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

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

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June 2010

ABSTRACT

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

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

IMPLEMENTATION STATEMENT

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

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

The outcomes of these changes yielded measurable and significant benefits when put to use for the Hurricane Katrina evacuation in August 2005.

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INTRODUCTION

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

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

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

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

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

Because of the highly dynamic and evolving state of contraflow, changes have occurred to some of the state plans as discussed at the time when this report was originally developed. Other changes have also occurred in the wake of Hurricane Katrina, which occurred after this report was written. However, none of the above changes impact the methodology, analysis, or findings of the original research.

It should also be noted that, due to publication limitation, several sections of this report had to be deleted from the printed report. These sections have been noted within. The full project report, containing all details, can be reviewed on the accompanying data disk as well as on the LTRC Web site at www.ltrc.lsu.edu.

OBJECTIVES

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

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

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

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

The CORridor SIMulation (CORSIM) model was used to perform the research because it produces a wealth of detailed measures of effectiveness (MOE) and is widely accepted within the transportation community. Unfortunately, CORSIM, like all traffic simulation programs, has limitations. Most critically, it does not explicitly support the creation of reversible flow freeway segments or the behavioral characteristics of evacuation drivers. For these and other reasons, many assumptions (discussed in a later section) were required to develop the models.

SCOPE

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

LITERATURE REVIEW

Interested readers are suggested to refer to the accompanying data disk for the project literature review. The full project report can be found online at: http://www.ltrc.lsu.edu/pubs_final_reports.html.

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, the CORSIM 5.0 microscopic simulation model was used to achieve the research objectives.

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

Network Construction

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

Aerial Photos

To construct the model, a number of aerial photos of the contraflow segment were obtained using the Geographic Information System (GIS) and were 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 1. In this figure, the red line represents the contraflow segment, and the circles show the I-10/I-55 and I-10/I-310 interchanges.

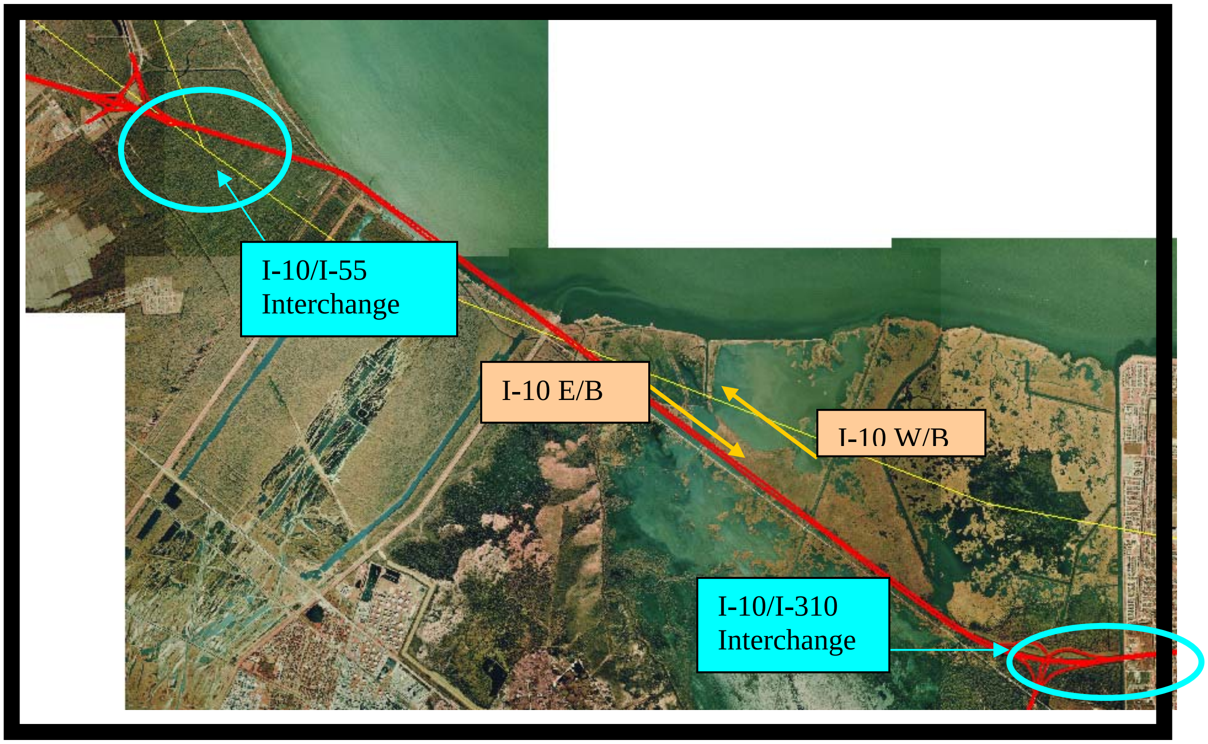

Figure 1
Aerial photo of the contraflow segment

However, Figure 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 2. The second was of the I-10/I-310 interchange, as shown in Figure 3, and the third was of the I-10/I-55 interchange, as shown in Figure 4.

