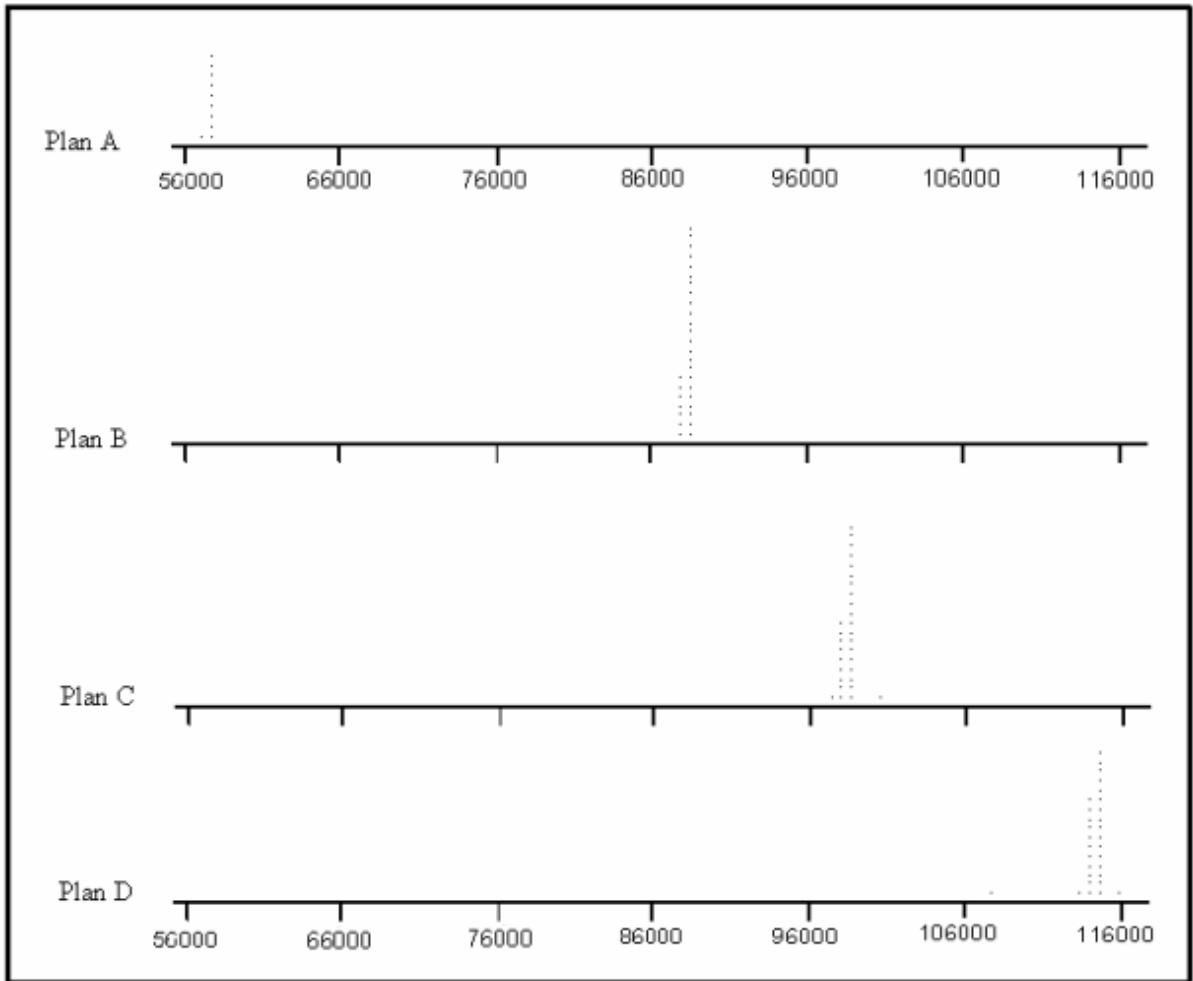
$\bar{X}_n$  is the mean value of the 30 samples in the first plan.  $\bar{Y}_m$  is the mean value of the 30 samples in the second plan.  $\mu_1$  and  $\mu_2$  are the real means of the two plans.  $\hat{\sigma}$  is the Pooled estimation that is also called sample standard deviation. The letters n 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 our four plans were plotted in the following figure. Figure 5-3 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 5-3 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.

#### 5.4.2 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 or equal to zero. If it was zero, it means that 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 5-3 Range of number of vehicles evacuated using the four plans until period 17**

Table 5-13 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 we 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  $\alpha$ . In this study, since the experiments constructed a 95 percent confidence, the value of  $\alpha$  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  $\alpha$ , 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.

**Table 5-13 Significant mean difference of Plan D and Plan C**

<b>1. Ho: <math>\mu_D - \mu_C \leq 0</math> Vs Ha: <math>\mu_D - \mu_C &gt; 0</math></b>	
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	

The same procedure was used to verify the difference between Plan C and B, and the output from the statistical package is shown in Table 5-14 below.

