Effects of incidents on freeway capacity

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Summary

Congestion on freeways has always been a big problem in the field of transportation. Over the years solutions for congestion problems have shifted from building new, and expanding existing roads to improving traffic operations on the existing freeways. On freeways, traffic operations can be affected by incidents, such as car crashes and disabled vehicles. Statistics show that incidents on freeways have a big impact on traffic operation, making up one-third of traffic delay in urban areas (U.S. Department of Transportation Federal Highway Administration Office of Operations, 2008). With this large influence of incidents on traffic operations, it is very effective to improve traffic operations by focusing on delay caused by freeway incidents.

To reduce delays caused by freeway incidents, incident management systems are in place. To make the incident management systems work and to improve them, the consequences that freeway incidents and measures of incident management have on traffic operations must be understood. The contribution of this report on to better understand the effects of incidents and measures to reduce delay is twofold. First there will be a focus on the effects that incidents have on capacity. Secondly, a microscopic traffic simulation tool is assessed on its capabilities of modeling incidents and their effects on traffic on a freeway that can be used to evaluate incident management strategies. Combined these two objectives can aid in the evaluation of incident management strategies.

Traffic incident management systems used for the reduction of delay caused by incidents are comprised of distinct activities that form the incident management process. These activities are carried out by personnel from a variety of response agencies and organizations. Although the activities are very distinct, they can however be performed simultaneously. The seven activities of incident management are:

- Detection
- Verification
- Motorist information
- Response
- Site Management
- Traffic Management
- Clearance

Detection is notification of the agency or agencies responsible for maintaining traffic flow and safe operations on the facilities. When the agencies are notified the incident is verified from an independent source to confirm it really happened. After confirmation the necessary agencies respond to the incident and assist in the clearance process. During the clearance motorists are informed of the incident location and best alternatives to avoid the affected roadway by 511 motorist information via the Traffic Management Center. At the site the appropriate agency is in charge or the agencies work coherently together to clear the incident.

An important part in seeing if measures against incident related delay can improve traffic operations is to look at how incidents affect freeway capacity. The premier reference in the United States regarding capacity related information is the Highway Capacity Manual 2000 (HCM). The HCM provides an analysis procedure for freeway facilities and in this analysis information is presented on the effects of incidents on capacity. The information on the effects of incidents on freeway consists of adjustments factors for capacity when different lane closures occur during incidents. This information, however, is outdated and somewhat limited. The main limitations are that it does not make a distinction in capacity reduction between minor and major incidents and it does not give

information on capacity reduction due to rubbernecking in the opposite direction of travel. The age and limitations of the material make it desirable to update the material on incidents affecting capacity in the HCM.

The limitations and age of the material in the HCM make it very desirable for the Highway Capacity and Quality of Service Committee (HCQSC) of the Transportation Research Board (TRB) to update the information on the effects on capacity from freeway incidents. The synthesis however shows that the information on the topic in more recent research is also very limited. There is simply very little research done on capacity reduction due to incidents on freeways. A comparison of the results that were found is shown in the table.

Table. Comparison of research outcomes

Study	Road characteristic	Lane configuration	Capacity reduction
Goolsby	Three-lane freeway	1 lanes blocked	50%
		2 lanes blocked	79%
		Shoulder blocked	33%
Smith et al.	Three-lane freeway	1 lanes blocked	63%
		2 lanes blocked	77%
		Shoulder blocked	N/A
Knoop et al.	Two-lane freeway	1 lane blocked, shoulder open	50%
		1 lane blocked, 1 lane open	53%
Chin et al.	Three lane freeway	1 lanes blocked	47%
		2 lanes blocked	78%
		Shoulder blocked	16%

The figures in the table show that the reductions in capacity are similar to each other. However it is vital that more research is being performed on the topic, so that results can be generalised. A good addition to the HCM could be the research performed by Masinick & Teng, 2004 on the effects of rubbernecking for the opposite direction of travel. Future research should focus on the same type of incident on different freeways, so that insight can be gained in a uniform reduction factor for certain lane closures. Furthermore future research should consider characteristics of incidents such as time of day (i.e. peak vs. off-peak vs. night time), portion of the freeway affected (e.g. vehicles on the shoulder, single lane closure, two-lane closure, full closure) and duration (1-hour, 2 hours, etc.).With more research on the topic a better update of the HCM can be realised with better and more complete information.

To further improve incident management systems, new strategies are planned within various areas of the incident management systems. These strategies need to be evaluated before, during or after implementation. A low-cost manner to evaluate different strategies is the use of a microscopic traffic simulation tool, because no strategy has to be implemented in reality. However the use of the simulation tool is limited to evaluating strategies for certain activities. Because the simulation tool is only useful for activities related to traffic flow, it is most effective when used for the activities of Traffic Management and Motorist Information. The microscopic simulation tool CORSIM was evaluated on its capabilities of modeling incidents and their consequences on a freeway. CORSIM is a useful tool for modeling incidents since it has a special option for modeling incident, so that a lane-blocking (incident) does not have to be created indirectly. Within the special incident option in CORSIM the most important inputs for modeling the incident on the freeway network are provided, such as the location, duration, lanes affected and rubberneck factor. The rubberneck factor is the extra capacity reduction due to the incident besides the physical capacity reduction. The rubberneck factor must be determined by the user and can be estimated using the field data or a reference such as the HCM, which makes it important that the HCM contains reliable information. The program has a limitation in the modeling that for simulating incidents would have been ideal. This limitation is the fact that law enforcement presence cannot be modeled into CORSIM, although it can be attempted indirectly via another parameter. Furthermore a flaw is present in the CORSIM tool. In the current version of CORSIM the merging process behind incidents does not work correctly, so repairing it and maybe including the special merging process for incidents should enable CORSIM to produce better results in simulating incidents. All in all CORSIM could be very useful in evaluating incident management strategies when the merging problem is fixed.

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1. Introduction

Traffic congestion is a great concern in all motorized countries, and the United States is no exception. The delays induced by congestion result in significant economic impact, among other things. Causes of congestion are generally classified as recurring and non-recurring. Recurring congestion can be defined as congestion occurring under normal conditions due to traffic volumes exceeding road capacity. Non-recurring congestion can be defined as an excess in traffic demand for a road section, due to special conditions. These special conditions can include incidents, adverse weather, construction activities, etc.

This study will focus on incidents occurring on freeways. An incident is defined as a non-recurring (generally random) event that causes a reduction of roadway capacity, which shows its uniqueness in occurrence. (Highway Safety Committee, 2004) Incidents on freeways can be classified as simple or complex incidents; with simple incidents the clearing time is much lower than with complex incidents. The difference between incidents is largely based on their duration, with complex incidents taking longer to clear than simple incidents. Examples of simple incidents include:

- Debris on the road
- A disabled vehicle in a traffic lane or on a shoulder

Examples of complex incidents include:

- Vehicle crashes involving serious or fatal personal injury
- Vehicle crashes involving hazardous material cargo
- Vehicle crashes where a load of cargo is spilled
- Vehicles on fire
- Overturned vehicles

Over one third of the traffic congestion in urban areas in the United States is caused by traffic incidents. (Ozbay & Bartin, 2003) Thus, it is obvious that any reduction in incident frequency and/or severity, as well as incident response and clearance times will result in reduced delays and economic savings. This is why incident management systems are in place in many cities to reduce congestion and time lost due to incidents. Many transportation agencies have Traffic Management Centers (TMC) that are generally responsible for planning and implementing incident management systems.

In order to make the incident management systems as efficient and effective as possible, the transportation agencies try to understand the roadway where the incident occurs and the entire roadway network around the incident location. Also the incident management systems are evaluated by either performing field studies or using traffic simulators. A benefit of traffic simulators is that they can evaluate the incident management systems prior to implementations and investigate different alternatives, whereas field studies can only evaluate one incident management system for one location. This research will try and contribute to the understanding of the effects of incidents on capacity on the freeway, by performing a literature study on capacity reduction on freeways. By evaluating the traffic simulation tool CORSIM, it is determined whether or not CORSIM, with its special incident option, can be used in the evaluation of incident management strategies. The key questions that will be answered in this report are:

1. What are the different activities in Incident Management and where can the HCM and the simulation tool be used?
2. What are the limitations of the information on capacity reduction due to incidents in the HCM?
3. Is there research on traffic incidents and their impact on freeway capacity present in recent research and can it contribute to the HCM?
4. Is it feasible to use the CORSIM simulation program to evaluate incident management strategies?

The organization of this document is as follows: Chapter 2 provides an overview of the HCM with respect to its strengths and limitations on the subject of capacity reduction from freeway incidents. Chapter 3 provides a synthesis of recent research on the subject that can help fill in the voids of the HCM. In the synthesis an overview of recent research is given with a discussion on the important studies at the end. In chapter 4 a review of state-of-the-practice in incident management is presented. For this review a visit to the Traffic Management Center (TMC) in Jacksonville, Fl was made, to see firsthand how an incident is being handled. In chapter 5 the microscopic traffic simulation tool CORSIM is being evaluated on its capabilities of modeling freeway incidents. For the evaluation a real incident is being used.

2. Overview of HCM 2000 Freeway Facilities Procedure

The Highway Capacity Manual (HCM) (Transportation Research Board, 2000) is the standard reference on freeway capacity in the United States and the most important source of capacity related information. An update of the HCM is tentatively scheduled for release in late 2010, and some discussion within the Highway Capacity and Quality of Service Committee (HCQSC), which oversees development and production of the HCM, has taken place on the extent and accuracy of the information presented on the effects of incidents on capacity. This chapter will first provide a more complete description of the HCM, then will describe in some detail the freeway facilities chapter of the HCM, focusing on the information on the effects of incidents on capacity, and finally will summarize the strengths and limitations of the incident information provided in this chapter.

The HCM is published by the Transportation Research Board in the United States. The purpose of the HCM is to provide transportation practitioners and researchers with a consistent system of techniques for the evaluation of the quality of service on highway and street facilities. The HCM does not set policies regarding a desirable or appropriate quality of service for various facilities, systems, regions, or circumstances. Its objectives include providing a logical set of methods for assessing transportation facilities, assuring that practitioners have access to the latest research results, and presenting sample problems (Transportation Research Board, 2000). The transportation facilities for which methodologies are presented are urban streets and freeways. These transportation facilities are then subdivided into segment level procedures that include signalized an unsignalized intersections, two lane highways, multilane highways ramp junctions and weaving segments.