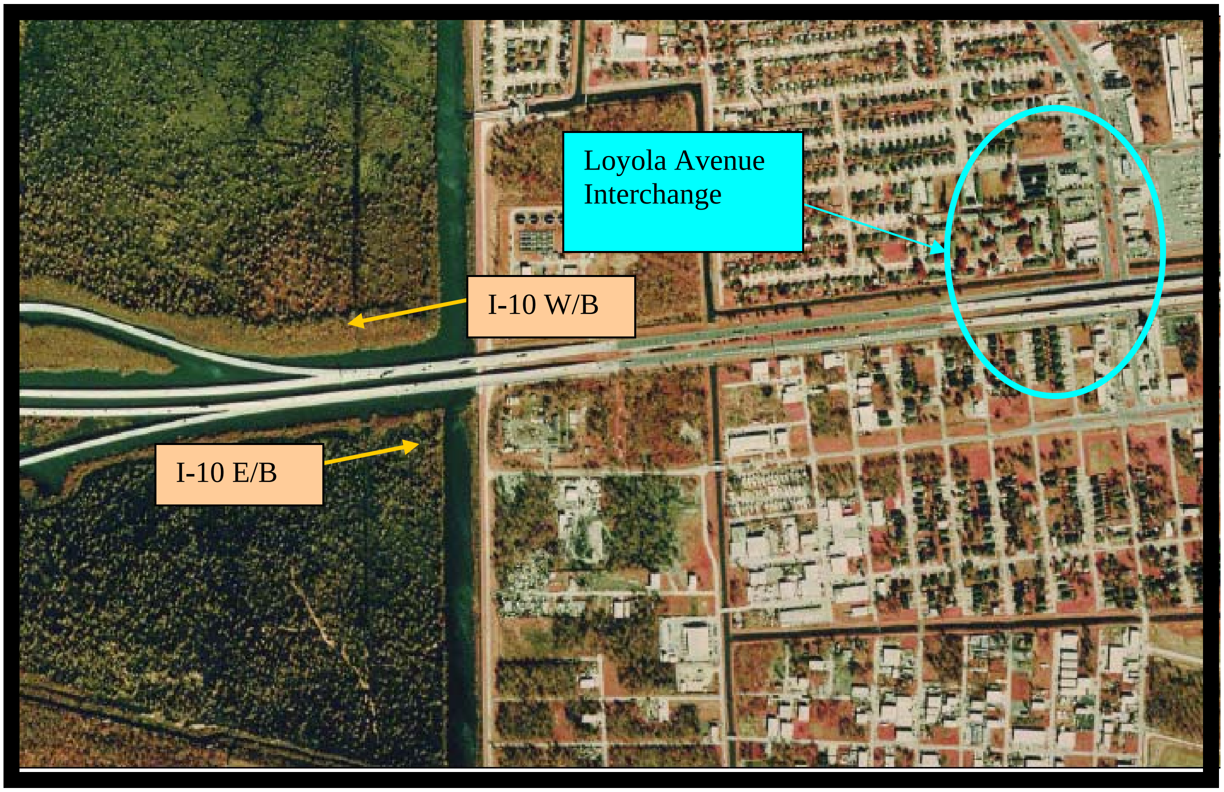

Figure 2
Loyola entrance ramp in westbound I-10

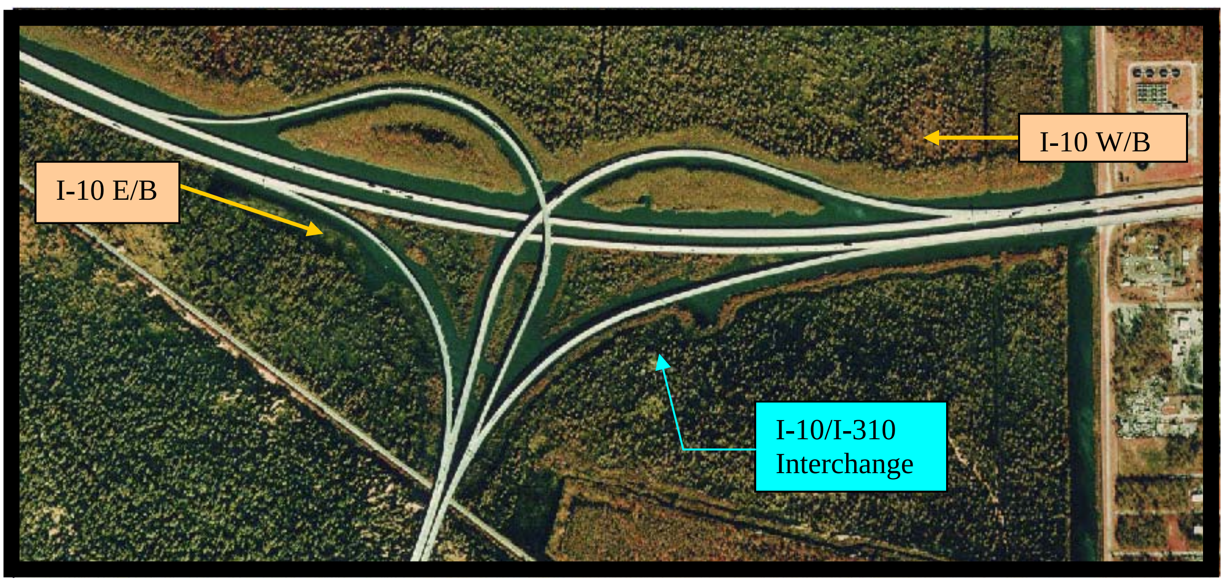

Figure 3
I-10/I-310 interchange

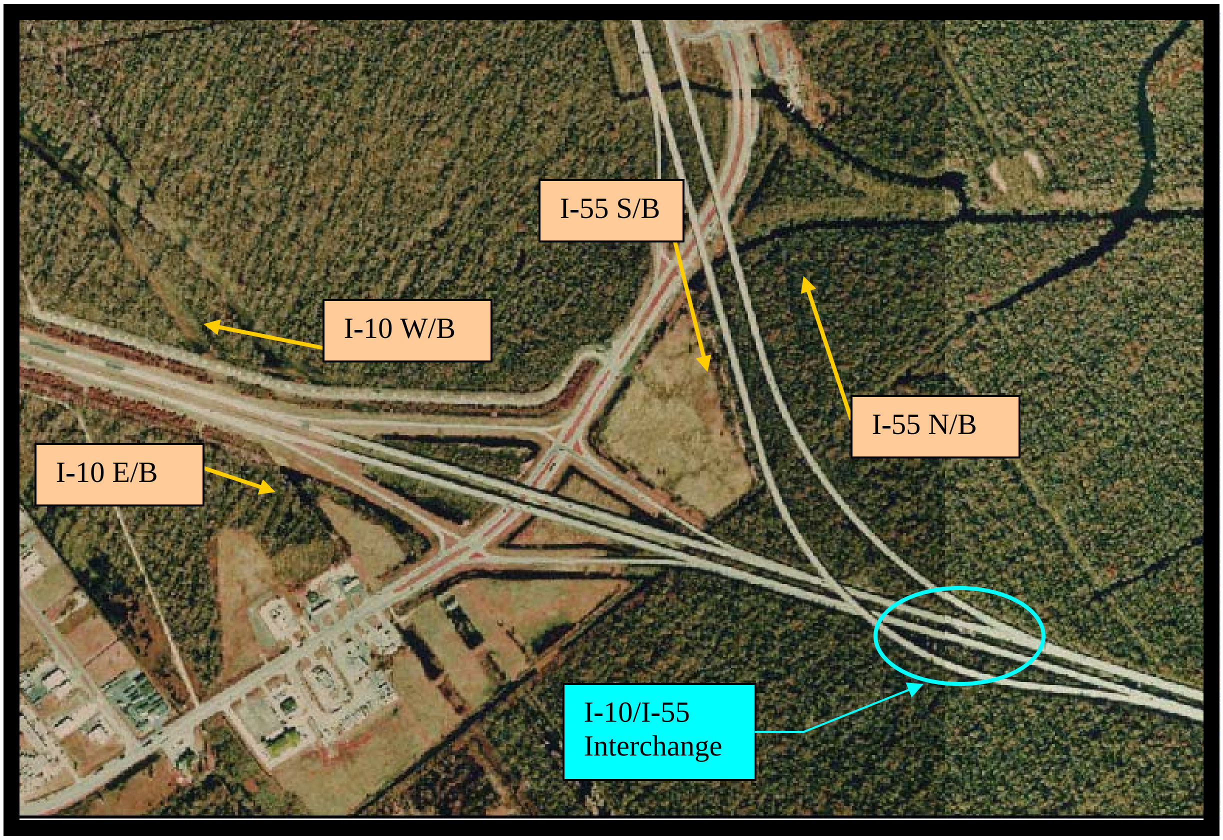

Figure 4
I-10/I-55 interchange

Geometric Layout

Although the aerial photos in Figure 1- 5 had an accuracy of one meter, they were not detailed enough to estimate the number of lanes in the contraflow segment. Therefore, the geometric layout of the segment was based on the emergency evacuation framework for metropolitan New Orleans developed by the LSP. LSP also 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. Finally, a free flow operating speed of 40 mph was assigned to the road segment of the two median crossovers. This free flow speed was based on similar studies that were conducted by the departments of transportation in Florida, Alabama, and Georgia.

Behavioral Input Information

The "Southeast Louisiana Hurricane Evacuation Study" *[1]* was used to determine the amount of evacuation traffic from the City of New Orleans used in this study. The data were developed based on varying categories of the hurricane and tourist occupancy. In this study, evacuation traffic volumes from a Category 5 hurricane were used as a worst case scenario.

These volumes, as well the volumes associated with other storm scenarios, are in the study report. In the report, the evacuating traffic volume for a Category 5 hurricane was estimated to be 124,334 vehicles. Based on the Behavioral Cumulative Evacuation Curve, 10 percent of evacuees would leave home before the order to evacuate. Therefore, 111,901 vehicles were used in the CORSIM network as the volume entering the system after the evacuation order. One entry node was on the 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 *[2]* and Baker *[3 and 4]* showed that evacuees have a tendency to take all of the belongings they can carry during an evacuation. These factors were assumed to affect driver characteristics. The fact that evacuees would feel uncomfortable while driving and would not have a clear view of the road was also assumed . Finally, the fact that 15 percent of the total evacuation volume would be heavy vehicles such as trucks, recreational vehicles, or vehicles with trailers, boats, etc. was assumed.

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

Addressing the Limitations of CORSIM

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

Reverse Lanes

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

The LSP plan calls for police cars to force traffic in the left and center lanes of westbound I-10 to continue on the contraflow lanes through the Kenner crossover. To code this in CORSIM, barricades were used between the center and rightmost lanes of westbound I-10, just east of Loyola Avenue. This would force vehicles in the left and center lanes to divert through the crossover to the contraflow lanes, as shown in Figure 6. In addition, since the left and center lanes of westbound I-10 were forced into the contraflow direction, the traffic in the vicinity of Loyola Avenue enters in the normal flow lanes, with two lanes added at 150 ft and 250 ft, respectively, after the Kenner crossover, as shown in Figure 5, to form the four lane freeway on westbound I-10 West based on the LSP plan.

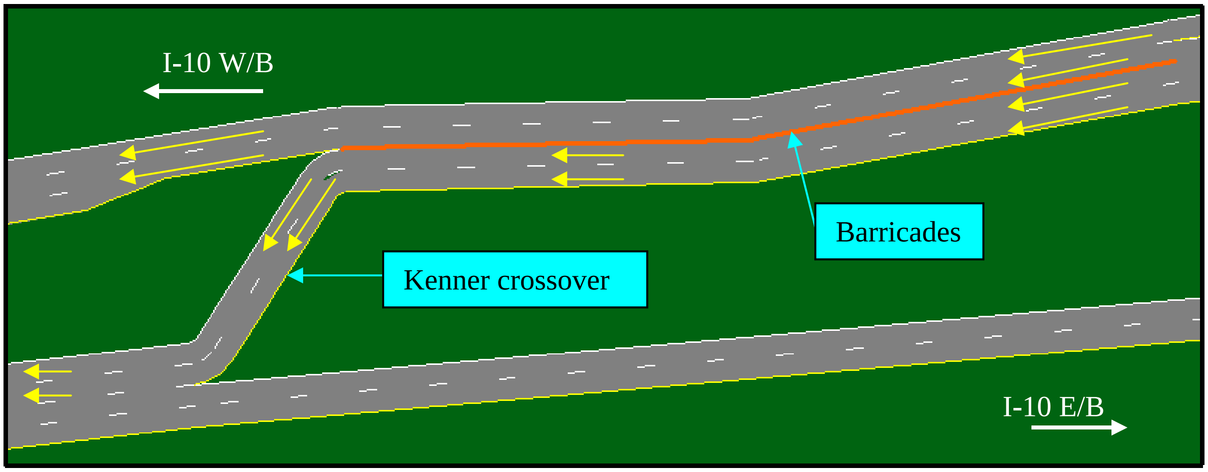

Figure 5
Representation of the Kenner crossover in the CORSIM model

At the I-10/I-310 Interchange, the entrance ramp will be blocked by the LSP to prevent "wrong way" exiting. To code this in the CORSIM, northbound I-310 was not joined with eastbound I-10. At the LaPlace 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 of the full project report. To represent this condition in CORSIM, the contraflow lanes were continued through the median crossover in westbound I-10. The normal flow lanes of westbound I-10, just before the LaPlace crossover, were discontinued to represent the LSP plans, as shown in Figure 6.

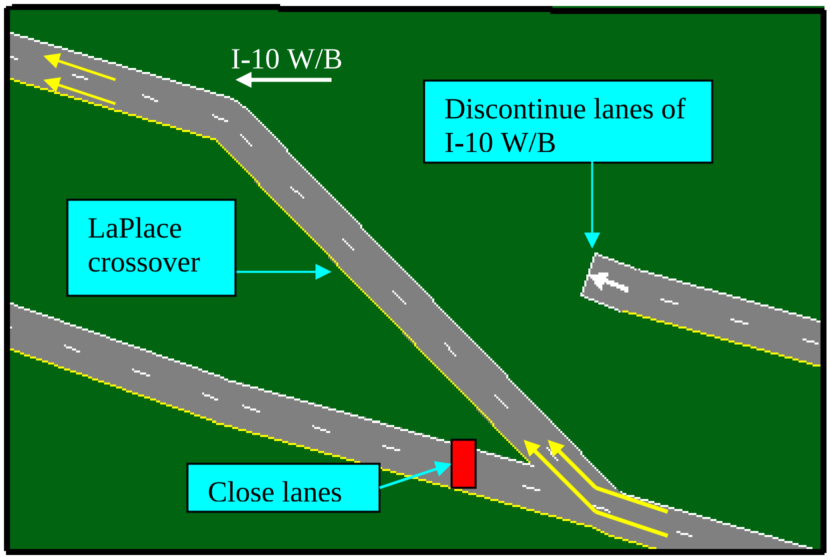

Figure 6
Representation of LaPlace crossover in the CORSIM model

Termination Point

The normal outbound traffic of westbound I-10 will be diverted to northbound I-55 to travel to Hammond, Baton Rouge, and beyond. To build this in CORSIM 5.0, a condition analogous to a construction zone was assumed *[5]*. 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 7. To code this in CORSIM, a reduction of speed to 55 mph was necessary in the redirected segment of the I-10/I-55 Interchange, based on the 2000 edition of the MUTCD. Moreover, incidents were set on the closed lanes at the LaPlace crossover, as shown in Figure 6, and at the I-10/I-55 interchange, as shown in Figure 8, to represent the closed lanes in the LSP plan.