**Table 5-14 Significant mean difference of Plan C and Plan B**

<b>2. Ho: <math>\mu_C - \mu_B \leq 0</math> vs Ha: <math>\mu_C - \mu_B &gt; 0</math></b>	
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	

Since p-value was very small, closed 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 more efficient than plan B.

**Table 5-15 Significant mean difference of Plan A and Plan B**

<b>3. Ho: <math>\mu_A - \mu_B \leq 0</math> vs Ha: <math>\mu_A - \mu_B &gt; 0</math></b>	
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	

From the comparison between Plan A and B (Table 5-15), the null hypothesis was not rejected. The p-value, that was equal to one, was larger than the  $\alpha$  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, it was 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 among 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 this time it was assumed that the variances were unequal.

**Table 5-16 Significant mean difference of Plan A and Plan B**

<b>1. Two-sample T for Plan A vs Plan_B</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		

**Table 5-17 Significant mean difference of Plan D and Plan C**

<b>2. Two-sample T for Plan_D vs Plan_C</b>	
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	

**Table 5-18 Significant mean difference of Plan C and Plan B**

<b>3. Two-sample T for Plan_C vs Plan_B</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	

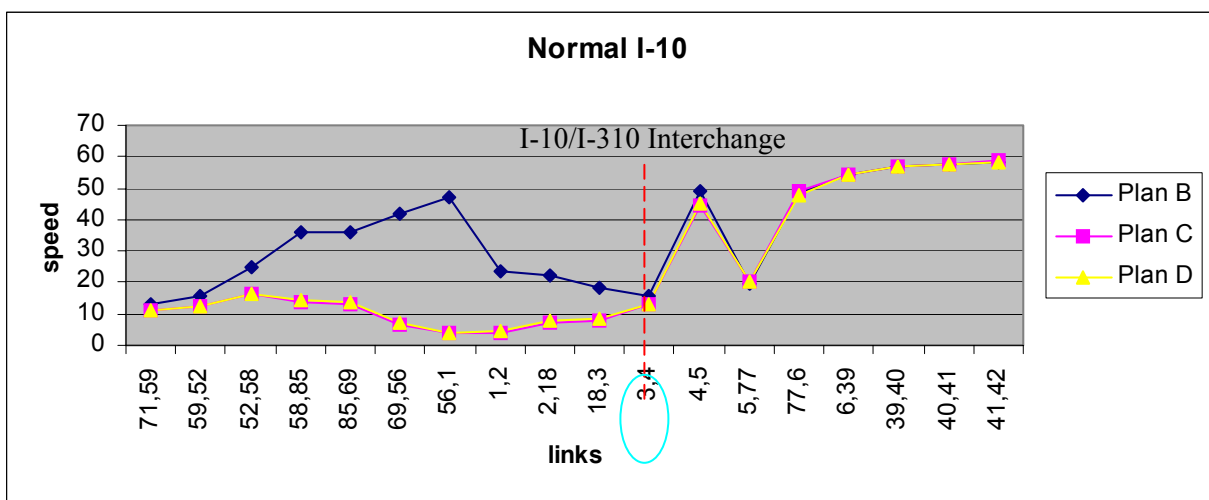
These tables show the output results from MINITAB. From these tables it can be concluded that the three tests with unequal variances had the same results as the previous three tests with equal variances.

### **5.4.3 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

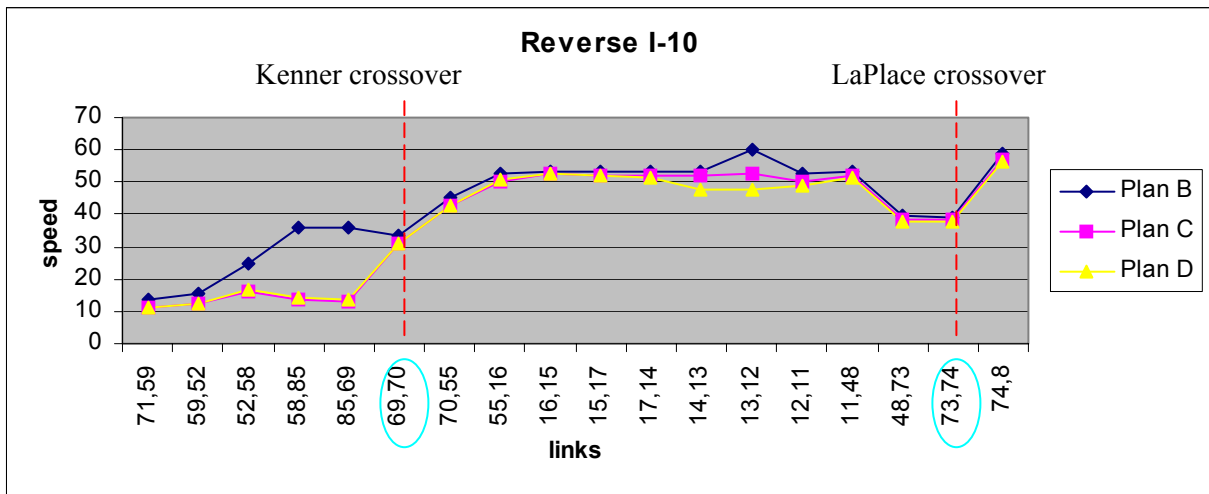
speed data, the average speed for each link was estimated based on the three-contraflow plans (Plans B to D).