The HCM 2000 freeway facilities analysis procedure allows an analyst to study extended lengths of freeway, which may consist of any combination of basic freeway segments, ramp junctions, and weaving segments (Transportation Research Board, 2000). The analysis procedures can be used to analyze the capacity, level of service (LOS), lane requirements, and effects of traffic and design features on a section of freeway. In the analysis procedure of Freeway Facilities capacity, estimates are necessary as a step in the procedure in determining measures of effectiveness on the Freeway Facility. The estimation of capacity is based on the analysis procedure of the individual segments. The HCM gives analysis methods of capacity for basic freeway segments, ramp junctions, and weaving segments. For analyzing a length of freeway, the analyst must select the right combination of segments to represent the studied freeway section. If conditions occur on the studied freeway sections that cause a reduction in capacity, the next step is to make adjustments to the estimated capacity in the Freeway Facilities analysis. The Freeway Facilities chapter provides some guidance on the selection of appropriate capacity values, as a function of various conditions such as weather, construction, incidents, etc. The focus of this study was on the effects of incidents on capacity, so this particular aspect of the freeway facilities chapter was examined in more detail.

A part of the analysis procedure is that certain conditions, as mentioned before, may be taken into account for capacity reductions. One of these conditions is when incidents occur on the freeway. In this research, the focus is on capacity reductions from incidents occurring on a freeway. This section discusses the strengths and potential limitations of the HCM in dealing with capacity reductions resulting from incidents. To determine potential limitations, there will be a review of information the HCM uses to consider capacity reduction from incidents and to what sources it references.

Furthermore an assessment is made on what type of information is missing from the chapter and what type of information could contribute to the chapter.

To determine the potential limitations of the incident-related capacity information provided in the HCM, the type of information and its source needs to be evaluated. Incidents occurring on freeways are taken into consideration in the freeway facilities chapter, although only to a small extent. There are only three references cited and two of the references are more than 20 years old. That is why there is a discussion on the need to update this information in the freeway facilities chapter, especially since there have been several more recent studies. In order to update the chapter, it is necessary to assess the strengths and limitations of the information that is currently presented in the chapter. The method used in the HCM is based on the normal capacity estimations for different freeway segments and adjusted for the number of lanes blocked. The adjustments are greater than the physical loss in road space, because of different effects incidents have on the behavior of motorists. The adjustment factors are based on a study by Reiss & Dunn Jr. (1991), which is more than 15 years old. After determining what information is present in the HCM, the assessment of the presented information is made. The strengths and limitations of the method using the adjustment factors are given in table 1.

Table 1 Strengths and Limitations HCM chapter 22

Strengths	Limitations
Simple estimation	No distinction between incidents
	Distance increase between vehicles
	Speed reduction at incident site
	Road characteristics
	Which lanes are closed
	Capacity reduction in the opposite travel direction

The strength of the Freeway Facilities methodology, for assigning capacity reduction to freeways with an incident, is that it is easy to apply and estimations can be made quickly when capacity is determined from the different types of freeway segments. The simplicity being its strong point, it is also its greatest limitation, as it does not make a distinction for different types of incidents.

The HCM mentions that there is a distinction between major and minor incidents and their necessary clearing time. But to calculate capacity reduction using the Freeway Facilities methodology, there is no dependence on the distinction between incidents. However the distinction between major and minor incidents is important, because motorists are more likely to adjust their behavior more for major incidents than for minor incidents. This change in behavior can consist of reduction in travel speeds and an increase in following distances between vehicles at high enough travel speeds. However the HCM does not make a distinction for the physical reduction of capacity between major and minor incidents.

Another aspect that is not discussed is the lane configuration at the incident location. Capacity may be more affected when the center lane on a three-lane freeway is closed than when the left or right lane is closed. Additionally, the characteristics of the road, such as lane width, can be a factor. Wider lanes allow for motorists to have more lateral separation between them and the incident, which can have the effect of raising travel speeds.

The final limitation of the HCM incident material is that it mentions that “rubbernecking” on lanes in the travel direction opposite of the incident occurs, but is not further quantified. The occurrence of an incident has the effect of drawing people’s attention and causing a reduction in capacity for a section of freeway for both directions of travel, thus including the opposite direction of travel.

Given these limitations, which are largely a function of the outdated studies that the HCM material is based on, it is very desirable for the HCQSC to try to update and enhance this material based on the more recent studies that have been performed. These studies are the focus of the next chapter

3. Synthesis of Current Research on Effects of Incidents on Capacity

The previous section dealt with the information that was present on capacity reduction from incidents in the HCM (Transportation Research Board, 2000) chapter regarding Freeway Facilities. It was established that the basis for incident impacts may be worth updating. To aid in the possible improvement of the HCM, a synthesis of past research is helpful. The synthesis is divided into 3 sections, the first dealing with the objective and process, the second a review of past research and the third a discussion of the identified research.

3.1 Objective and Process

3.1.1 Synthesis objective

The objective of this synthesis was to summarize past research on the effects that incidents have on freeway and highway capacity. The main aim of the synthesis is summarizing information that links capacity reduction directly to incidents. This synthesis is designed to help identify research needs by identifying shortcomings. But because of limited available research the synthesis also incorporates delay on freeways resulting from incidents, as delay and capacity reduction are linked under incident conditions.

3.1.2 Study Process

A literature review reveals relevant research linking capacity reduction to incidents. The literature review was performed using the TRIS online database, scholar Google, the Transportation library at the TRC, and the University of Florida science library.

In order to find the right information relating to the subject, different keywords were used as input into the search databases. These keywords were used in different combinations. The following keywords delivered results, either on their own or as a combination:

- Incident(s)
- Capacity
- Highway
- Freeway
- Reduction
- Non-Recurrent Congestion
- Accident
- Crash
- Traffic flow

Because the research discussing capacity reduction resulting from incidents was limited, the search was broadened to include ”delay” as well Delay was included because it is linked to capacity reduction from incidents and can be helpful to the objective. To find information with the broadened search, a few keywords were added. These keywords being:

- Delay
- Impacts

3.1.3 Format of Literature review

The literature review is divided into two parts, one containing research directly dealing with capacity reduction from incidents and the other dealing with research examining delay as a product of incidents. There were five researches dealing with capacity reduction and three researches dealing with delay. The format for the summaries of each research contains these components: the objective of the research, the research approach, the findings and recommendations for further research.

3.2 Literature Review of Past Research

3.2.1 Research dealing with capacity reduction

The information presented in the HCM is partly based on research conducted by Dunn Jr. & Reiss, in 1991. Dunn Jr. & Reiss based their findings on research performed by Goolsby, 1971. So this research performed by Goolsby is the beginning of studies related to capacity reduction by incidents herein.

The research Goolsby conducted was on the influence of incidents on freeway quality of service in 1970. The research sought to quantify the impact of incidents on operations by quantifying frequency, duration and flow passing freeway incidents.

Data was collected on the Gulf Freeway in Houston, because of the extensive surveillance system that existed there at that time. The 6.5-mile study section has three lanes in each direction. For a two year period, a log of freeway incidents on weekdays from 6.00am to 6.00pm was maintained for the study site. Incidents included accidents and disabled vehicles. This study collected the traffic volume in 1-minute intervals in the bottleneck created by an incident. The volume counts in the bottleneck were available for 27 incidents. As a reference frame, 1-minute volume counts were also taken at a location downstream of the study site under normal conditions.

With these interval counts, the capacity reduction can be determined. Based on the data, the research found that an incident, such as an accident or a disabled vehicle, blocking one lane out of the three lanes present reduces traffic flow and thus capacity by 50 percent. An incident involving two blocked lanes reduces the traffic flow by 79 percent, and an incident blocking a shoulder lane reduces the traffic flow by 33 percent.

Research conducted by Smith, Qin, & Venkatanarayana, (2003) studied the impact of incidents on capacity. The objective of the research was to characterize urban freeway capacity reduction resulting from traffic accidents as a deterministic and a random variable.

In order to characterize urban freeway capacity reduction resulting from traffic accidents, the research consisted of the following activities:

1. Compiling a large set of accident and traffic flow data for the Hampton Roads region of Virginia (obtained from the Hampton Roads Smart Traffic Center) for a six lane freeway.
2. Estimating capacities under prevailing conditions by calibrating speed-flow curves for freeway segments.
3. Measuring accident capacity
4. Calculate accident capacity reduction.
5. Modeling accident capacity reduction as a random variable based on the samples.

The data was divided into Incident Data and Traffic Flow Data. Where Incident Data gives a description of the incident, with measurements as duration, and is obtained from the HRSTC database. The traffic flow data was recorded through loops in the roadway. The capacity was estimated from the traffic flow data by plotting a speed-flow diagram. The capacity during an accident was estimated by assuming that the traffic flow passing the accident corresponds with the maximum traffic flow, and thus represents capacity.

The HCM describes capacity reduction from freeway incidents as a deterministic value. The first part of the research dealt with capacity reduction as a deterministic value. This research compares the obtained results with the results given in the HCM. The results for the deterministic values are a capacity reduction of 63% for an accident blocking one of three freeway lanes and a capacity reduction of 77% for an accident blocking two of three freeway lanes. The results for one lane blocking accidents in this research deviate from the values presented in the HCM for that specific lane configuration.

Another way to define capacity reduction from incidents is as a random variable. Evidence was found that capacity reduction may best be modeled as a random variable. The model was developed by considering each incident in the database as a single sample of the random process. Then, all the samples were used to plot a histogram and explore possible probability density functions to model the accident capacity reduction. The best density function to model accident capacity reduction was found to be the Beta distribution.

To generalize the results found in this study, the research needs to be repeated on other three-lane freeway segments. Another aspect that needs further attention is to repeat the research for other lane configurations.

In research conducted by Masinick & Teng, (2004) the focus was not on capacity reduction in the direction of travel where the accident occurred, but on capacity reduction in the opposite direction of travel from the accident. The impact is indentified in terms of rubbernecking likelihood, traffic delay and capacity reduction. This research dealt with the two areas of impacts that are presented in this synthesis, so it is applicable both.

For data collection, two parts of interstate were chosen in the Hampton roads area, namely Interstate 64 and Interstate 264. The data was collected by the Hampton Roads Smart Traffic Center using closed circuit television cameras and detectors loops on the specified freeway segments. From the collected data, the three impacts under investigation were examined. To determine impact of rubbernecking, plots of “occupancy vs time” were created and judged via visual observations, and then the likelihood was determined using the binary logit model. For delay calculations, the delay was derived from cumulative volume plots. The plots were made for station volumes upstream and downstream of the incident. The area between the two curves provides the total incident delay. For capacity reduction calcutions, the capacity of the road section was based on historical data. With these two calculations the capacity reduction in percentages was deteremined.