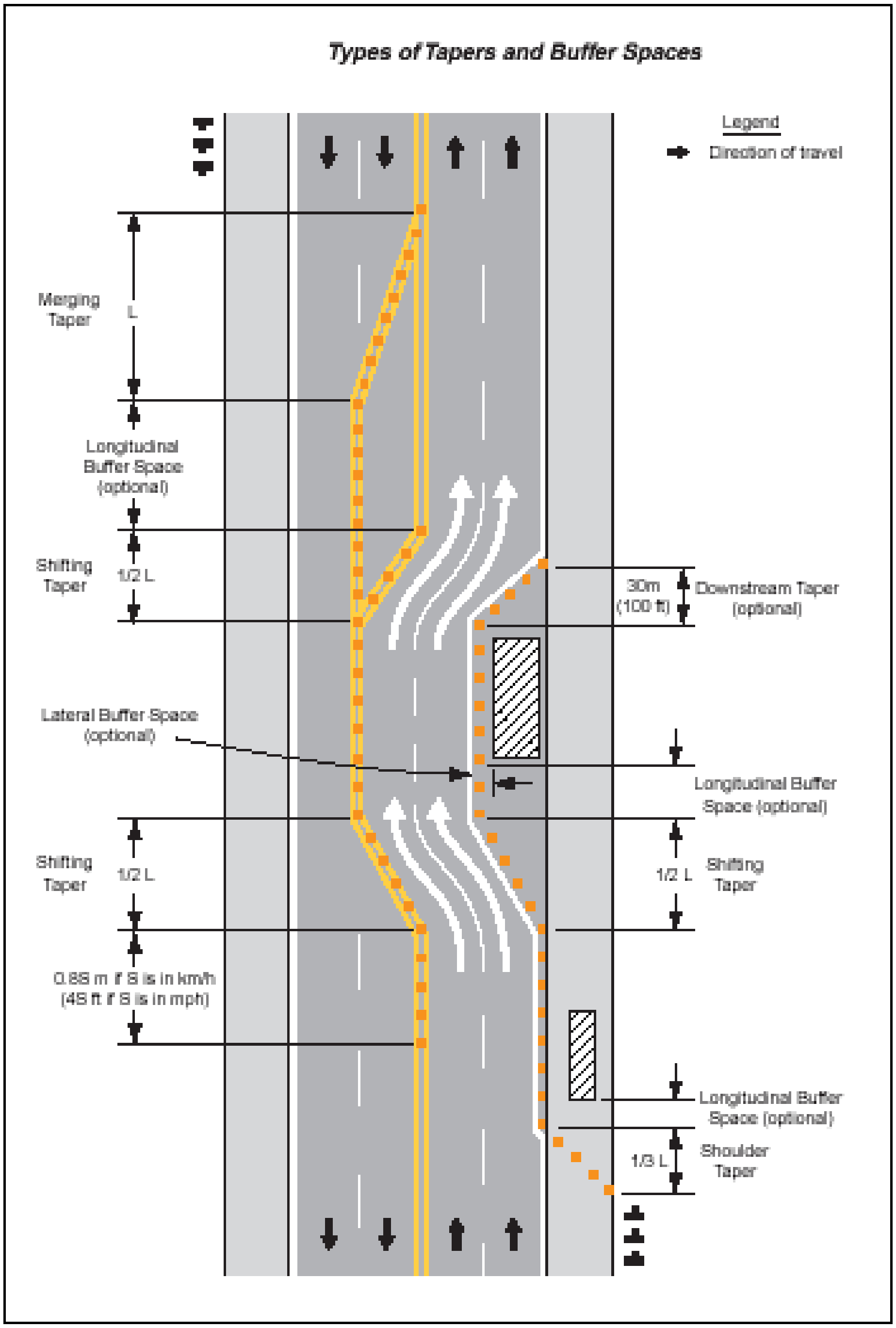

Figure 7
Transition area in a construction zone
[5]

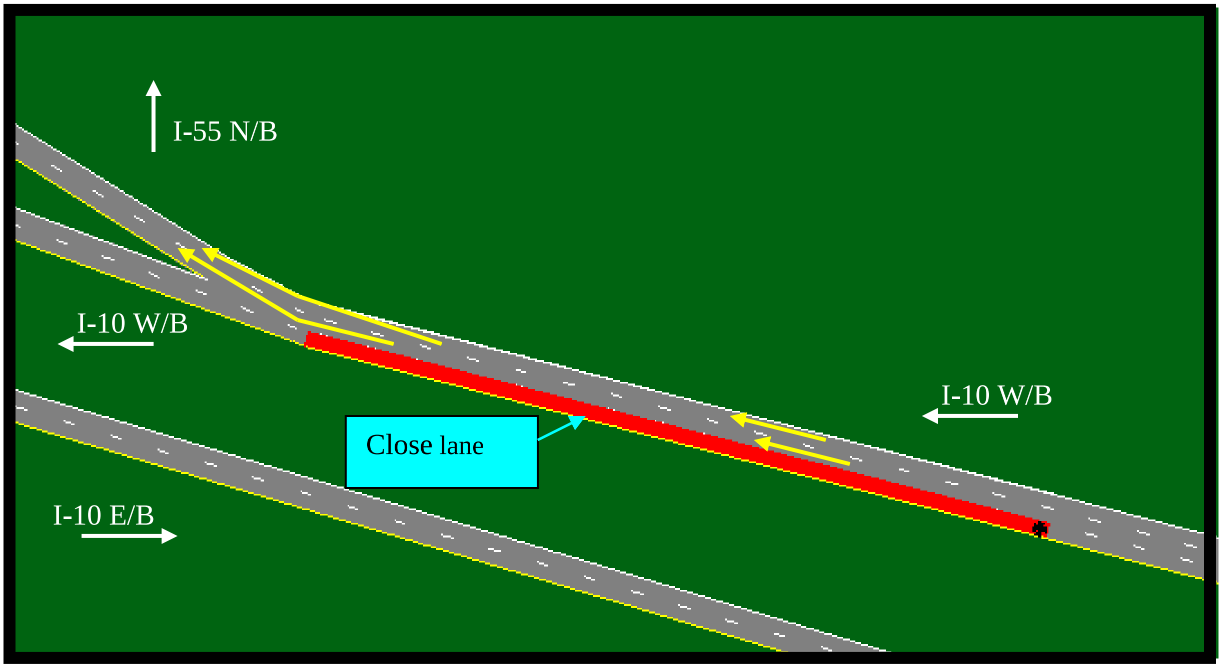

Figure 8
Representation of the closed lane at I-10/I-55 interchange

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

Capacity Limitations

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

Using the fast response behavior, the assumption that 10 percent of the total evacuation volume would depart prior to an order being issued is made. This would result in a demand of nearly 12,000 vehicles prior to the start of the simulation period. Thus, 111,901 vehicles were generated and used in the model. However, this amount was larger than the CORSIM's maximum allowable discharge rate of 8,000 vehicles per hour. To avoid having backups, a constant evacuation response rate of 8,000 vehicles per hour was used for the duration of the simulation. Using a total demand of 111,901 evacuation vehicles and a discharge rate of 8,000 vehicles per hour, 14 one hour periods were needed. Consequently, a simulation of 19 one hour periods was used in CORSIM, assuming a start time of 8:00am. The fact 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 should also be noted. These five extra periods were used to estimate clearance time, as 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 led to CORSIM failure. This was partly because the barriers and the median crossover restricted the flow into the contraflow segment, creating queues. Consequently, CORSIM was not possible to evaluate the expected demand of 111,901 vehicles in the limitation of 19 periods. Based on the output during the 19 periods, CORSIM was able to process 92,650 vehicles.

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

Termination Point Analysis

To evaluate the various contraflow termination point designs, the microscopic computer traffic simulation software package, CORSIM, was used to build and simulate the network models. The flowchart of Figure 9 shows the step by step procedure of preliminary network configurations selection as well as the development of the preliminary network configurations selection into final network models.

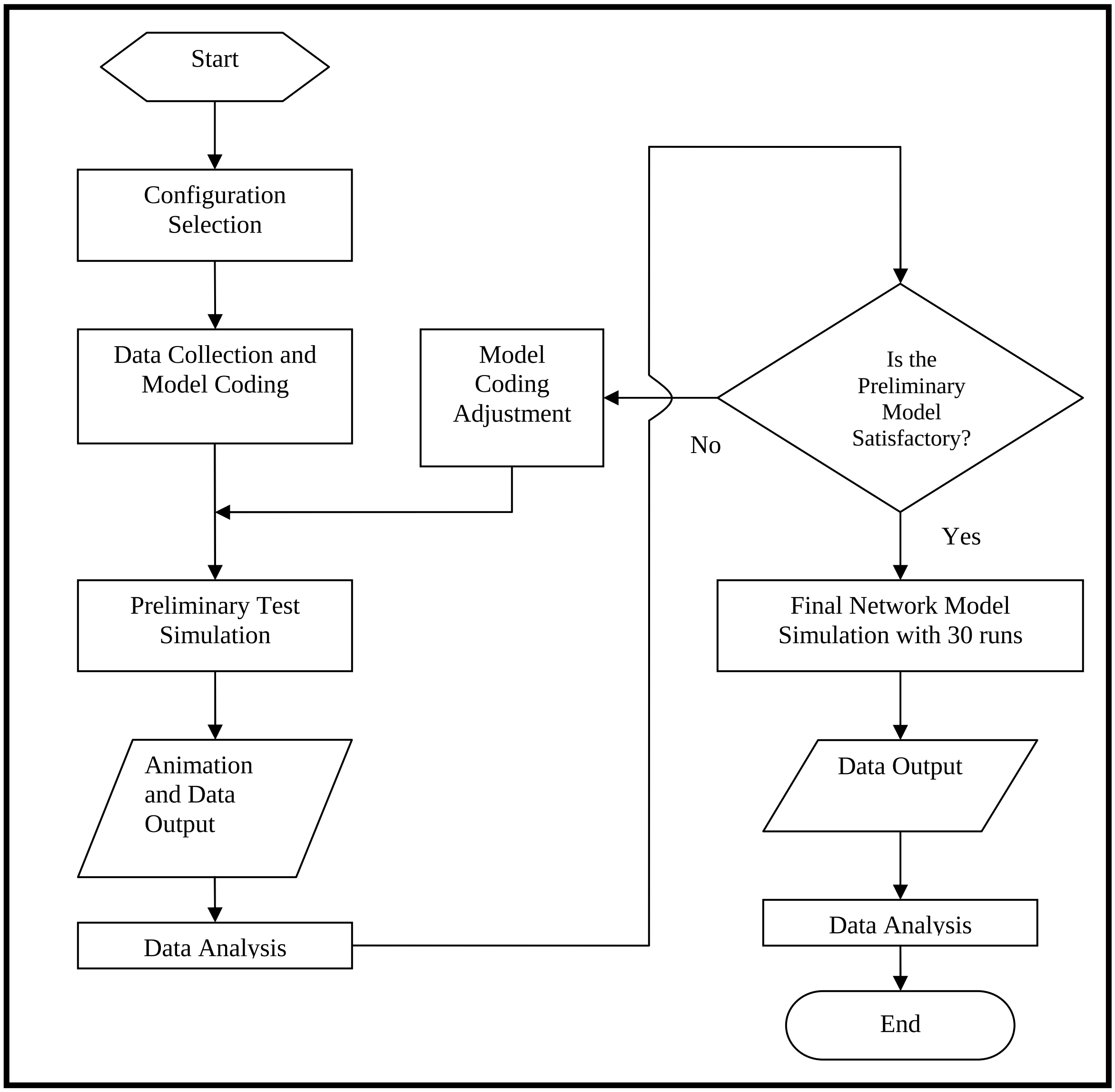

Figure 9
Model building flowchart

Configuration Selection

A review of the existing designs of contraflow termination points available from a prior survey *[6]* found that six types of contraflow termination designs use a median crossover or freeway interchange to redirect the contraflow traffic. Figure 10 to Figure 15 show the six detailed configurations of design in the order of A, B, C, D, E, and F models. These figures show the node and link number that were used to build the CORSIM models. The operating description of each model and input parameters assumption are discussed in the previous section and the following sections, respectively.