Figure 5-4 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 Table 5-12 Plans C and D had higher percentage of vehicles that used the reverse lanes compared with Plan B.



**Figure 5-4 Average speed on the normal I-10 for plans B, C and D during Period 17**

Figure 5-5 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 plan 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 5-5 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 5-19. From this table it was found that a maximum of about 31 minutes was required to clear the

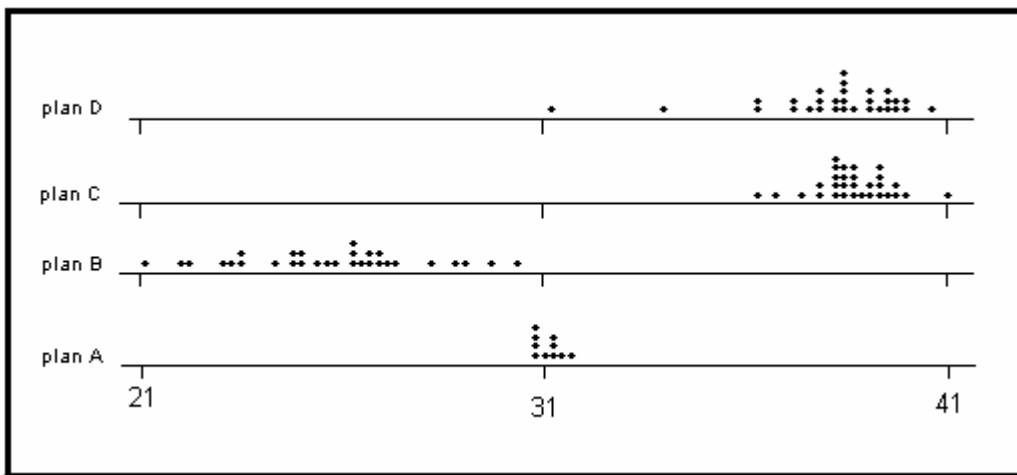
segment using Plan A. A maximum of around 25 minutes was required to clear the segment using Plan B. Using plan C, around 40 minutes were required to clear the segment since an additional flow volume entered from the normal lanes of I-310. A maximum of around 38 minutes was required to clear the segment using Plan D that was less than the required time in Plan C. The possible reason for this was that based on Table 5-12, 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 5-19 Travel time and Mean speed on the routes at Period 17 for the four Plans**

<b>Plan A</b>	<b>I-10 to I-55</b>	<b>Loyola to I-55</b>	<b>I-10 to I-10</b>	<b>Loyola to I-55</b>	
<i>Time (minutes)</i>	29.53	20.30	30.34	21.10	
<i>Mean Velocity (mph)</i>	26.63	38.09	27.48	38.88	
<b>Plan B</b>	<b>Normal I-10</b>	<b>Normal Loyola</b>	<b>Reverse I-10</b>		
<i>Time (minutes)</i>	24.33	22.06	17.09		
<i>Mean Velocity (mph)</i>	32.33	35.06	48.85		
<b>Plan C</b>	<b>Normal I-10</b>	<b>Normal Loyola</b>	<b>Reverse I-10</b>	<b>Normal I-310</b>	
<i>Time (minutes)</i>	39.51	37.02	19.46	19.23	
<i>Mean Velocity (mph)</i>	19.91	20.89	42.91	36.03	
<b>Plan D</b>	<b>Normal I-10</b>	<b>Normal Loyola</b>	<b>Reverse I-10</b>	<b>Normal I-310</b>	<b>Reverse I-310</b>
<i>Time (minutes)</i>	38.08	35.80	20.43	19.03	15.13
<i>Mean Velocity (mph)</i>	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 5-6 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 5-6 Range of travel times to clear the segment for each plan in minutes**

#### **5.4.4 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 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. Table 5-20 shows the results from MINITAB output. Plan C and B had a range of 30 values respectively and their mean value was 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 it was found 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  $\alpha$ , 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.

**Table 5-20 Significant mean difference of Plan C and Plan B**

<b>Two-Sample T-Test and CI: plan C vs plan B</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				

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

**Table 5-21 Significant mean difference of Plan D and Plan C**

<b>Two-Sample T-Test and CI: plan D vs plan C</b>				
	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				

From the comparison between Plan D and C (table above), the null hypothesis was not rejected. The p-value, that was equal to 0.895, was larger than the  $\alpha$  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 rest of the 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.

**Table 5-22 Significant mean difference of Plan C and Plan B**

<b>Two-Sample T-Test and CI: plan C vs plan B</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				

**Table 5-23 Significant mean difference of Plan D and Plan C**

<b>Two-Sample T-Test and CI: plan D vs plan C</b>				
	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				

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.