The research found that 10 percent of accidents caused rubbernecking, contributing to an average delay of 107 vehicle-hours and a 12.7 percent reduction in capacity. The results also show that the rubbernecking likelihood is influenced by certain events, such as peak periods, weather, presence of barriers and weekday travel. For travel delay the influences were duration, presence of barriers and V/C ratios of traffic before the occurrence of an accident. The capacity reduction was influenced by peak periods, duration and day/night travel.

The report recommends using the methodology and results presented, as a basis for future research. In future research the following issues should be addressed: incident and traffic quality, statistical modeling and human factor characteristics.

Knoop, Hoogendoorn, & van Zuylen, (2008) used aireal photos of incidents to research capacity reductions on roadways in the Netherlands. The research employed a unique way of microscopic data collection, using a helicopter. The data was analyzed to examine the impact of an accident on the remaining capacity.

The data collection was performed by shooting images from a helicopter. The helicopter was staged at the Dutch Transportation Management Center until an accident occurred and then it flew to its location. Upon arrival, cameras started recording traffic operation for both directions of travel. By filming the two directions of travel the rubbernecking effect could also be seen. Two incidents were filmed, one near Apeldoorn and the other near Gorinchem. From the image sequence, the passing times of the vehicles at the incident were recorded with making distinctions between light and heavy vehicles. The passing times were conversted into traffic flows, aggregating over time and over the roadway.

For the incident near Apeldoorn, both directions of travel are analyzed with the accident occuring in the eastbound direction and for Gorinchem only the westbound direction of travel was analyzed, because no congestion in the opposite direction of travel was present. The findings of the research are shown in table 2:

Table 2 Capacity values for the different locations

Location	Lanes	Median (pcu/h/lane)	Mean (pcu/h/lane)	Std. Dev. (pcu/h/lane)	Expected without Rubbernecking (pcu/h/lane)	Percent of Capacity remaining
Apeldoorn Eastbound	2	1170	1103	239	2325	**50%**
Apeldoorn Westbound	2	1230	1246	163	2325	**53%**
Gorinchem Westbound	**1**	**1080**	**1072**	**326**	**2310**	**47%**

The expected capacity is the free flow capacity based on the number of lanes open at the accident. At the Apeldoorn location, 2 lanes were open, because the shoulder lane was used, whereas at the Gorinchem location it remained closed. So accidents with one lane closed, cause approximately 50% capacity reduction, even if the shoulder lane is used. Causes for the reduction in capacity are probably, because motorists tend to be more careful and alert. At the opposite direction of travel, the rubbernecking effect contributes to a drop in capacity.
The authors concluded that the sample size should be increased. They also concluded that incident management measures, like screens between two directions of travel, need to be evaluated.

A study performed by Chin, Franzese, Greene, Hwang, & Gibson, (2002) developed estimates of highway capacity losses and delay caused by transitory events, such as construction work zones, crashes, breakdowns, extreme weather conditions, and sub-optimal traffic controls. Because the focus of this synthesis is on capacity reduction and delay caused by incidents, these topics will be the only ones discussed in this summary.

Data for the study was collected by using existing data from a variety of souces, as well as results from evaluation studies sponsored by the Intelligent Transportation System Joint Program Office, in the United States . Gaps in data were filled with data or findings from liturature sources, reasonable assumptions, and Monte Carlo simulations. Though new data was limited, real data was used when possible. For estimating capacity reduction from incidents the following three data sources were used: Fatality Analysis Reporting System (FARS), General Estimates System, and Highway Performance Monitoring Systems.

The results of the study show the reduction in capacity due to lane closure from a freeway incident and the probability of a lane closure by a freeway crash. The probability of a lane closure is a function of the number and type of vehicle involved, and these variables were used to describe the severity of the crash. The results for capacity reduction and probablity of lane closure are shown in tables 3 and 4.

Table 3 Reduced capacity due to freeway crashes

Effect of crash	Number of freeway lanes				
	1	2	3	4	5+
Vehicle on shoulder	0.450*	0.750	0.840	0.890	0.930*
1 lane blocked	0.000	0.320	0.530	0.560	0.750
2 lanes blocked	N/A	0.000	0.220	0.340	0.500
3 lanes blocked	N/A	N/A	0.000	0.150*	0.200*
4 lanes blocked	N/A	N/A	N/A	0.000	0.100*

*Assumed

Table 4 Probability of lane closures

Type of incident	Number of vehicles involved	Lanes closed
Fatal crash	1 vehicle	0.892
	More than 1 vehicle	1.000
Injury crash	1 vehicle	0.892
	More than 1 vehicle	1.000
Property damage only	Less than 3 cars and at most 1 truck	0.600
	3 or more cars and/or 2 or more trucks	1.000
Breakdowns	N/A	0.154

Delay was calculated using plots of cumulative volume counts for departure and arrival. The area between the departure and arrival curves is the total delay caused by an incident. The results show an average delay for every crash of 573.2 vehicle-hours. This delay can be further divided into fatal and non-fatal incidents. For fatal incidents the average delay per incident is 447.6 vehicle-hours, and for non-fatal incidents the average delay per incident is 574.0 vehicle-hours.

3.2.2 Research dealing with Delay

Garib, Radwan, & Al-Deek, (1997) researched the delay caused by incidents on freeways. The research presented two models for estimating freeway incident delay and a third model for predicting incident duration. These models potentially help freeway traffic operations.

The data for the research was gathered on a 7.3 mile strip on Interstate 880 in Oakland Ca. On this selected freeway segment, roadway detectors are present every third of a mile.

From the data gathered the incident delay models were developed using multiple regressing analysis. For these models the dependent variable were chosen to be cumulative incident delay and a list of candidate independent variables was composed. For the two models the independent variables are calculated to be:

1. Number of vehicles involved in the incident
2. Number of lanes affected by the incident
3. Incident duration
4. Traffic demand upstream of the incident.

With the exception of variable 4 which is only present in model 1.

The two models are:

$$Delay = -4.26 + 9.71X_1X_2 + 0.5X_1X_3 + 0.003X_2X_4 + 0.0006X_3^2 \quad (1)$$

$$Delay = -0.288 + 3.8X_1X_2 + 0.51X_1X_3 + 0.06X_3 + 0.356X_2^3 \quad (2)$$

The research shows that model one can explain 74% of the variation in incident delay and model two can explain 85% of the variation in incident delay. Based on these findings, the latter appears to be a better estimator. However, model one uses the the exact same variables in the equation as in the analytical model for delay. The analytical model is a mathimatical derivation from the area between arrival and departure curves in the cumulative incident queuing diagram.

Along with the models for incident delay, the research presented a model for incident duration. The incident duration model was developed with the same methodology used for the delay models. The analysis yielded the following model:

$$Log(Duration) = 0.87 + 0.027X_1X_2 + 0.2X_5 - 0.17X_6 + 0.68X_7 - 0.24X_8 \quad (3)$$

The model can explain 81% of the variation for incident duration can be explained by the model. The model explains this variation using six variables, namely

1. Number of lanes affected
2. Number of vehicles involved
3. Truck involvement
4. Time of day
5. Police response time
6. Weather conditions.

Future research should focus on integrating the developed models with an incident detection algorithm and calibrating the models using data from other sites.

Skabardonis & Geroliminis, (2004) developed a model to estimate impacts of isolated incidents under undersaturated and saturated conditions. The objective of the research was to develop methodologies for estemating incident impacts and test them against field measurements.
The data for field measurements is acquired from the freeway performance measurement system (PeMS). The data was collected on several California freeways. PeMS was also used to analyze the impacts of several incidents.

The research provides an analytical model for estimating total delay on a freeway, as a result of an incident on the freeway. The model consists of two parts, one estimating the total delay under undersaturated conditions and the other total delay under saturated conditions. The conditions are undersaturated when traffic demand on a freeway section is less than capacity . The conditions are saturated when traffic demand on a freeway section is greater than capacity, in which case a queue starts to form.

For the comparison of the analytical methodology with field measurements, the freeway performance measurement system (PeMS) database and algorithms was used to analyze impacts of several incidents. PeMS stores and processes 2 GB/day of 30-second loop detector data in real time from most urban freeways in California. PeMS also stores incident information from the California Highway Patrol (CHP/CAD) system.

After comparing the analyzed results using PeMS with the results estimated using the analytical methodology, it was concluded that the results are in close agreement. Most of the differences found were because of the variability in traffic deman pattern, and the differences in capacity flows.

No suggestions were made for future research.

A recent study performed by Wang, Cheevarunotha, & Hallenbeck, (2008) quantifies incident-induced delay on freeways by developing a new algorithm. The research objective was threefold, log loop detector and incident data, construct a new algorithm traffic sensor data, and finally automate the proposed algorithm delay calculations.

The research used incident log data from the Washington Incident Tracking System. The loop detector data that is associated with the incident log data was acquired from the Traffic Data Acquisition and Distribution (TDAD) website. The loop data acquired from the TDAD has a standard resolution of 20-seconds, so to reduce data fluctuations the 20 second intervals were converted to 1-minute intervals.

The new algorithm that was developed based on deterministic queuing theory, for quantifying incident-induced delays on freeways. Deterministic queuing theory uses cumulative arrival and departure volumes. The area between these two plots is considered the incident delay. The new aspect of the calculation in this study was that it uses a dynamic traffic-volume-based background profile for the delay calculation. The use of the background profile is considered a better representation of prevailing traffic conditions for recurrent congestion. With the total delay associated to an incident and the recurrent delay from the background profile, the incidentinduced delay can be calculated.

The algorithm was automated in the Advanced Roadway Incident Analyzer. To verify if the algorithm could return accurate results, it was validated using a microscopic simulation model with the VISSIM simulation tool. Results showed that the proposed algorithm can provide reasonable estimates of incident induced delay.

The authors recommended that future research concentrate on algorithms implementing shock wave movements in traffic flow. Next to new algorithms, a new method for identying the best traffic volume-based background profiles should be further improved an tested.

3.3 Discussion

In chapter one the limitations of the methodology in the Highway Capacity Manual 2000 (HCM) (Transportation Research Board, 2000) for assessing impacts of incidents on freeway capacity were discussed. In this chapter a synthesis is composed on recent research dealing with the topic. This discussion comments on the research that was found and the possibility of the research to add to the HCM.