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

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

Data Collection and Model Coding

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

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

To simulate and compare the simulation network models, the models were generalized to have the same link distances and speed limits. Various detailed aspects of the roadway design geometry for each contraflow termination point design were based on American Association of State Highway and Transportation Officials standard criteria *[7]*. The major assumptions made in this study for the CORSIM input data were:

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

The details of these assumptions are discussed in the next sections.

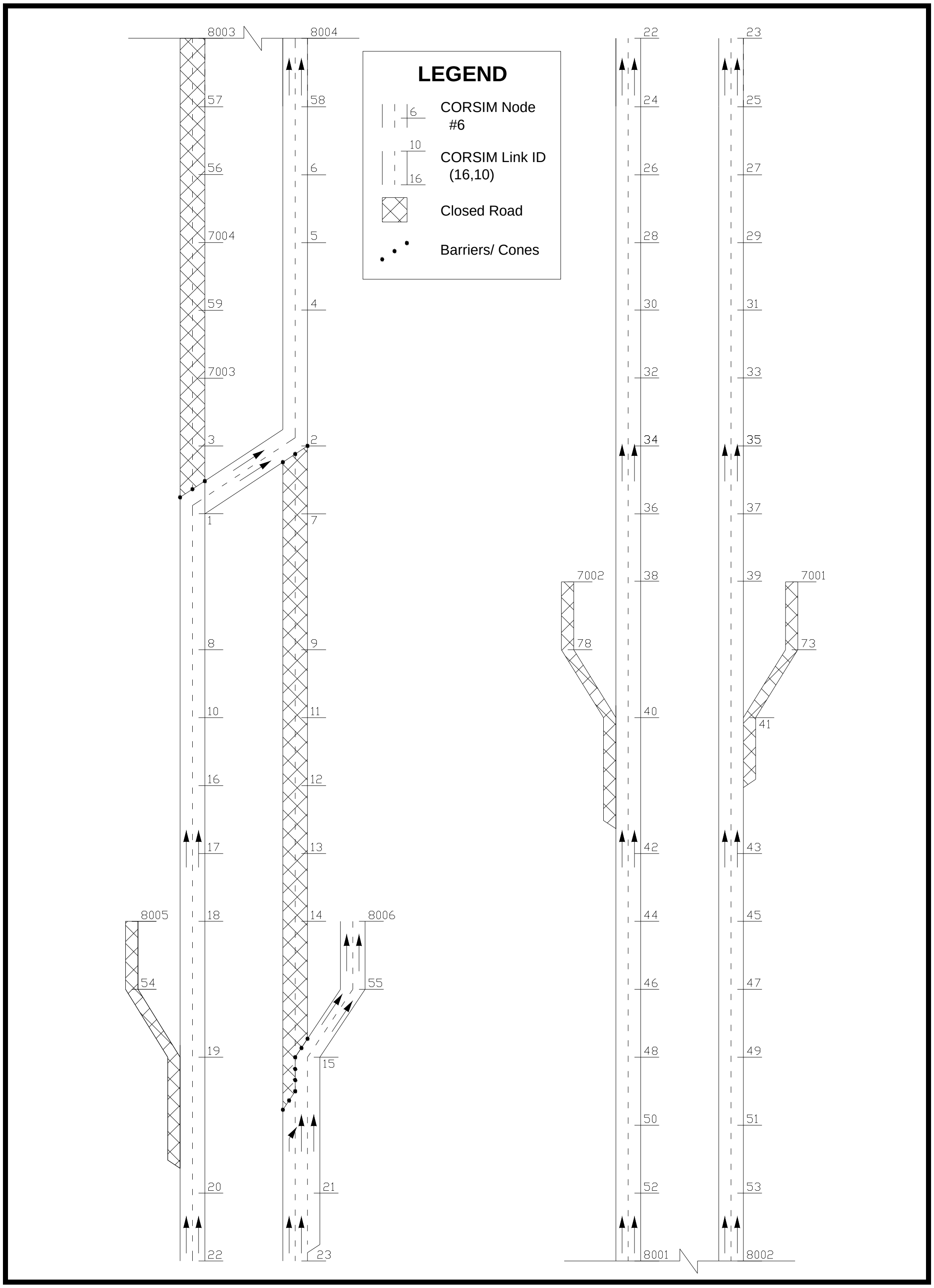

Figure 10
Type A model

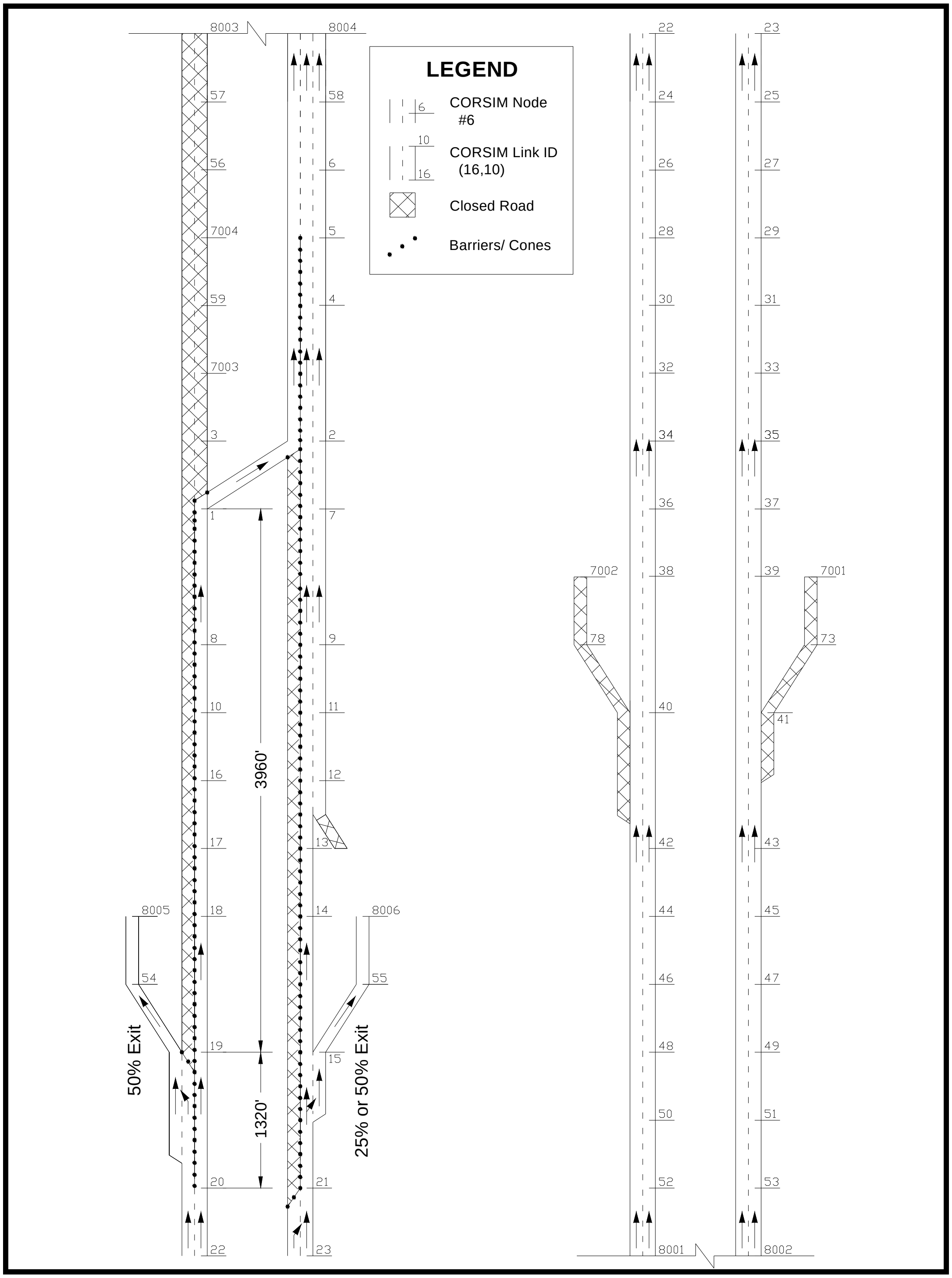

Figure 11
Type B (B_{25}, B_{50}) model

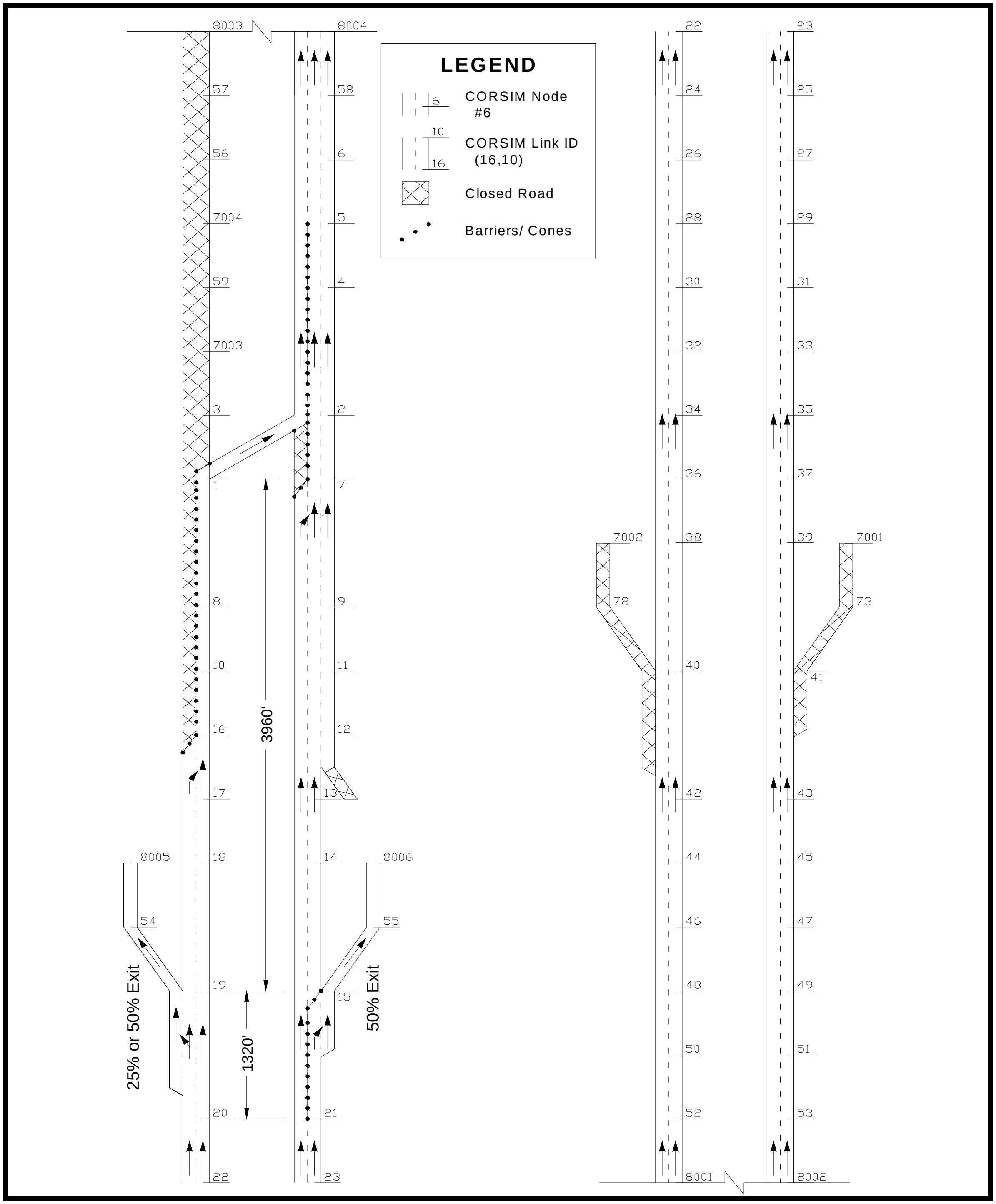

Figure 12
Type C (C_{25}, C_{50}) model

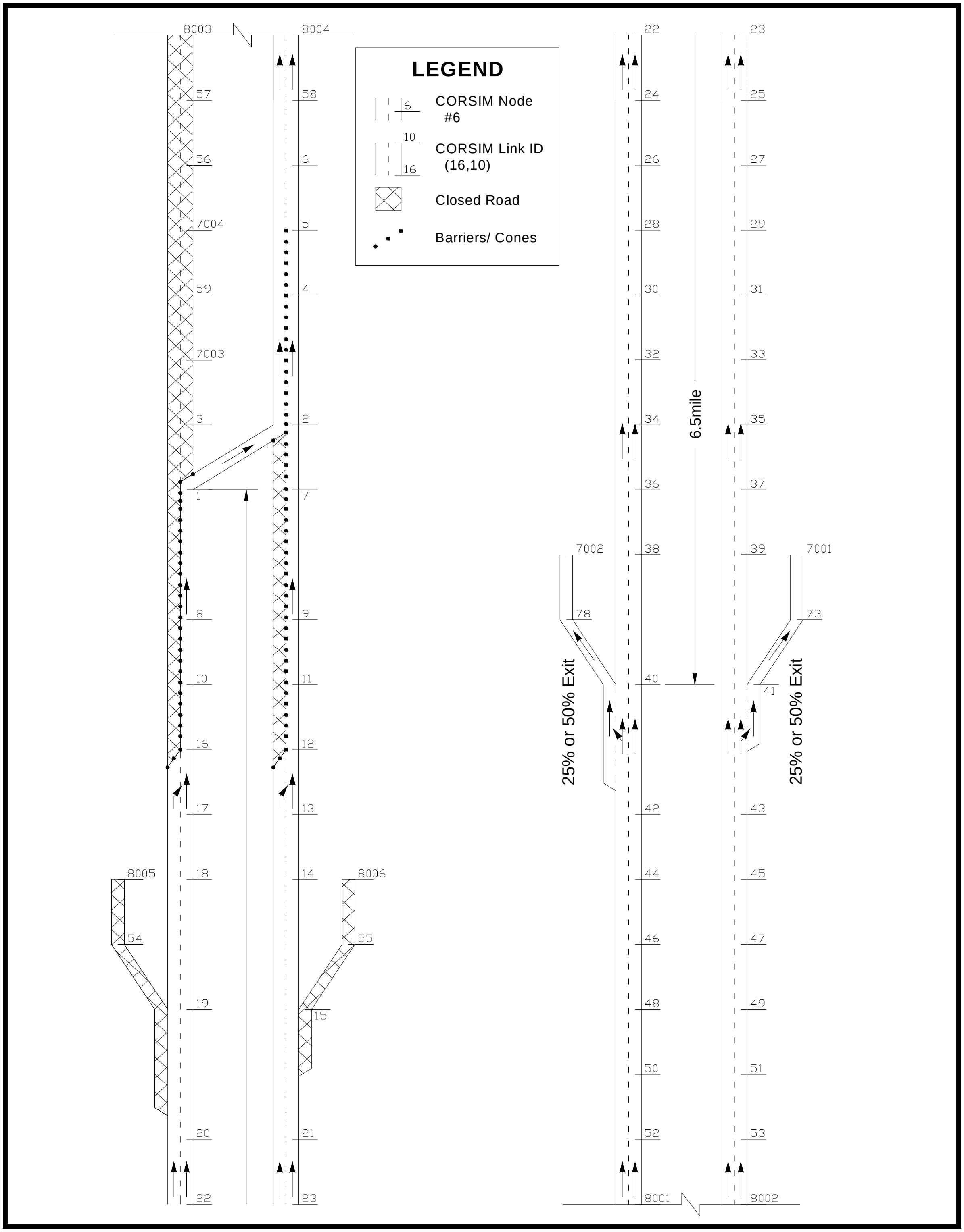

Figure 13
Type D (D_{25}, D_{50}) model

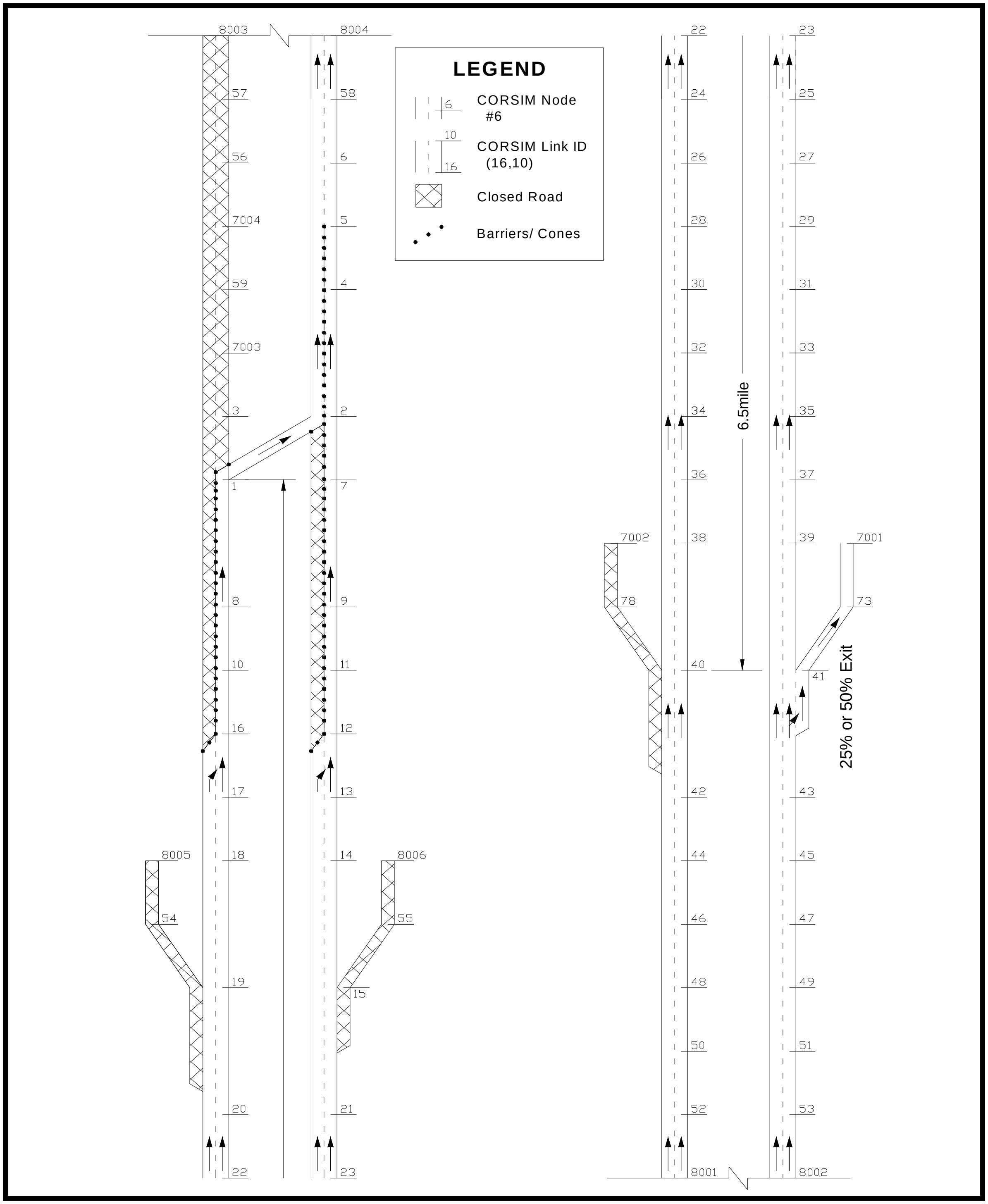

Figure 14
Type E (E_{25}, E_{50}) model

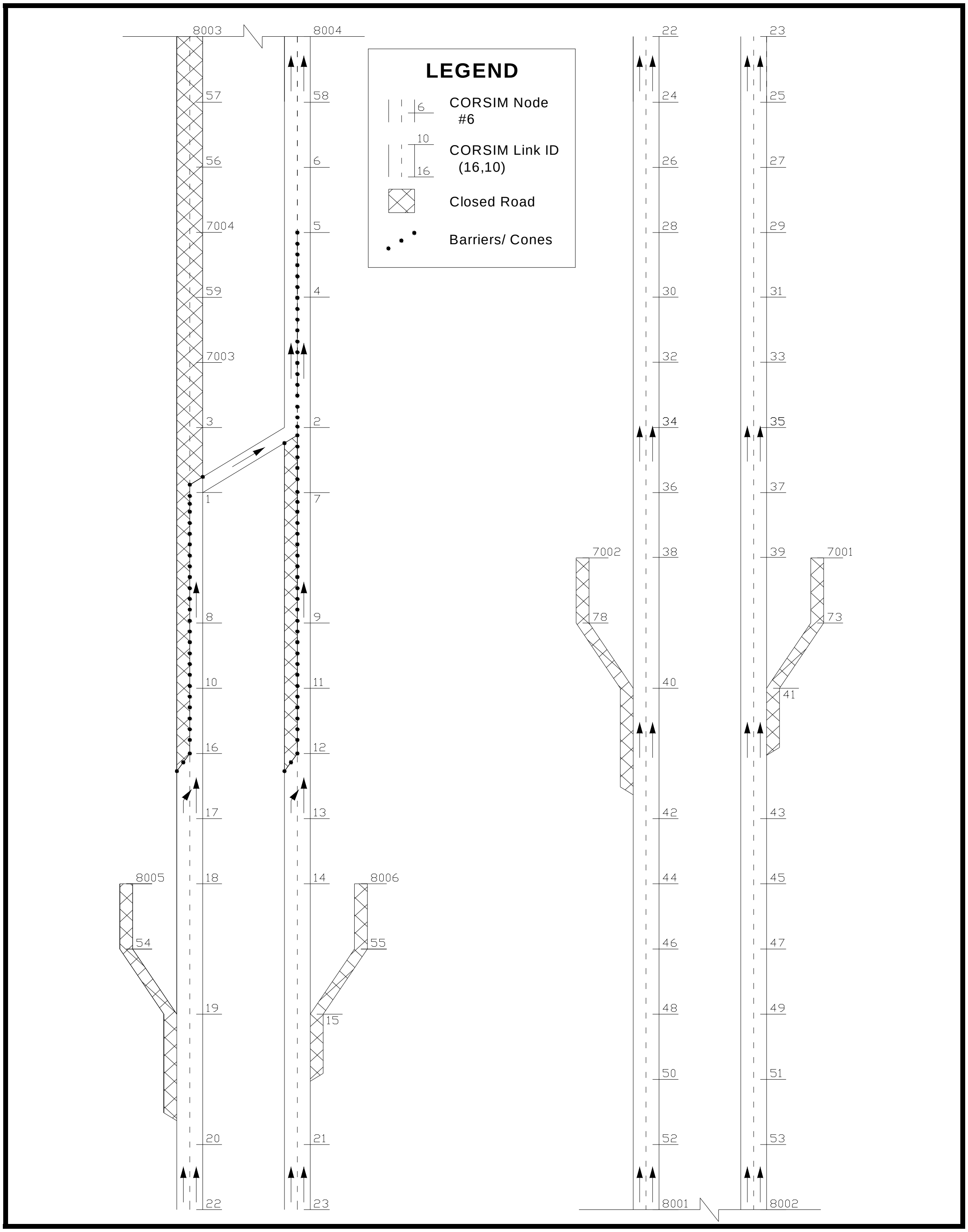

Figure 15
Type F model

Selection of Traffic Flow Direction Percentage

In this research, a conservative traffic distribution of 45/55 was used on the reversed and normal lanes. This distribution ratio was the average value of numbers based on the recent studies of contraflow for college sports events *[8]* and the I-37 reverse flow analysis *[9]*. The first study showed that there was not much difference between the reverse flow and normal traffic movements. In the latter study (I-37), a 40/60 distribution was used on the reversed and normal lanes.