## **Chapter 6 Summary and Conclusions**

### **6.1 Summary of the Research Study**

New Orleans is one of the most vulnerable cities from hurricanes in the US. With much of the city below sea level, a major hurricane has the potential to flood vast portions of the city. As a result, New Orleans officials seek to evacuate the population under the threat of significant hurricanes.

During Hurricane Floyd in 1999, Georgia and South Carolina officials initiated a contraflow operation to evacuate the people faster in vulnerable areas. During Hurricane Floyd the SCDOT analyzed traffic flow under four different contraflow configurations. Using the two normal outbound lanes plus the two-contraflow lanes, the flow rate was increased by 67 percent over a standard two-lane evacuation. In view of the fact that the reverse of both inbound lanes of the freeway to the outbound direction offers the largest increase in capacity, officials in New Orleans planned to use the same contraflow strategy on westbound I-10 out of the city during an evacuation.

However, no actual data of the traffic flow on the contraflow segment have been collected during an evacuation. Thus, nobody really knows how this form of operation will function. The cost and benefits of contraflow in terms of freeway capacity improvements also remain unknown. To address this problem, computer simulation models are being applied to evaluate the effectiveness of contraflow operation.

Microscopic models have been suggested to analyze contraflow operation, especially for small segments. Since the contraflow segment in New Orleans is only about 14 miles, CORSIM was able to be used. For the construction of the network, information was

gathered regarding the geometric layout, the amount of evacuation vehicles that will use this segment and human behavior during an evacuation.

## **6.2 Summary of Results and Analyses**

CORSIM was used to estimate the objectives of this study. The traffic flow exiting the segment under the Plan B configurations was about 5,000 vehicles per hour. A total of 88,224 evacuation vehicles were estimated to have exited the network for duration of 17 hours. The speed per link was also estimated and with the length of each link, the travel time per link was calculated. The time needed to travel a route was estimated from the summation of travel times of the links for that route. The longest travel time was estimated to be about 25 minutes. Knowing the volume and speed of each link, the density was also calculated. In addition, knowing the total travel time, the delay time was also calculated. Since the posted speed was 65 mph and the length of the segment was around 70,000ft, the actual travel time was around 12 minutes. Therefore, the delay time was only 13minutes.

From the analysis of Plan B, three alternative plans were conducted to evaluate the contraflow operation. The alternative plans had the same objectives as Plan B. Comparing the results between the four plans; Plan D was the best among the four in respect of the amount of evacuation vehicles exiting the network. From Plan D it was found that almost double the amount of vehicles left the network compared with Plan A, where only the two normal outbound lanes were used. The second best plan was Plan C, followed by Plan B. a statistical test was also used to rank the four plans. The results from the statistical test verified the ranking of the four plans.

### **6.3 Conclusions**

Based on the results and analyses, Plan C and D were more efficient plans than Plan B because they used more effectively the available roadway. The additional flow from the normal lanes of I-310 to the normal lanes of I-10 increased the congestion on the normal lanes. Due to the congestion, more vehicles used the contraflow lanes, and consequently, vehicles used more effectively the available roadway.

Nevertheless, a lot of the information that were used in the model was based on assumptions for human behavior. Thus, nobody really knows how the contraflow operation will function during a real emergency evacuation. However, the same assumptions were taken for the four plans. The numerical results from the plans may not be exactly correct, but they can estimate which plan is more efficient than the other. In addition, the goal of this study, which was to improve the understanding of a contraflow evacuation on a highway segment, was achieved. From the comparisons of the alternative plans, it was found that using multiple entry-nodes in a segment can lead in higher traffic flow.

### **6.4 Areas of Future Research**

The tests for these experimental plans were based on assumptions. However, the theoretical results showed that Plan C and D were more effective than the evacuation plan prepared by LSP. New Orleans officials can have in-mind the two alternatives plans and make a further study for allowing additional flow from I-310 on the westbound I-10 out of New Orleans.