The reference stated in the HCM regarding loss of capacity due to incidents dates back to 1991. So there was no recent research supporting the methodology used in the HCM. After checking the document prepared by Dunn Jr. & Reiss (1991), it was found that the document made reference to research performed by Goolsby (1971). Essentially, the methodology in the HCM may be based on research that is more than 35 years old. The research of Goolsby is included in the synthesis, because it represents the starting point of research into capacity reduction from incidents.

The Goolsby results defined capacity reductions on a three-lane freeway for one lane blocked, two lanes blocked and a shoulder lane blocked. The results of the research compared to the other researches are given in table 5. There were other researches who mirrored the methodology used by Goolsby, namely Qin, & Venkatanarayana (2003), Knoop, Hoogendoorn, & van Zuylen (2008), and

Chin, Franzese, Greene, Hwang, & Gibson (2002). The results for these studies are shown in table 5 for comparison.

Table 5. Comparison of research outcomes

Study	Road characteristic	Lane configuration	Capacity reduction
Goolsby	Three-lane freeway	1 lanes blocked	50%
		2 lanes blocked	79%
		Shoulder blocked	33%
Smith et al.	Three-lane freeway	1 lanes blocked	63%
		2 lanes blocked	77%
		Shoulder blocked	N/A
Knoop et al.	Two-lane freeway	1 lane blocked, shoulder open	50%
		1 lane blocked, 1 lane open	53%
Chin et al.	Three lane freeway	1 lanes blocked	47%
		2 lanes blocked	78%
		Shoulder blocked	16%

The first of the three is research conducted by Smith et al. The research updates the Goolsby's research, although there was no information given for blocking of the shoulder lane. Furthermore, evidence was produced in this research that indicated the capacity reduction needs to modeled as a random variable instead of a deterministic value. To this date no research has been published that concentrates on this statement, although this approach could be very important. The Knoop, et al research effort in the Netherlands used a helicopter to shoot images from the traffic at the incident site. The third research that produced deterministic capacity reduction values was performed by Chin, et al. For this research only the three-lane freeway results are shown, because this is the only freeway type that can be compared. The other types of freeway are discussed later.

From the results presented in table 5, it can be seen that the capacity reduction results vary by study. Where Goolsby found a capacity reduction of 50% for one lane blocked on a three-lane freeway, Chin, et al. states similar results. Smith, et al produced different results for incidents blocking one lane, as compared with the other studies. This difference could be explained by the location and the road characteristics for the location of the data collection. The study sites in the Netherlands were both two-lane freeways, so a direct comparison of the results with the other studies is not possible. Only for the Apeldoorn site, the assumption can be made that the site represents a three-lane freeway during the incident, because the shoulder lane is opened for traffic during the incident. In that case the results can be found similar to those found by Goolsby and Chin, et al.

For two-lanes blocked the research performed by Knoop, et al did not present any results, so the research was discarded from the comparison. The differences between the results given by the remaining studies present a reduction range from 77% to 79%.

Only two researches present results where vehicles block the shoulder lane and affecting capacity, Goolsby and Chin et al. However the results show a significant difference in capacity reduction. This may be attributed to differences in the studied locations.

In table 5 only the three-lane freeway results for the studies have been shown, except for Knoop et al because they did not study a three-lane freeway. This was done so the results could be compared with each other. However the research performed by Chin et al, also provides results for other freeway configurations, like two-, three-, four-, and five-lane freeways. Also the results for a three-lane freeway seem to be supported by at least one other study for a three-lane freeway, which gives the impression that these results could be applicable to use in the HCM.

The previous paragraphs dealt with results that potentially improve HCM limitations. If a limitation in the HCM is the lack of information on the effects of rubbernecking, there seems to be research to fill the gap. Research produced by Masinick & Teng (2004) performs a study into the effect of rubbernecking and produces results for the phenomenom for both directions of travel. Also the research by Knoop et al. produces results for the rubbernecking on one study site. Masinick & Teng found a capacity reduction as a result of rubbernecking by motorists of 12.7 percent reduction of capacity in the opposite direction of travel. Knoop et al. found other results for there investigation into the rubbernecking effect. They found a capacity reduction of 47%, however a observation was made that the opposite direction of travel was experiencing heavy traffic and was already near capacity at the time of the incident. So it is found that research has been done on this subject, that could enhance the HCM.

Another potential HCM limitation is the lack of distinction between incident types. In the research performed by Chin et al it is discussed that a the distinction can be made between incidents and therefore a difference in capacity reduction. The research presents a likelihood of lane blockage occurring during a type of incident and with this, quantifies the distinction between incidents. With the research from Chin et al. the distinction can be quantified in the HCM.

The synthesis was expanded with material relating to delay from incidents. All three studies presented provide a method for estimating total delay resulting from incidents on freeways. Chin et al. and Masinick & Teng, which mainly focus on capacity reduction, give results and a methodology for assessing delays. The most used method for determining delay from incidents involves calculating the area between cumulative arrival and cummulative departure plots. In the future, a way may be found to convert incident delays into capacity reduction, contributing to improvements in the HCM.

It can be concluded that the amount of research that is present today, is limited. Therefore future research should be done on the topic of capacity reduction due to incident. The further research can then be used to generalize results and provide uniform adjustment factors. In future research the distinction between the severity of an incident should also be included in determining capacity reduction due to incident. Results in the studies differ from each other and can be explained by differences in road characteristics. The differences in road characteristics are probably also the reason why the results do seem to be of the same magnitude. When further research is done a good update of the HCM can be realised. Another valuable contribution to the update could be the quantification of the rubbernecking of motorists on for the opposite direction of travel. The update of the HCM is important because research found often references to the HCM on capacity reduction, with the consequence that in recent research results from 35 years ago are a important input value.

4. Review of State-of-the-Practice for Incident Management and Reporting

Incidents are a big concern on freeways, since they cause about one-third of the delay on these roads. (U.S. Department of Transportation Federal Highway Administration Office of Operations, 2008) In order to keep delay caused by incidents on a freeway to a minimum, they need to be cleared from the roadway quickly. To expedite incident clearance, traffic incident management, or TIM, is applied throughout the United States. This section discusses the state-of-the-practice for TIM and reporting through literature review and personal observations at the Traffic Management Center at Jacksonville, Florida. This will contribute to the analysis of CORSIM, because a better understanding of the processes behind the events at the incident site is obtained.

Managing roadway accidents is only part of TIM. Incident management encompasses all types of roadway incidents and major emergencies, such as such as hurricanes, wild fires and flooding. In 2004 the U.S. Department of Homeland Security published a guide for emergency responders, the National Incident Management System (NIMS). The NIMS was designed to standardize the management of emergencies in the United States and establish a framework for jurisdictions to work together to manage emergencies when necessary. (I-95 Corridor Coalition, 2008). The NIMS provides a set of components that address all facets of incident management.

- Preparedness
- Communication and Information Management
- Command and Management
- Ongoing Management and maintenance

Accidents/incidents on the roadway are part of the emergencies mentioned in the NIMS. But because managing incidents on roadways is a distinct part of incident management a more narrow definition of incident management on roadways is required. Incident management is defined as the systematic, planned, and coordinated use of human, institutional, mechanical, and technical resources to reduce the duration and impact of incidents, and improve the safety of motorists, crash victims, and incident responders (PB Farradyne, 2000). From now on when incident management is discussed, incident management on roadways is meant since this is the focus of this section of the report. All management aspects of incidents on roadways must satisfy the guidelines provided by the NIMS. Although the NIMS has improved a coordinated response to large-scale events, response to more common events, such as car crashes involving few patients, rarely benefits from preplanning. (National Traffic Incident Management Coalition) Therefore the NIMS is more loosely complied with, for less significant emergencies such as car crashes.

Traffic incident management is comprised of distinct activities that form the incident management process. These activities are carried out by personnel from a variety of response agencies and organizations. Although the activities are very distinct, they can however be performed simultaneously. The seven activities of incident management are:

- Detection
- Verification
- Motorist information
- Response

- Site Management
- Traffic Management
- Clearance

4.1 Detection and verification

The first phase in incident management is incident detection. The incident detection is the process that brings the incident to the attention of the agency or agencies responsible for maintaining traffic flow and safe operations on the facilities. There are several techniques, for an incident to be detected and brought to the attention of the agencies. These techniques include

- wireless telephone calls from motorists
- Closed circuit TV (CCTV) cameras viewed by operators
- Motorist aid telephones or call boxes
- Police patrols
- Aerial surveillance
- Roaming service patrols

With the detection of an incident comes the verification of the incident. The verification is confirming that the incident did occur. The confirmation for the incident is obtained by a notice of the same incident from another source. Therefore the same techniques are used for both detection and verification.

With the proliferation of cellular telephones, most traffic incidents are detected by wireless telephone calls from motorist. These calls are made to the 911 dispatch center, which then notifies emergency first response agencies, generally defined as law enforcement, fire and rescue, and emergency medical services (EMS). When present, a Traffic Management Center (TMC) may be notified, which can verify and monitor the incident using highway traffic. The traffic cameras in the TMC can also be used to detect incidents. The other techniques have the same method of detection. They are units roaming the freeways and streets and happen to come across an incident, which is then reported. The state of Florida also has service patrols that are called “Road Rangers” to assist motorists and maintenance on freeways in order to reduce breakdown.

4.2 Motorist information

Motorist information systems disseminate incident-related information to affected motorists. The dispersing of traffic information is an important task of the TMC. The TMC informs the motorists by changing the Dynamic Message Signs (DMS), and updating the 511 traveler information system. The 511 traveler information system in Jacksonville, Florida is called jax511 and consists of a webpage and a call service where motorists can obtain their travel information. Whenever an incident occurs in the Jacksonville area the TMC operator updates the 511 system by leaving a voice message and adjusting the webpage http://jax511.com. An impression of the webpage for jax511 motorist information can be found in appendix 7.2. A third method for motorist information is a collaboration of the TMC with local media. Traffic reports and live video feeds from highway cameras help the media dispense traffic information via radio, television, or internet.

4.3 Response

The main activity with response is the deployment of the right personnel, equipment, communication links, and motorist information media as soon as it is reasonably certain that an incident has occurred. The right response to an incident requires understanding of the incident's nature, scope and necessary steps to clear the incident and restore normal roadway conditions. After the public safety dispatch center is notified of the incident, emergency first response agencies are notified. The emergency first response agencies that are notified depends on the information the dispatch center has available and from that information judges what agencies are required at the scene. The first response agencies response to traffic incidents has been based on intra-disciplinary tradition, training, and experience gained from multidisciplinary responses. Though law enforcement, fire, EMS and transportation responders tend to focus on their respective roles, evolution of the TIM and the incident command system (ICS) as part of NIMS, improve response.