Selection of Traffic Turning Movement at Exit Ramp

Table 1 uses different exiting percentages at the off ramp. Types B, C, D, and E models were subdivided into Type B_{25}, B_{50}, C_{25}, C_{50}, D_{25}, D_{50}, E_{25}, and E_{50} models, where the subscript following the model type indicates the different exiting traffic percentages of 25 percent and 50 percent turning movements at the off ramps, respectively.

Table 1
Exiting traffic percentage at the interchange for simulation models

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

Traffic turning movement at the exit ramp was assumed to be controlled either by a barrier divider or with on-site police enforcement. In this study, 25 percent and 50 percent of traffic was assumed to exit at the exit ramps. In some cases, due to each specific configuration design, 100 percent, 50 percent, or 0 percent of traffic turning movement might occur at a particular off ramp. Barrier dividers can be configured to direct all traffic to make a mandatory exit, force a particular single lane of traffic to exit, or close the off-ramp. For the Type A model, all traffic was directed to the exit with the two lane off ramp at the termination point of normal flow direction. In this study, the barrier dividers for the Type B and C models were assumed to achieve 50 percent exiting traffic at the offramp using advance warning signs to notify drivers who are traveling on the restricted lane to make a mandatory exit for the Type B models. A barrier divider was set up before the contraflow off ramp to direct all traffic using the left lane to exit. In the same manner, for the Type C model, a barrier divider was set up before the normal flow off ramp to direct all traffic using the right lane to exit. In Figure 16, white lines on the freeway show the setup of barrier dividers in the simulation network models.