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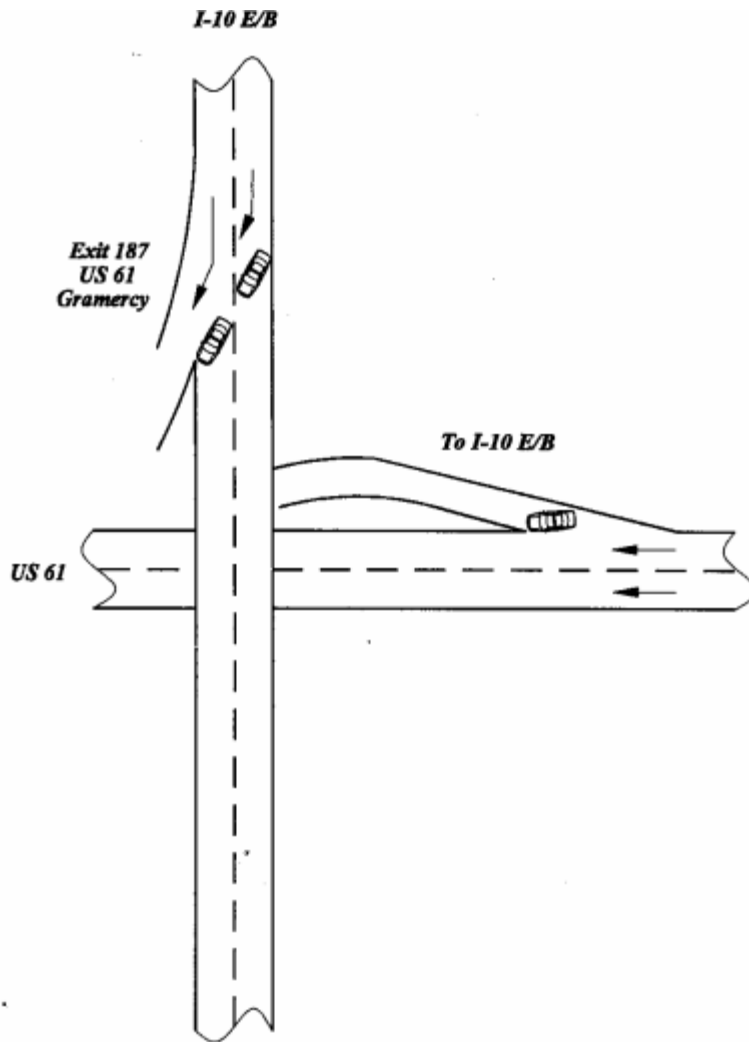
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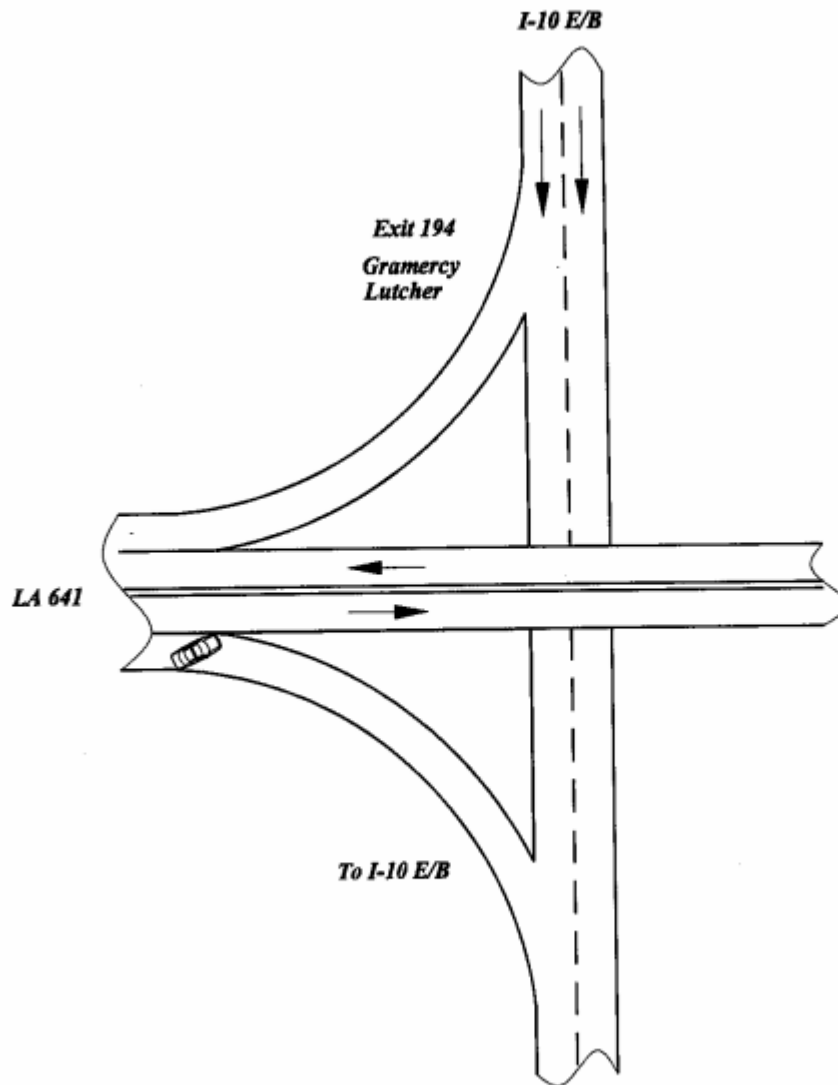
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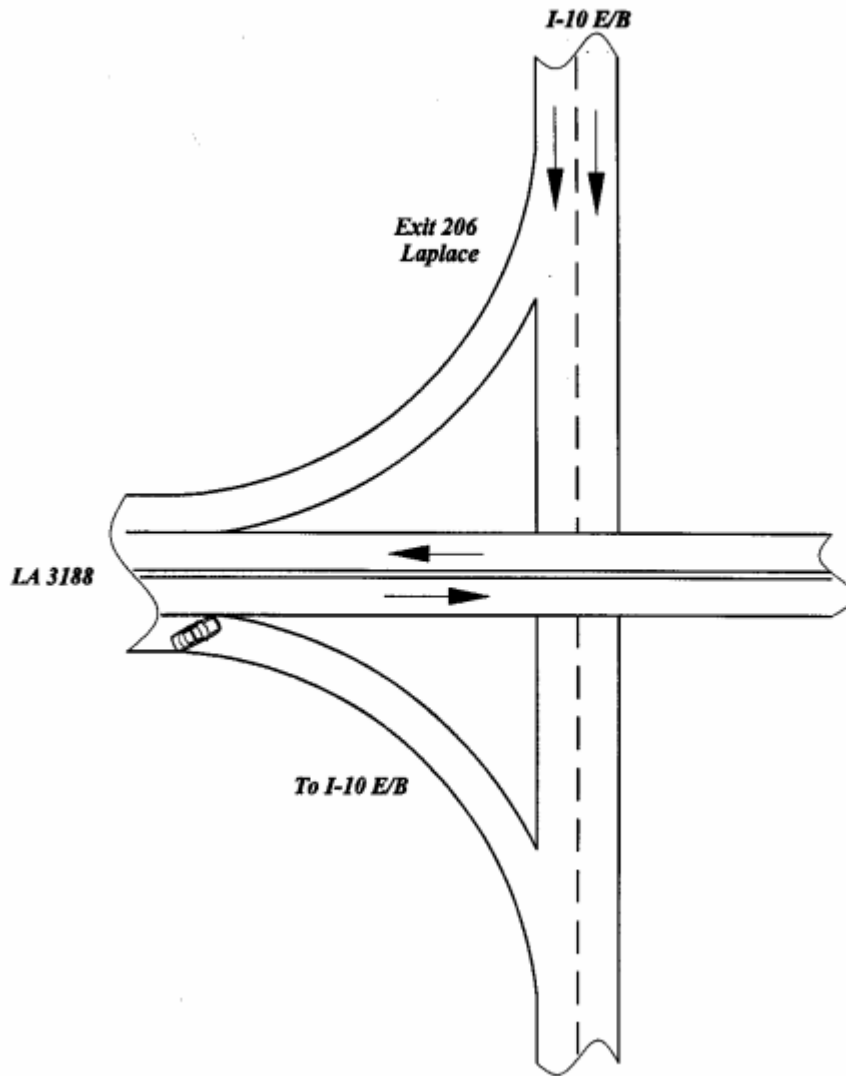
# Appendix 1: Termination of Eastbound I-10 through Exit 187