4.4 Site management

Management of an incident site is the process of assessment, establishing priorities, notifying and coordinating with each responder, and maintaining clear communications with each responder. (PB Farradyne, 2000) To run smoothly, an Incident Command System (ICS) may be used. The ICS provides a planned and organized approach to the management of incidents and emergencies. It is expandable and flexible but clearly designates one person as incident commander. ICS can also be very informal. When agencies are accustomed to working together on short-term incidents, they do not wear Incident Command vests or identify a command post, but they still work together to resolve the incident. This usually occurs when the response is small from each agency. Responders often recognize one other and go about their business in a professional and cooperative manner. The latest version of the Incident Command System (ICS) is called the "Unified Command Structure" and can be used when multiple agencies respond. Unified Incident Command (UC) is a method for coordinating efficient incident response at larger, more complex traffic incident scenes, where the incident involves several responding agencies with contrasting functional responsibilities and missions, and/or affects multiple political or legal jurisdictions. (National Traffic Incident Management Coalition) Because most incidents are usually very short-term, with most incidents the site management is done in an informal fashion.

4.5 Traffic management

To keep traffic delays to a minimum on the road network during an incident, traffic management is applied. Traffic management involves the application of traffic control measures in areas affected by the incident. The traffic control measures that can be used are managing the road space (i.e. closing lanes when necessary), actively managing traffic control devices (i.e. ramp meter, lane control signs, and traffic signals), and assigning and operating alternate routes past the incidents. At the incident scene, the emergency agencies are responsible for a proper traffic management, although this may not be their main concern. The safety and protection of responders and establishing advance warning and other traffic control for motorists is however, always a concern. For the control measures away from the incident the TMC has an important task. The TMC can plan alternate routes and guide traffic along these routes by changing message signs and traffic signals. Also the flow around the incident can be controlled by using ramp meters. All these control measures can be used until the incident is cleared and normal flow conditions return.

4.6 Clearance

Clearance is the last step during incident management. During clearance all vehicles, wreckages, debris, spilled material, and other items are removed from the roadway and shoulders, so that capacity can return to normal levels. So an incident is only cleared when it stops having an effect on traffic flow. Although it is the last step in incident management it is the most critical step, because of the time required to perform this step. Especially during major incidents clearing the roadway can take a very long time. Variation in Variations in recovery, removal and cleanup operations can have big variations in time for recovery, removal and cleanup operations can have big consequences on the clearance of the incident, which needs to be as short as possible to reduce effects on traffic. In order to clear the incident, tow trucks are usually required. These tow trucks are commonly hired from private towing companies.

4.7 Intelligent Transportation Systems

Within Incident Management an important role is reserved for Intelligent Management Systems (ITS). Intelligent Transportation Systems apply well-established technologies of communications, control, electronics and computer hardware and software to the surface transportation systems. In Florida the Intelligent Transportation System is called Sunguide. Sunguide is active at a few levels of incident management, namely detection, verification, motorist information and traffic management. The nerve system of Intelligent Transportation Systems are the Transportation Management Centers (TMC) and therefore play an active role during incident management. The TMC's monitor traffic conditions, respond to traffic incidents and coordinate ITS programs. Information comes in at the TMC's from detectors and traffic cameras, which is used for detection and verification of incidents. Whenever an incident is reported to the TMC via the detector loops or the dispatch center, it will be verified using traffic cameras. The information is then used for distribution to motorists via 511 motorist information, as mentioned in paragraph 6.3.2. Also the TMC monitors the incident and allows for a coordinated response to incident by assisting emergency agencies that are brought into action at the incident scene. After the incident an incident report is made in which all the actions that were taken by all participants in the process of incident management during the incident are being logged. To allow for the best coordination between the emergencies, the goal is to integrate the 911 dispatch center and the TMC. This will create short communication paths, which helps the response to an incident. If a major incident has occurred and it will take a long time to be cleared, traffic is usually being rerouted. The TMC will coordinate the new traffic assignment by providing the motorists with information via Dynamic Message Signs or other media.

5. Evaluation of Incident Modeling Capabilities of CORSIM

5.1 Introduction

This chapter will evaluate the incident modeling capabilities of a microscopic traffic simulator for freeway incidents. The use of traffic simulators related to incidents is often as a tool to evaluate the impact incident management strategies or the impacts of Intelligent Transportation Systems (ITS) on network performance. The reason that traffic simulators are often used is that they serve as a substitute for field studies for traffic analyses, since field studies are generally very expensive to carry out. The use of computer modeling and microscopic traffic simulation in particular, offers a better and more cost-effective approach, in which the modeler can vary input conditions and measure their impact on network performance. (Dia & Cottman, 2006) The microscopic traffic simulator that was evaluated in this report was the traffic simulation tool CORSIM, because of the close relationship between the University of Florida and McTrans (the manufacturer of CORSIM).

The chapter will evaluate the traffic simulation tool CORSIM. A brief description of this simulation tool is given before the evaluation is started, to get a background on the uses tool. For the evaluation of the traffic simulation tool CORSIM a real incident is used to establish the needs for the incident model. A description of the incident is given in the chapter. After the incident is described, the needs for the model are derived from this description. Then simulations are made for an assessment of CORSIM's behavior for simulating incidents on a freeway network. Afterwards the important parameters are discussed using a sensitivity analysis.

5.2 CORSIM

CORSIM (CORridor SIMulation) was the simulation tool selected for evaluation. CORSIM is a microscopic traffic simulation program that enables users to conduct traffic operations analysis. CORSIM can handle surface street systems, freeway systems, or combined surface-street and freeway systems. The development of CORSIM started in the early 1970s and was sponsored by the Federal Highway Administration (FHWA). Over the years, many improvements and upgrades have been made. The biggest improvement in recent years has been the development of the user-friendly interface and environment called Traffic Software Integrated System (TSIS). TSIS was built around the tool CORSIM, to create an environment for executing the traffic simulation models, without needing to memorize DOS commands. (Holm, Tomich, Sloboden, & Lowrance, 2007)

Currently, several additional tools are integrated into TSIS, to provide easier and quicker use of the traffic simulation. One of these tools is TRAFED, which can be used to create models of roadway networks using a point-and-click graphical user interface. Another tool, TRAFVU, is a user-friendly graphics post-processor for CORSIM. The tool displays the roadway network and shows an animation of the simulated traffic on the network, which helps the user visualize the simulation.

CORSIM is the traffic modeling engine in TSIS. The other tools serve to aid the user with the input or output of the traffic simulation. The fact that CORSIM is a microscopic simulation tool means that the movements of individual vehicles are modeled on a road network using driving behavior models and vehicle movement models.

CORSIM actually encompasses two microscopic simulation models. These models are NETSIM and FRESIM, where NETSIM models surface street traffic and FRESIM models freeway traffic. Based on the road network configuration, CORSIM will select the proper model—either NETSIM, FRESIM, or both (in the case of a mixed network of freeways and arterials). Figure 1 shows how the multiple model network is simulated. For this research focused on incidents occurring on freeways, only the FRESIM model is required.

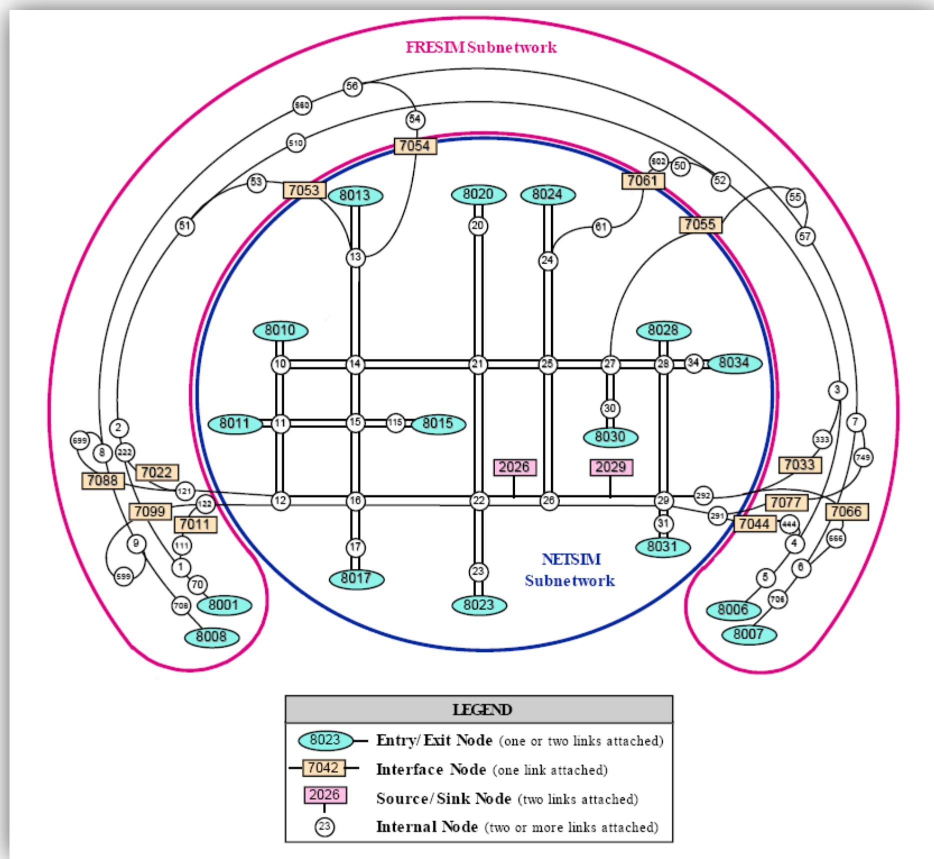

Figure 1. Multiple Model Network

Source: ITT Industries, Inc. Systems Division, CORSIM User's Guide, 2006

5.3 Incident Description

A real incident was modeled in CORSIM. The incident selected for modeling occurred on September 19, 2008 and started at 16:59 hours in Jacksonville, FL. The location of the incident was on Interstate-295 in the northbound direction at the interchange with US-17 (Roosevelt Boulevard). In this section, a description of the incident, the incident timeline, location characteristics and scope of the network are given, to define the all the relevant characteristics of the incident.