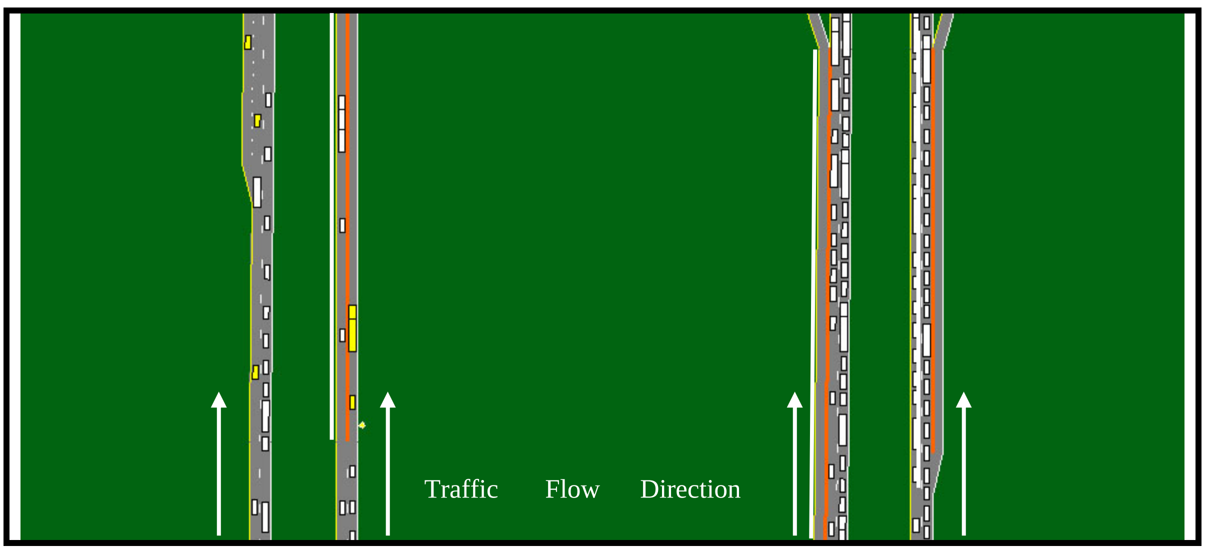

Figure 16
Barrier divider setup in CORSIM

Selection of Truck Percentage

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

Figure 17
Hurricane evacuation photos
(Photo Source: The Corpus Christi Caller Times)

However, as shown in Figure 17, the aerial photos taken of the previous evacuations showed that a truck percentage of 30 percent could be considered a high value. The 2001 FHWA *Highway Statistics Annual Report* showed that the heavy vehicle percentage on an interstate system was around seven percent to eight percent, which is the total percentage of three axle or more combination trucks *[10]*. Prior studies showed that evacuees tend to bring all of the belongings they can carry during an evacuation *[3 and 4]*. Hence, in this study, a double amount of heavy vehicles was assumed to occur during an emergency evacuation, meaning 15 percent of the total amount of traffic would be heavy vehicles such as trucks, recreational vehicles, vehicles with trailers or boats, etc.

Selection of Geometric Design and Speed Limit

A generic 13 mile segment of two lane freeway prior to the contraflow termination point was coded for each configuration. Based on the design speed from AASHTO, the free flow speeds of 65 mph and 35 mph were assumed for the freeways and off ramps, respectively. In this study, the speed limit on the median crossover was assumed to be 45 mph. This was based on the designs of *I-4 Emergency Crossover Design Plan* and *I-65 Northbound Crossover Design Plan* from the Florida Department of Transportation *[11]* and the Alabama Department of Transportation *[12]*. Figure 18 and 19 show these design plans.