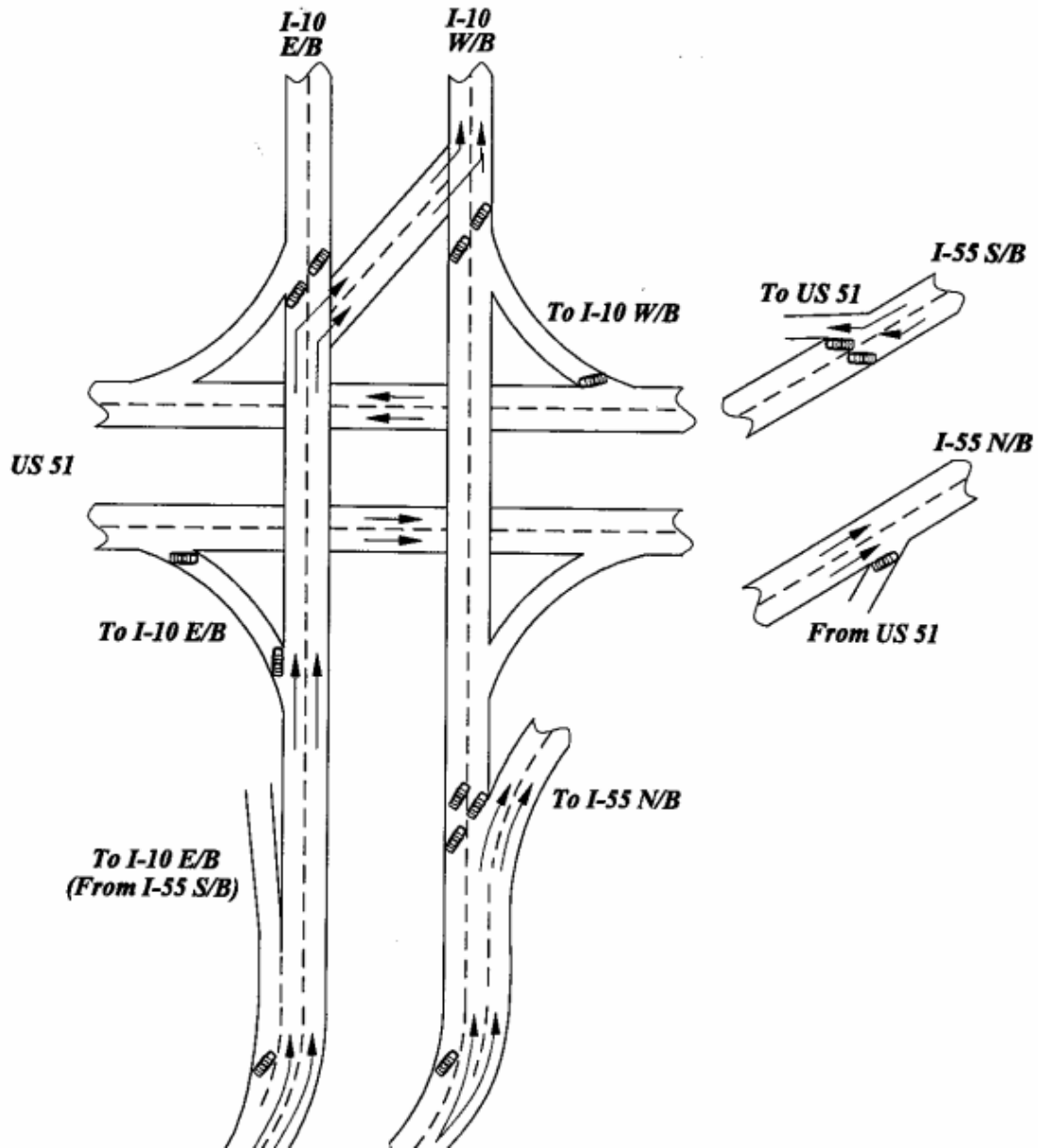
## Appendix 2: Closed Entrance to I-10 E/B from LA 641