5.3.1 Incident information

In the chapter on state of the practice for incident management, the outline of handling an incident on a freeway in Jacksonville was described. The same principles that were mentioned in that chapter were also applied with handling the incident on I-295. Because the TMC was involved in handling the incident, an incident report was made. In the incident report from the TMC, a rough description of the incident is given, and different stages during the management of the incident are identified. The complete incident report is in appendix 7.1. The incident report summarizes the actions that were taken to handle the incident. The incident report also gives a description of the incident, with the duration and the impacts on road characteristics being described. The impacts on the road characteristics consist of reporting, for example, the shoulder or the number of lanes that are being closed or blocked by the incident.

The incident on I-295 was selected for its characteristics in combination with the documentation in the incident report, and queue buildup behind it. The incident had obvious consequences on traffic operations. Images of the incident are included in appendix 7.2. The collision caused the right lane and right shoulder on the freeway to be blocked during the incident, which meant the physical road space was reduced from a three-lane freeway to a two-lane freeway. The blockage of the lane and the capacity reduction resulting from it, along with the duration of the incident caused a queue to buildup downstream of the incident. Images of the queue are shown in appendix 7.2. This particular incident was a fairly typical type of incident; thus, it was felt that this would be a good one to use for testing CORSIM's incident-modeling capabilities.

5.3.2 Incident timeline

Table 1 provides a timeline of the various events and characteristics of the incident.

Table 6. Incident Timeline

Time stamp	Event description
16:59	Incident reported on I-295 at the on-ramp from US-17 by a Road Ranger
16:59	Incident blocks the right lane
16:59	Road Ranger deploys cones to close the right lane and part of the on-ramp, for handling the incident
17:19	Jacksonville Sheriff's Office arrives at the incident site
17:19	Florida Highway Patrol arrives at the incident site
17:19	Fire Department arrives at the incident site
17:19	TMC notifies FDOT maintenance
17:40	Wrecker arrives at the scene to tow the vehicles for the site
17:41	Incident blocks the right lane, the right shoulder, and the entry ramp
17:41	FDOT maintenance arrives at the incident site
17:43	Incident blocks the right lane and the right shoulder, and part of the on-ramp
18:00	Fire Department leaves the scene
18:00	Jacksonville Sheriff's office leaves the incident site
18:41	Wrecker leaves the incident site
18:57	Incident blocks right shoulder

19:30	Florida Highway Patrol leaves the scene
19:30	FDOT maintenance leaves the incident site
20:10	Roadway and shoulder cleared, incident end

5.3.3 Incident location

From the pictures taken of the incident and the incident report, the location of the incident can be precisely determined. The exact location is shown in figure 2 with a more detailed display in appendix 7.3. The images of the location were obtained using the Google Earth application. With the images recovered from the jax511 motorist information web site, the length of the blockage and number of lanes blocked can be determined from the incident report. Jax511 is a web site maintained by the Florida Department of Transportation. The web site provides travelers with up-to-date traffic information for the Jacksonville area. At this web site, live still images from traffic cameras on the freeways in the area are accessible. This allows interested people, e.g., commuters, to check the traffic conditions for their desired freeway route.

The road configuration at the incident location can be viewed in appendix 7.3. The roadway at the location of the incident consists of three mainlines. At these three mainlines two on-ramps enter the freeway from US-17, with both on-ramps having an acceleration lane. Between the two acceleration lanes a short section of shoulder is present. The length of roadway space consumed by the incident was estimated at about 500 ft (this is approximately half the length of the acceleration lane). This distance did not change during the duration of the incident; however, the number of lanes that were blocked due to the incident did change during the incident duration. The lane blockage started with just the right-most travel lane, then expanded to the shoulder, and finally also included the center travel lane. A reconstruction of the incident scene during the incident is given in appendix 7.3.

Figure 2 Accident location

5.4 Data Collection

In the previous section, a description of the network with the incident being modeled is given. For the simulation of the incident, traffic data are necessary. These data can be obtained from detectors present in the vicinity of the incident. In figure 3, the detector locations on I-295 and its ramps, near and on the Buckman Bridge are shown. These detectors measure vehicle volume, speeds, and lane occupancy. Unfortunately, it was not possible to obtain the data from the time of the incident. At the freeway segment with the observed incident, the detector system failed because of a system upgrade. As a result of the detectors failure, there were no traffic data collected during the time of the incident. This lack of traffic data for the time of the incident forced the use of historical data in the simulations.

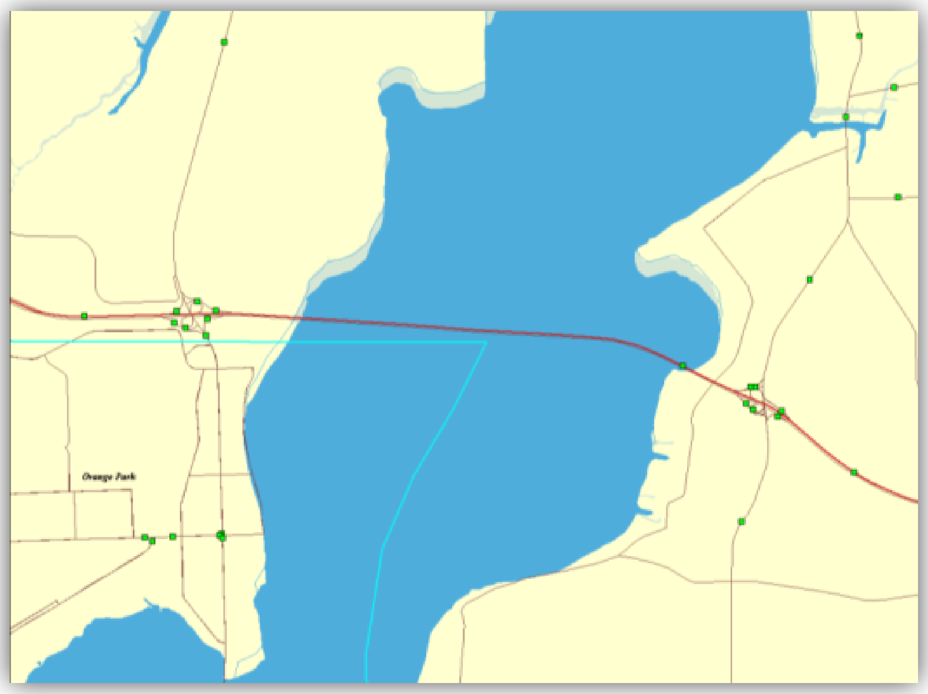

Figure 3 Detector locations

The historical data for the simulation were obtained from the 2006 Highway Data (Florida Department of Transportation, 2006). In these data the Average Annual Daily Traffic (AADT) recorded by the detectors can be found. In appendix 7.5, the counts from the detectors around the Buckman Bridge are presented. Also, a map with the names of the detectors are shown as clarification for the locations of the retrieved traffic counts. The AADT values were already categorized by travel direction. So in order to determine the peak hour, peak direction volume (which would be used as input into CORSIM), it was only necessary to multiply the provided AADT by the K-factor. The detector sites that are of interest for the simulation, along with the directional AADT, K-factor, and peak hour directional volume are shown in table 7.

Table 7. Converting AADT from January 1st 2006 till December 31st 2006 into Peak Hour Volumes

Detector name:	AADT	K-factor	Peak hour volume
Ramp from SR 13 SB to I-295 NB	9600	0.1001	961
Ramp from I-295 NB to SR 13 SB	3600	0.1001	360
Ramp from I-295 NB to SR 13 SB	18500	0.1001	1852
Ramp from US 17 SB to I-295 NB	3400	0.1001	340
Ramp from I-295 NB to US 17	23000	0.1001	2302
Ramp from US 17 NB to I-295 NB	7400	0.1001	741
SR 9A(I-295) between St. Augustine Rd and SR 13	59500	0.1001	5956
SR 9A(I-295) 0.6MI NW OF SR 13	65000	0.1001	6507

5.5 Data Requirements for Incident Modeling

In order to evaluate the incident modeling capabilities of CORSIM, a set of data requirements need to be specified for the evaluation. As a starting point, the characteristics of the selected incident were considered.

The incident timeline and incident specifications for the incident on I-295 indicated the events that took place and what the dimensions of the incident were, with the progression of the incident. These characteristics can influence the traffic flow on the freeway. The different characteristics found are then examined for their influence on traffic flow, so as to find the important characteristics that should be modeled in a computer simulation. The analysis of the different events and characteristics, with their relevance to traffic flow are attached in appendix 7.6.

The analysis of the events and their possible relevance to traffic flow on the freeway were converted into a set of requirements for modeling a freeway incident. These requirements are as follows:

- Incident location:
  The actual spot where the incident occurred and the length of road it takes up.
- Incident duration:
  The time it takes from the accident taking place to the incident being cleared and normal conditions being restored on the freeway.
- Lane blockage:
  The incident causes a lane of the freeway to be blocked and causes a section of the lane to be inaccessible to the traffic traveling along the freeway. The physical capacity of the freeway will be reduced from a three lanes to two lanes for a three-lane freeway.
- Shoulder blockage:
  An incident can block the shoulder of the freeway. This does not change the physical capacity of the freeway, but can have an effect on traffic on the freeway. Traffic on the freeway can reduce speed and increase following distance, which leads to a capacity reduction. The effect of traffic during shoulder blockings is similar to rubbernecking.
- Entrance ramp blockage:
  The incident causes a part of the acceleration lane to be blocked, and reduces the length of the acceleration lane. This gives merging traffic a smaller distance to accelerate.
- Capacity reduction due to rubbernecking:

Rubbernecking is the phenomenon of motorists checking out the incident that occurs on the freeway, either in the same or opposite direction of travel. Because of the attention being given to the incident, speeds are reduced and the following distances are increased. This leads to a reduction in capacity.

- Law enforcement presence:
  Warning motorists happens, because the law enforcement agencies are visible at the incident site. A state trooper usually turns on his flashing blue light that is visible for traffic further upstream of the incident to warn for lane closure. In other cases it is possible for the TMC to warn motorists on the freeway, using matrix signs. For the incident on I-295 this was not possible.
- Traffic demand changes:
  The incident can take several hours. In this period of time the traffic demand can change on the section of freeway, where the incident takes place. This demand change can be caused by the transition into rush hour or people are changing their routes, because they were informed of the incident.
- Changes in incident status (e.g., an extra lane being blocked during the clearance of the incident.):
  The incident can change its characteristics during its duration. For instance, an incident blocking two lanes can be reduced to an incident blocking one lane, because the vehicles involved in the incident were removed from one of the lanes. In another case a one lane blocking incident can change into a shoulder blocking incident.
- Forced merging upstream of the lane blockage:
  In real life conditions the lane blocking on the freeway forces traffic, arriving on the blocked lane, to merge onto the left lane. Motorists do not stay stuck behind the blocked lane, but intend to keep traveling along the freeway.
- Merging allowed from the on-ramp:
  At the incident site an on-ramp enters the freeway. Traffic entering the freeway from this on-ramp still has to have the ability to merge onto the freeway from the right site, even if a part of the acceleration lane is blocked

5.6 CORSIM input options

The previous section specified the data requirements for modeling a freeway incident. If the simulation tool cannot account for one or more of these requirements, its ability to simulate the incident in a fully realistic manner will be limited. CORSIM’s ability to account for each of the requirements outlined in the previous section is assessed in the following subsections.