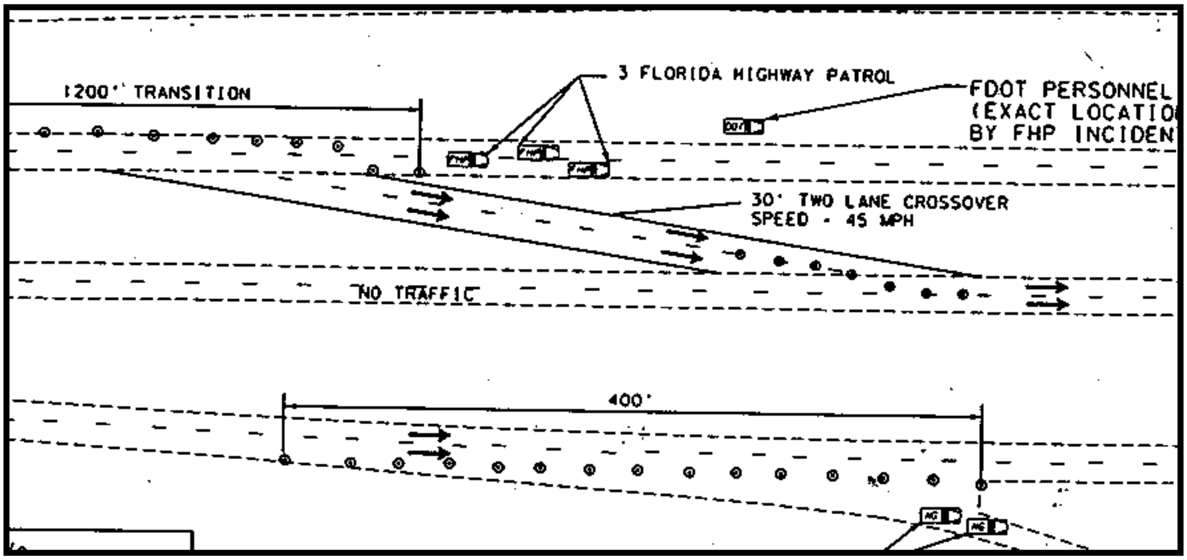

Figure 18
I-4 emergency crossover design plan
(Source: Florida Department of Transportation *[11]*)

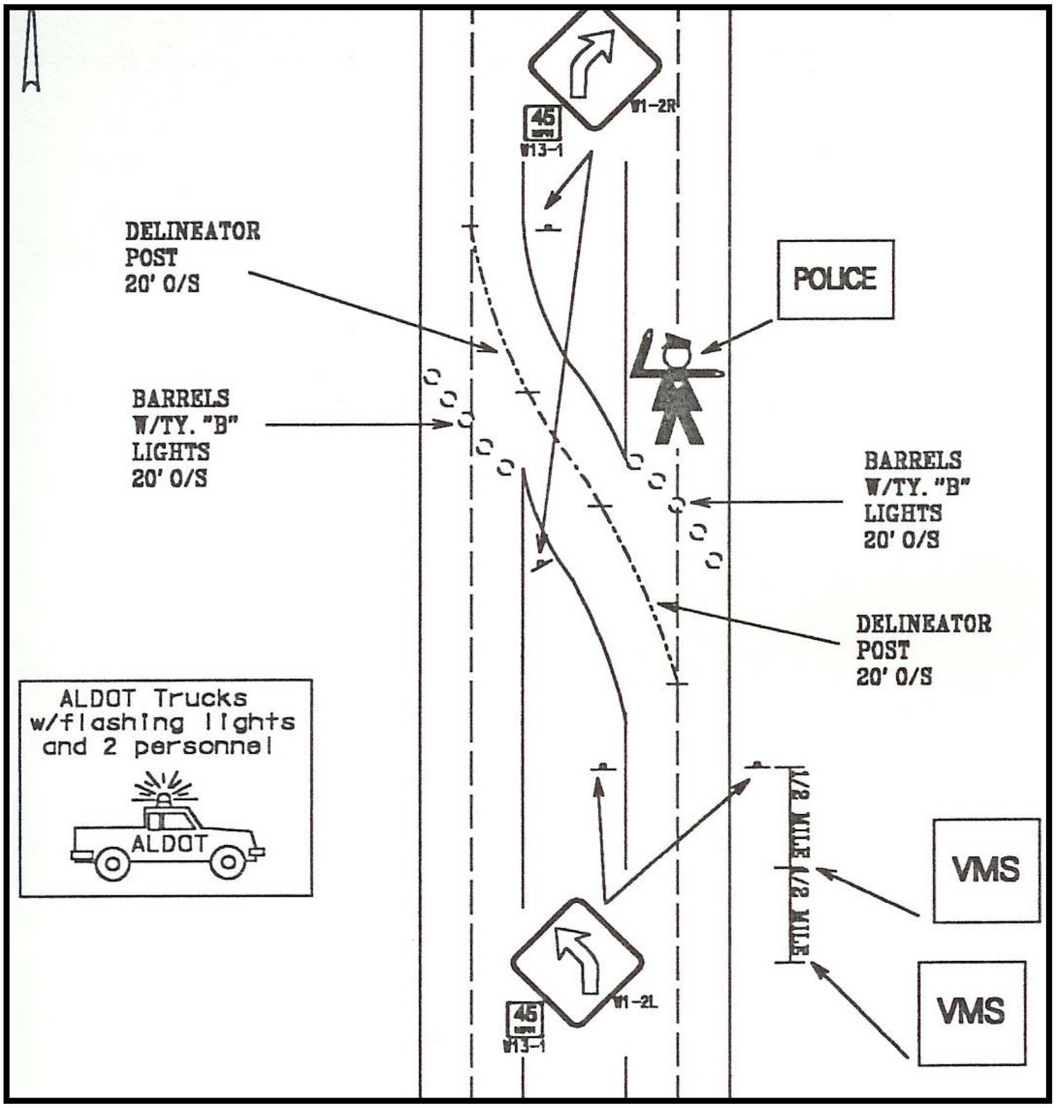

Figure 19
I-65 northbound crossover design plan
(Source: Alabama Department of Transportation *[12]*)

Incidents/Blockages Setup on Network Model

CORSIM can be customized to simulate lane closure traffic operation using the incident function. In this research, incident events were created on certain segments of the network models to enable CORSIM to represent two lanes, reducing to one lane at those lane closure segments. Lane blockages were set up on the freeway and assigned a warning sign one mile away from the incident location. The white band in Figure 20 shows the lane blockage set up on the left lane of the freeway. The location of the first incident warning sign is usually set up one mile ahead of the incident location and reads “One-Way Ends 1 Mile.”

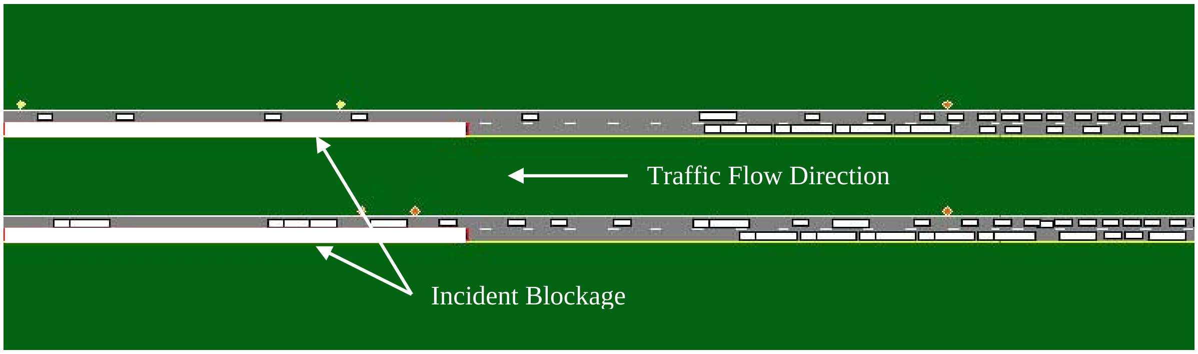

Figure 20
Incident blockage setup

Model Revision and Evaluation

TRAFVU was used to display animations of the 10 preliminary models. Each model was checked and revised until more realistic traffic conditions were achieved. Although CORSIM provides a large number of parameters for fine tuning the simulation models to achieve imitated real traffic conditions, no actual data of contraflow operation for validation were available at the time that this study was conducted in 2005. A calibration of the simulation models should be done for relative accuracy using the on-screen animation and model outputs.

Parameters Adjustment in CORSIM

In this study, most of the parameters in CORSIM used the given default values. The only parameter adjusted was the *Minimum separation for generation of vehicles*. This parameter controls the maximum flow rate of vehicles entering the entry nodes in CORSIM. Under ideal traffic operation and geometric conditions, the capacity of a freeway can reach 2,400 passenger cars per hour per lane (pcphpl) *[13]*. To create a heavily congested condition on the simulation model, a value of 1.4 seconds was used in all simulations that allowed a flow of 2,500 vphpl to be achieved when entering the entrance links on the network simulation models. As the default value of *minimum separation for generation of vehicles* in CORSIM was set at 1.6 seconds, the traffic flow entering the freeway was limited to 2,250 vphpl.

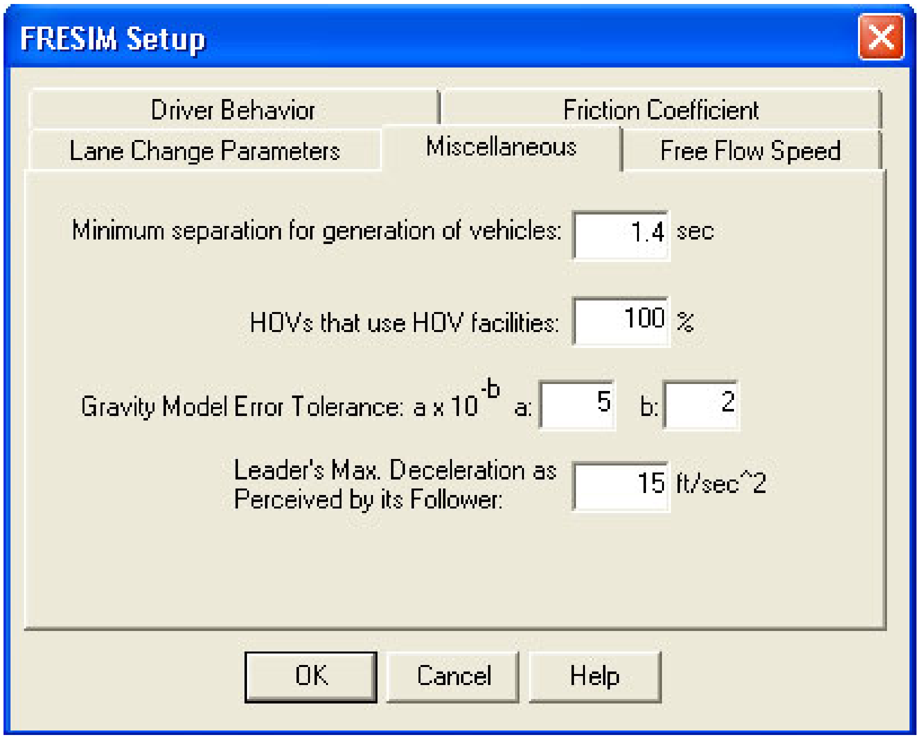

Figure 21
FRESIM setup

Selection of Traffic Volume for Final Simulation Models

First, for the model development process, a traffic volume of 5,000 vph was used to code and develop the ten preliminary testing simulation models. This volume was assumed based on a prior study *[14]*. The prior study showed that all lanes in reversed contraflow operation (two reversed inbound lanes plus two normal outbound lanes) can provide an outbound traffic volume of 5,000 vph. After the creation of the 10 preliminary testing simulation models, these models were conducted using different traffic flows of 4,000 vph, 5,000 vph, 6,000 vph, 7,000 vph, and 8,000 vph. A total of 50 runs was executed using a simulation time of four hours, representing the cumulative network-wide average statistical results of the five preliminary test simulation groups.