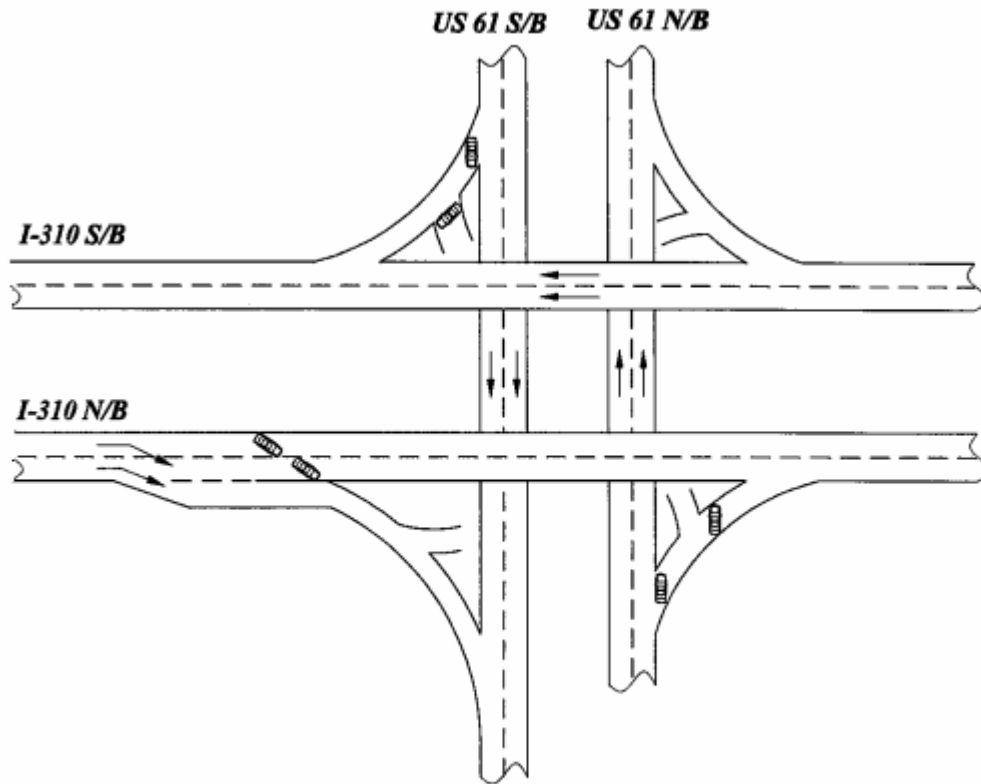
### Appendix 3: Closed Entrance to I-10 E/B from LA 3188