5.6.1 Entry volumes

This option is not specifically related to incidents in CORSIM. Traffic demand has to be defined for every simulation carried out with CORSIM. This option is taken into consideration, however, because of the general ability of CORSIM to handle changes in traffic demand. These demand changes can influence traffic operations during the incident, with a higher traffic demand usually leading to more delay. When traffic demand exceeds the capacity of the freeway during an incident, congestion starts to arise and a queue will build up behind the incident. In reality, traffic demand on a freeway will not be constant during the entire course of the incident, especially with the incident on I-295. This incident occurred at 5:00 p.m., roughly the time peak afternoon traffic volumes begin, and ended at approximately 8:00 p.m., a time when the peak afternoon traffic flow is usually completed. So it is desirable to have an option that allows the modeler to change traffic demand during the course of the simulation. In CORSIM, different time periods during the simulation can be defined and for each time period a new traffic demand can be specified. These traffic demands must be input as entry volumes, as shown in figure 4, at the entry point to the defined roadway network.

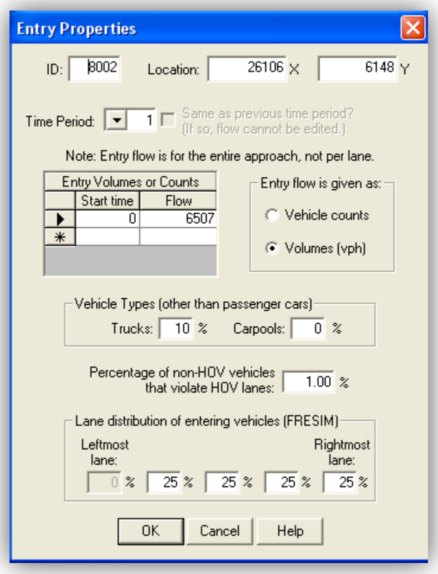

Figure 4 Entry volumes

5.6.2 Incident input

With the construction of the link-node diagram complete, the incident can be modeled. The incident occurs on a specific link of the network. In CORSIM, there is a special link option which allows the user to put an “incident” on the link. Figure 5 shows the dialog box page for this option.

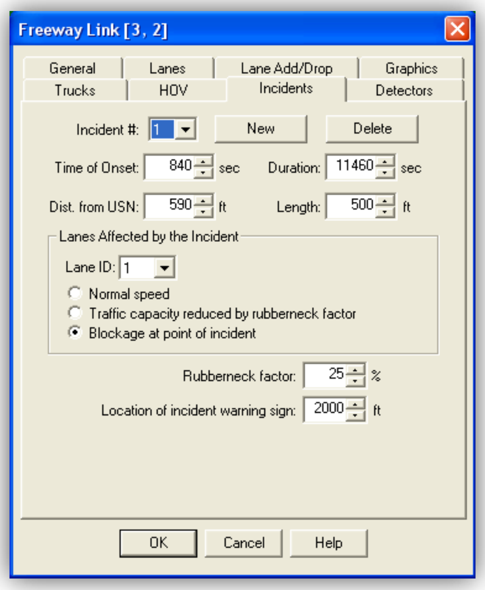

Figure 5 Incident input tab

In this menu, several incident data requirements are met and can be specified, such as:

- Incident location
- Incident duration
- Lane blockage
- Entry-ramp blockage
- Capacity reduction due to rubbernecking
- Law enforcement presence

There are two model requirements that can be set indirectly

- Shoulder blockage
- Changes in incident status

The incident occurs over time and space, so it is important that the location and the duration of an incident can be input into CORSIM. So naturally, CORSIM provides the option of specifying the onset time (start) and duration of the incident. The time of onset is the time difference between the start time of the simulation and the time at which the incident occurs.

The incident location is defined as the distance from the upstream node to the location of initial lane blockage. So it is important that the node upstream of the incident is set at a specific location in order to set the right distance to the incident. The other parameter for the location of the incident is to assign the length of the road that is affected by the incident. However, these parameters do not specify the configuration of how the individual lanes on the freeway are influenced by incident.

CORSIM provides the ability to indicate how each of the lanes is affected by the incident. The relation between the incident and the freeway lanes can be set as: no effect from the incident or capacity reduction by rubbernecking, or blockage at point of incident. The lanes for which the blocking can be set include the main, acceleration, deceleration, and auxiliary lanes. CORSIM does not provide the ability to specify shoulder blockage. There is, however, the potential to capture the effect of should blockage by assigning capacity reduction due to rubbernecking (described below) to the main freeway lanes. The input for the rubbernecking factor should result in an affected traffic flow on the freeway past the shoulder incident.

The traffic flow past an incident is affected by more than just from the blocking of a lane. That is, the capacity is reduced by a greater amount than the physical reduction in road space. This effect is called rubbernecking and is caused by motorists looking at the incident and being more cautious past the incident. These actions of the motorists result in a reduction of speed and an increase of following distances, and leads to a reduction in capacity. In CORSIM, it is possible to assign a parameter called the rubbernecking factor to lanes affected by the incident. With this rubbernecking factor the reduction in capacity is assigned for the lanes that are present in the incident road section.

Law enforcement presence cannot be modeled in CORSIM. However there is a parameter that could reproduce some of the effects that a law enforcement officer at the scene can create. A warning sign can be put upstream of the incident. The warning sign is put upstream of a blockage incident and represents the location at which vehicles will respond to the blockage by attempting to change lanes out of the lane(s) affected by the blockage. This warning sign is designed to represent signs that are put up to indicate which lanes are affected in case of a work zone. However this sign can also be used in case of incidents, only it should be put closer to the actual blockage point since motorists can only respond to the blockage when they see it. With law enforcement the blockage can be spotted sooner, by the better visibility of the flashing lights of the police vehicle, and therefore the place of the warning sign should be changed.

Although certain characteristics, such as traffic demand, can be varied during the course of the total simulation period, the characteristics of an incident is not one of them. The chosen incident on I-295 had different lane closures over time. A way around this in CORSIM is by treating the one incident as multiple incidents happening on the same section of road. For every incident the parameters have to be specified again, with the location of the incident staying the same for every new stage in the incident. So indirectly, the different stages of the incident can be represented during the total simulation period.

5.6.3 Lane changing characteristics

In the model requirements two requirements involved the merging of vehicles at the blockage point, namely the forced merging upstream of the lane blocking, and allowing merging from the on-ramp. During the blockage of the right lane traffic merges from the right lane to the left lanes due to the incident in order to continue travel along the freeway. Another merge occurs for vehicles entering the freeway from the on-ramp that need to merge onto the freeway to continue traveling. The merging process during the incident is different from the merging under normal conditions. The difference is the fact that during the incident, motorists are required to make a lane change to continue travel past the incident or an extra lane change when entering the freeway from the on-ramp. While under conditions without an incident, motorists only make lane changes to obtain an increase in traveling speed or enter the freeway from the on-ramp. The required merging is a mandatory lane change and the lane change to increase speed is the discretionary lane change. In CORSIM the lane change behavior of motorists can be changed by adjusting the lane change parameters, if necessary. The menu for adjusting lane changing parameters is shown in figure 6. By adjusting these parameters influence can be exerted on the merging process in the simulation of incidents.

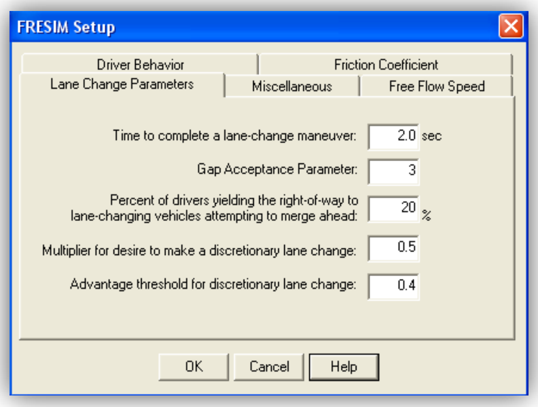

Figure 6 Lane change parameters

The parameters related to lane changing behavior in CORSIM are: time of a lane-change maneuver, gap acceptance, percent of drivers yielding to vehicles attempting a merge, desire to make a discretionary lane change and threshold for discretionary lane change. For the lane change parameters there are three parameters that could influence the mandatory lane changes directly, namely the parameters for time to complete a lane change, gap acceptance, and percentage of drivers yielding to vehicles to merge ahead. The two other parameters only influence discretionary lane changes and do not directly influence the merging process at the blockage point of the incident.

Table 8. CORSIM's options for the data requirements

Data requirements for CORSIM	Direct or indirect input possibility?	CORSIM’s input option
Incident location	Direct	• Distance from node • Length
Incident duration	Direct	• Time of onset • Duration
Lane blockage	Direct	• Lanes affected by the incident: Option of setting lane blockage
Entry-ramp blockage	Direct	• Lanes affected by the incident: Option of setting lane blockage
Capacity reduction due to rubbernecking	Direct	• Lanes affected by the incident: Option of setting rubberneck factor
Law enforcement presence	Indirect	• Location of a warning sign
Shoulder blockage	Indirect	• Option of setting rubberneck factor
Changes in incident status	Indirect	• Specifying multiple incidents

5.7 Incident Simulation in CORSIM

CORSIM provides the option of modeling an incident on a freeway network. The previous chapter summarized the input options and limitations for specifying incidents and their characteristics within CORSIM. This section will describe the CORSIM simulation experiments performed to evaluate its incident-modeling capabilities.