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

Preliminary Test Simulation

Interested readers are suggested to refer to the accompanying data disk for a description and quantitative details of the preliminary test simulation.

ANALYSIS

Since the simulation process of CORSIM is stochastic, each scenario was executed a total of 30 times using different seed numbers to establish a large range of traffic conditions and MOE values. The results represented the averages of these multiple runs.

The results and of the simulations and their accompanying analyses showed both expected and unexpected results. As expected the models clearly demonstrated the enormous benefits that can be gained by contraflowing the inbound lanes to serve outbound traffic during an evacuation. More interesting, however, was that the research showed that contrary to the widely held view, the traffic volume on the contraflow segment never exceeded its capacity. Although it was not due to the availability of two additional lanes, rather this underutilization was due to the flow restriction created by the planned loading of the section as well as the entry point design.

In its current state, the LSP plan calls for the three outbound lanes of westbound I-10 to be divided into four lanes (two normal and two contraflow). Based on the results of simulation this adds an additional 73 percent to the existing (non-contraflow) outbound capacity. However, since it is expected that traffic operations within the vicinity of the crossover are expected to diminish free flow speeds by 10 to 15 miles per hour, a bottleneck is created as flow through the area would be about 1,000 vphpl. This would result in a condition similar to those of the classic freeway lane drop scenario. The simulation suggests that under the demand generated by an evacuation this would create congested conditions that would extend for many miles upstream.

The simulation also suggests that traffic approaching the Loyola Avenue split would move through the crossover at flow rates at or near capacity, then at a near free flow state throughout the remainder of the segment since there are no other downstream capacity limiting restrictions in the system. Thus, it would be expected that if no incidents occur, no congestion would be apparent through with the length of the intermediate section.

The recognition of this condition led to the development of Plans C and D. Both of these scenarios propose to take advantage of the excess capacity that exists within the contraflow segment by adding traffic evacuating from the Westbank of the Mississippi. The volume added from one or both I-310 ramps would increase the utilization of the contraflow segment adding volume that would permit it to operate nearer to its capacity and, most importantly, significantly increasing the total number of people that can evacuate the New Orleans region.

When compared to the non-contraflow plan the study results clearly demonstrate both the benefit of the existing LSP contraflow plan the added benefit that could potentially be gained by the C and D alternative loading scenarios. The LSP contraflow plan increased the daylong evacuation volume through this segment by nearly 53 percent or a total of 30,538 vehicles over a non-contraflow use configuration. Similarly, the alternative scenarios of using I-310 to load additional vehicles into the segment would add another 10,000 to 26,000 vehicles over the current LSP plan and would nearly double the total exiting volume of a conventional (non-contraflow) configuration. These statistics become even more significant when it is also realized that the typical occupancy of vehicles during an evacuation has been estimated at about 3.5 passengers per vehicle.

The CORSIM models were also able to show the operating conditions within the various segments of the contraflow section. Average speeds and travel times for vehicles traveling within the contraflow section were calculated from the individual link segments. Evacuees in the contraflow lanes under Plan C experienced the best travel conditions. Travel speeds in these lanes averaged nearly 49 miles per hour (mph) with a travel time of about 17 minutes across the 14-mile segment. In contrast, traffic in the normal outbound lanes of the segment in Plan C and D experienced speeds of about 20 miles an hour and travel times of about 40 minutes. Though less than the contraflow lanes, these benefits came from the fact that the increased densities that accompanied these lower speeds also increased the overall flow rate through this section. Statistical testing (the results of which are not included here) also supported the significance of these conclusions.

Interested readers are suggested to refer to the accompanying data disk for a complete description of the analytical process and quantitative details of the analysis output.

CONCLUSIONS

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

Termination Points

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

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

The results of the "number of vehicles processed" measures were also consistent with the findings above. Again, the A, C_{50}, and D_{50} models showed the best performance, with C_{25} close behind. One of the more interesting results was that, despite the fact that the A model maintained all lanes open, its average hourly flow rate (1,441 vph) was just below the C_{50} and D_{50} models (1,463 vph and 1,462 vph, respectively). At the opposite end of the spectrum, the F model, with no exits or lane drops, merges on both the normal and contraflow lanes. The F model had average hourly flows of 822 vph, just more than half of these rates.

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

When the general relationship of traffic volume is plotted against its corresponding travel delay resulting from the lane drop merge, shown in Figure 22, the fact that delays and travel times increase fairly rapidly once traffic volumes begin to exceed half of the maximum flow volumes is evident. This would strongly suggest that the use of intermediate exits throughout the length of the segment to diminish traffic volumes at the termination of the contraflow evacuation segment would be advantageous.

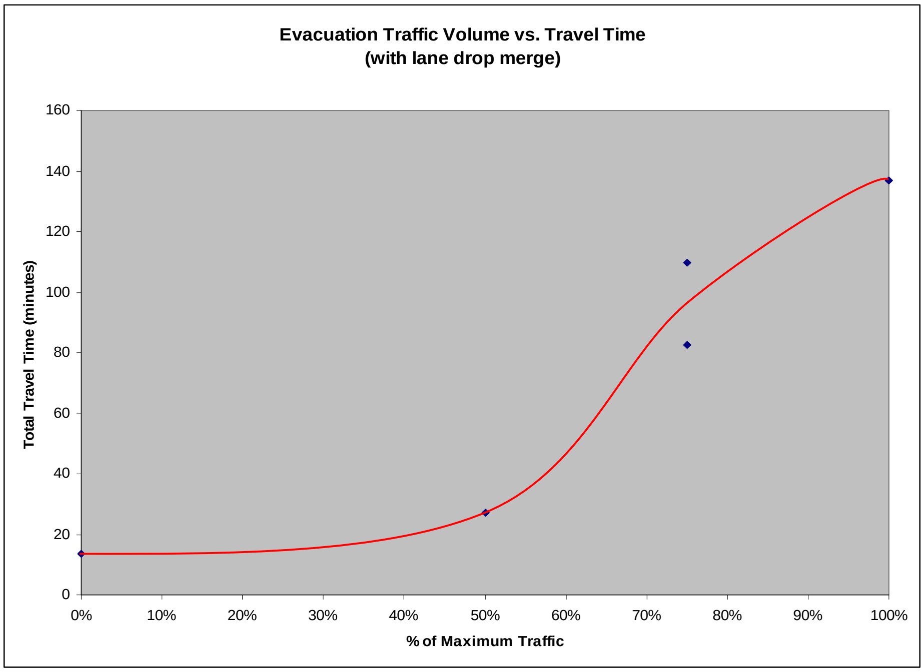

Figure 22
Relationship of traffic volume and travel time on the test route

Initiation Point

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

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

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

Simply put, this would result in a condition similar to that of the classic freeway lane drop scenario, as diagrammed in Figure 23. In this scenario, traffic approaching the Loyola Avenue split would move through the crossover at flow rates at or near capacity, then at a near free flow state throughout the remainder of the segment, as there would be no other downstream capacity limiting restrictions in the system. Thus, the fact that if no incidents occur, no congestion would be apparent within the remaining segment downstream of the initiation point would be expected.

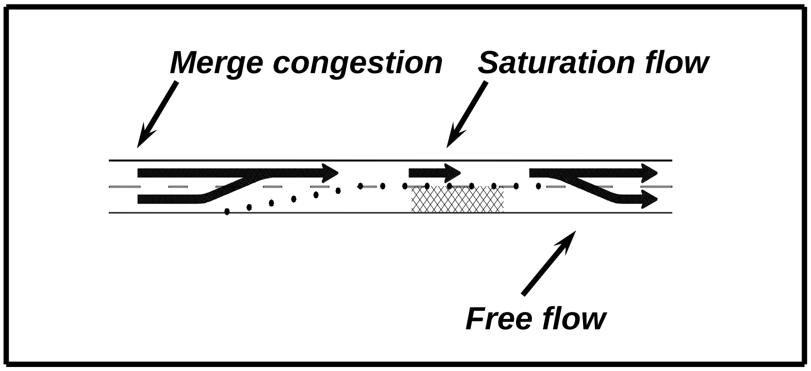

Figure 23
Lane drop bottleneck diagram

Plans C and D proposed to take advantage of the excess capacity that exists within the contraflow segment by adding traffic evacuating from the west bank of the Mississippi. As illustrated in Figure 24, the volume added from one or both I-310 ramps would increase the utilization of the contraflow segment, adding volume that would permit it to operate nearer to its capacity and, more importantly, would significantly increase the total number of people that can evacuate the New Orleans region.

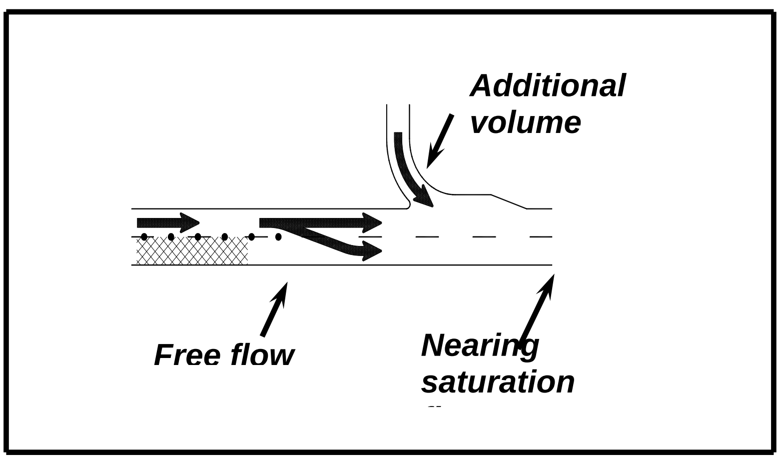

Figure 24
Increased utilization of contraflow segment

When compared to Plans A and B, the study clearly demonstrates that benefits could be realized using the C and D alternative loading scenarios. As Table 2's comparison of total exiting volume shows, the LSP contraflow plan increased the day long evacuation volume through this segment by nearly 53 percent, or a total of 30,538 vehicles, over a non-contraflow use configuration. Similarly, the alternative scenarios of using I-310 to load additional vehicles into the segment would add another 10,000 to 26,000 vehicles over the current LSP plan and would nearly double the total exiting volume of a conventional (non-contraflow) configuration. These statistics become even more significant when the typical occupancy of vehicles during an evacuation has been estimated at about 3.5 passengers per vehicle is recognized.

Table 2
Comparison of total exiting volume

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

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