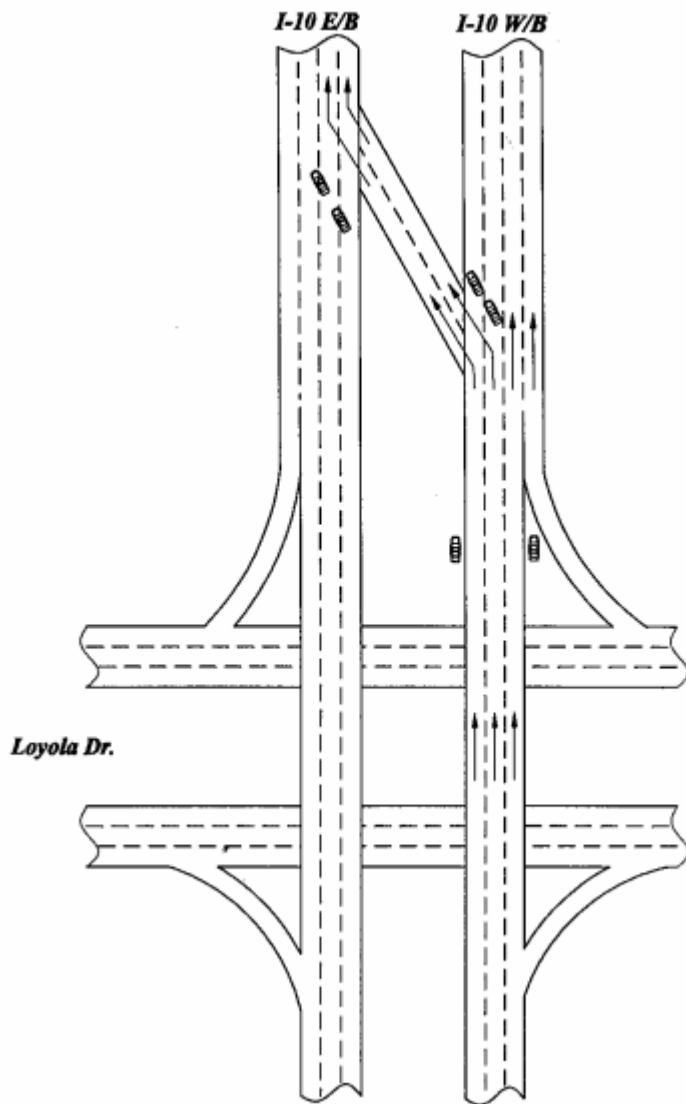
## Appendix 4: Termination Point



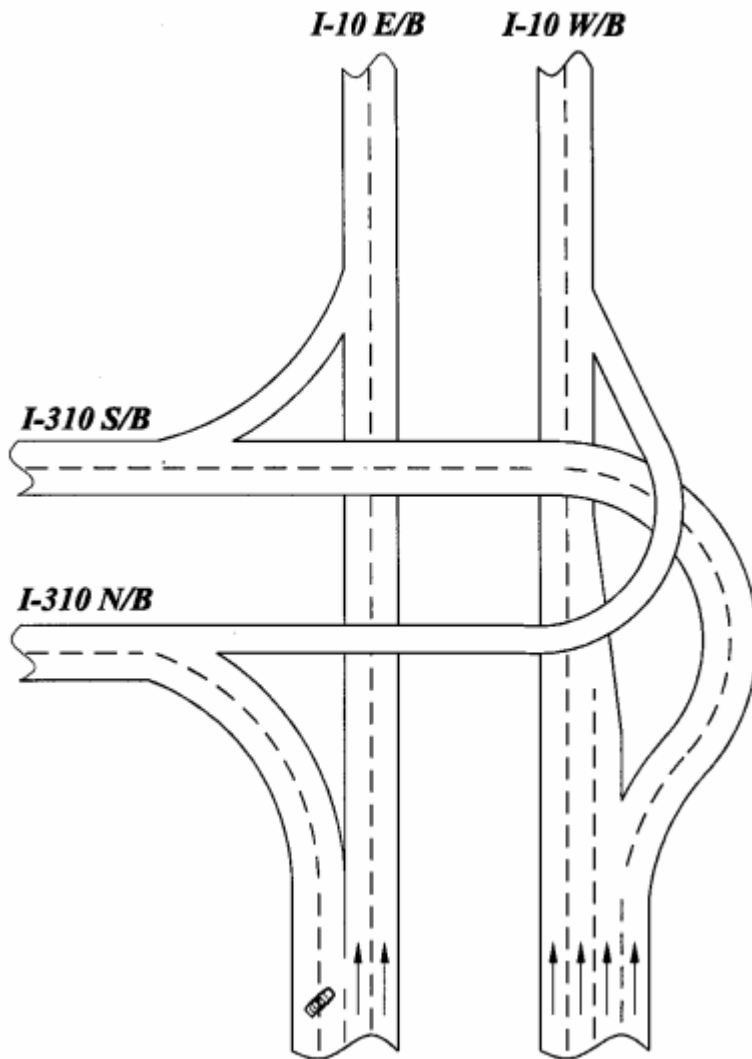
**Appendix 5: Flow from I-310 N/B to I-10 W/B Will Be Closed**



## Appendix 6: Initiation Point



**Appendix 7: Prevent Exit to I-310 N/B from I-10 E/B**



## **Vita**

Gregoris Theodoulou was born on December 17, 1976, in Nicosia, capitol of Cyprus. He obtained his Bachelor of Science degree in Civil Engineering in 2001 from Louisiana State University, United States. He joined the master program in the same university with major in transportation engineering. In August 2003 will receive the degree of Master of Science in Civil Engineering.