The results of the simulation that will be analyzed are the typical traffic flow measures of effectiveness (MOEs), such as Total Travel Delay, Average Speed, and Total Travel Time and Total Vehicle miles Traveled and the animated simulation of traffic. The results of these simulations are presented and compared to each other in this section. The MOEs are compared for the entire network to evaluate the behavior of CORSIM in simulating incidents on the freeway. . The MOEs are for every simulation interval on the entire network. Because the simulation interval was set to 60 seconds, the intervals represents one minute of the simulation. So at interval 30, 30 minutes have elapsed since the start of the simulation. This means, for instance that the total travel delay on the network is given for every minute of the simulation. The total delay on the network is the difference between the time it would take a vehicle to travel the length of its trip if it is traveled at the free-flow speed and the actual time that it takes the vehicle to travel that distance. The average speed figure plots the average speed on the entire network for every minute of the simulation. The total travel time for the network for every minute of the simulation is also given. The total travel time is the summation of the individual travel time of every vehicle on the network. And finally, Total Vehicle-Miles Traveled are displayed. The total vehicle-miles traveled indicate the total distance that all the cars on the network traveled during one interval of the simulation.

5.7.1 Model input

In this paragraph the most important values and assumptions of the inputs in CORSIM are discussed, for a base simulation of the network without the incident present, and a base simulation of the network with the incident. The complete input data were presented in appendix 7.9 and entry volumes on the network was presented in appendix 7.8.

The total simulation time of one simulation comes down to 4 hours. The simulation is set to start 14 minutes before the incident occurs, to allow a period of normal traffic. The end time is set at 35 minutes after the incident is cleared and let the network restore to normal operations. During the time of the simulation the entry volumes are changed to represent the end of rush hour and evaluate how CORSIM handles traffic demand changes. After 134 minutes the entry volumes are lowered to 80% of the values that were input at the start of the simulation. The entry volumes are attached in appendix 7.8.

The scope of the network that needs need to build in CORSIM was determined to be the intersection of I-295 and US-17 and upstream from this point the Buckman Bridge. In CORSIM a link-node diagram is used as input to represent the network. The road network was constructed using the TRAFED editing tool in the TSIS package. By loading a background image into the program, and setting the scale for the image, the link-node diagram is constructed on top with the correct measurements. The link node diagram can be found in appendix 7.7. The links represent road sections that are connected to each other via nodes. One link represents a road section on which most geometric data are consistent. When changes occur in the geometric data a new link is constructed and connected through a node to the other link. Nodes are either put in at changes in data or when the link becomes too long. Geometric data for the road network was obtained from Google Earth and visual observation at the location of interest. The links in the network are assigned the correct properties for free flow speed, and grade. From visual observations the speed limit on the Buckman bridge and at the intersection was 65 mph, so this is assumed to be the free flow speed on the freeway. For the on-ramps there is no speed limit available, so for these free flow speeds an assumption was made based on the curvature of the ramp. The road network does not show any vertical gradients along its course, except for the Buckman Bridge. At the center of Buckman Bridge a rise in the road deck is present. The gradient at this point is calculated to be 4%, with the calculation attached in appendix 7.9.1.

Onto the constructed road network, the incident is modeled. This option is only relevant to the simulation in which the incident is being simulated. As discussed in the previous section CORSIM cannot put the incident on the freeway as one incident. Because of the different stages in the incident with different lane configurations etc., the incident is divided into six different incidents all occurring on the same location. So location parameters are unchanged for all six incidents. Each incident starts after a change in the incident characteristic and continues until another change in the configuration takes place. The complete entries for the different incidents are attached in appendix 7.9.2. The change during the incident can be the configuration of the lane closures or a difference in the place of the warning sign.

With the configuration of the lane closures the rubbernecking factor also changes, because this factor adjusts the lane capacity to its reduced capacity during rubbernecking. The remaining capacity of a lane is changed by a percentage that can be inputted by the user. So with this rubberneck factor the remaining capacity of the freeway is set after the blocking of a lane or shoulder. The Highway Capacity Manual (HCM) (Transportation Research Board, 2000) reports on what the remaining capacity is for a freeway when a lane is being blocked by an incident. So for the blocking of one lane the remaining capacity will be set to 49%, and for the blocking of two lanes to 17%. When only the shoulder is being blocked by the incident the remaining capacity on the freeway is determined to be 83%.

For the simulation of the incident it is not necessary to change the lane changing parameters in CORSIM. It is possible to use the default values, as set in CORSIM. For these simulations however the parameter for yielding to other drivers who want to make a mandatory lane and the gap acceptance parameter are changed because of the incident. These parameters are changed, because a large portion of motorists will allow vehicles to merge in front of them in order to get around the incident. The ‘yielding’ parameter is increased 80% and the ‘gap acceptance’ parameter is lowered to 1. The purpose of altering these parameters is to obtain a more realistic merging process at the blockage point. Because CORSIM can only change these parameters for the entire network, the parameters need to be changed for both simulations in order to get a proper comparison between the two simulations.

5.7.2 No incident on network

In order to judge if the behavior of CORSIM with an incident on the freeway is logical, and therefore confidence can be put into its simulating abilities of an incident, a reference is needed for comparison of results. This reference will provide results for the model under normal operating conditions. For this simulation all the model inputs discussed in section 5.6 are used, except for the inputs that deal directly with modeling the incident. The results of the simulation are shown in the figures 7 through 10.

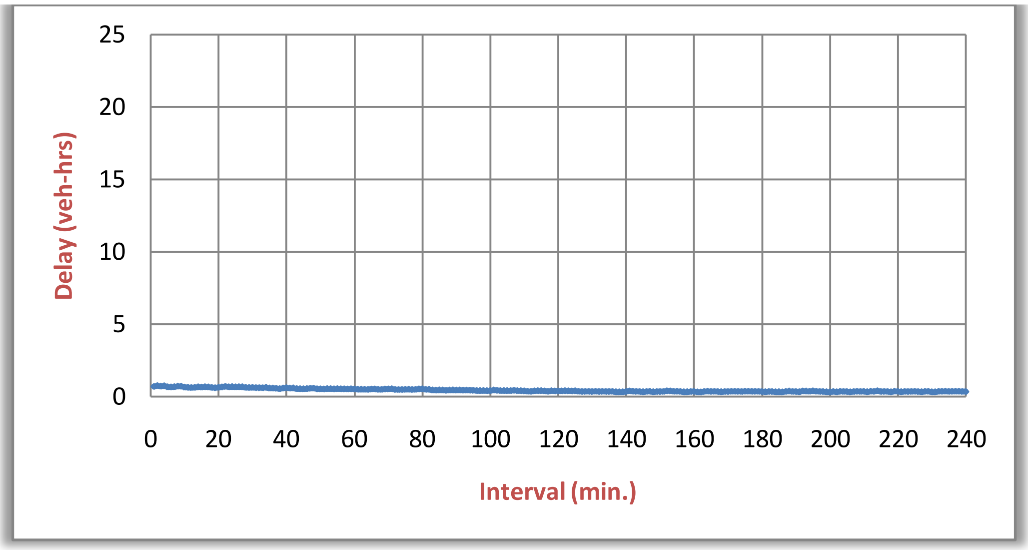

Figure 7. Total Travel Delay

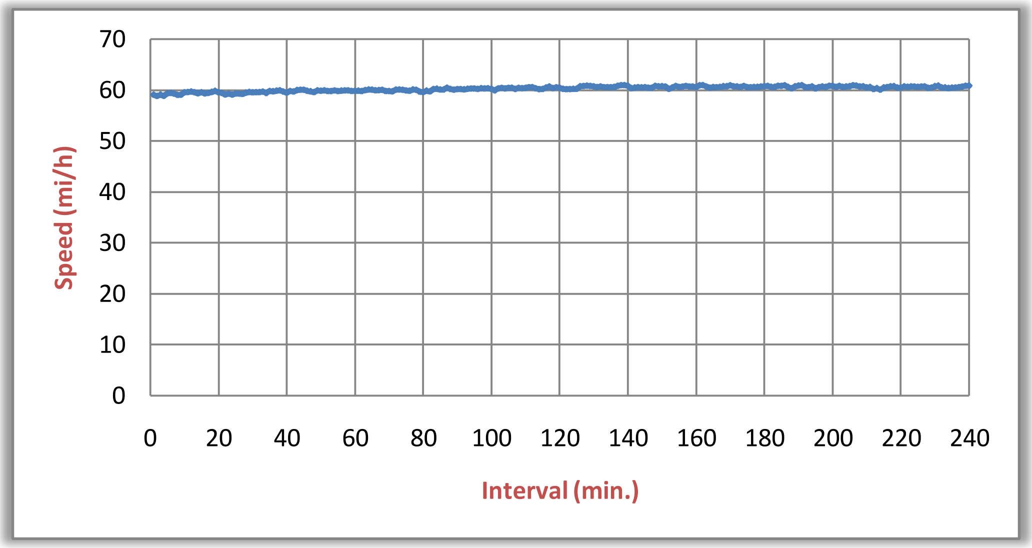

Figure 8. Average speed

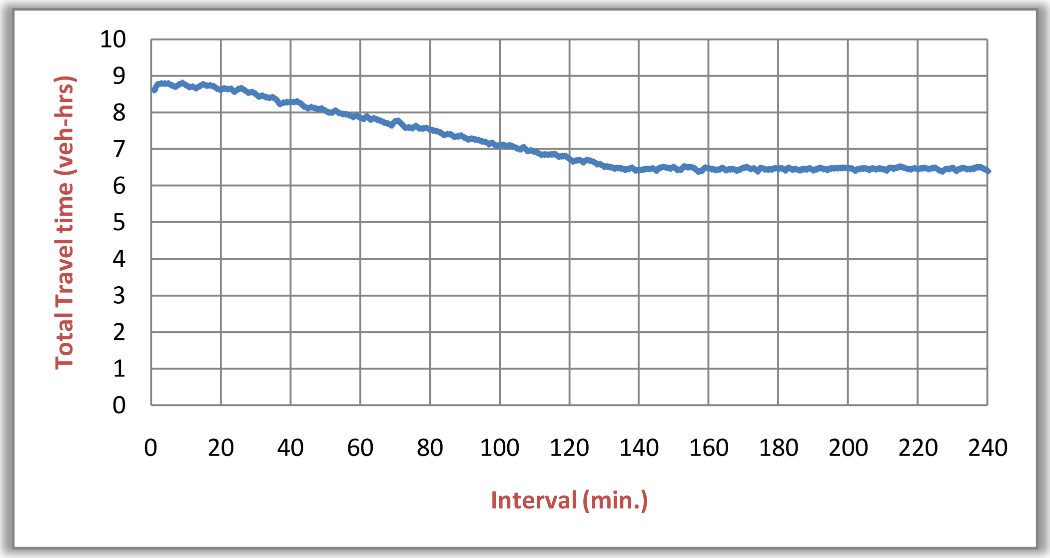

Figure 9. Total Travel Time

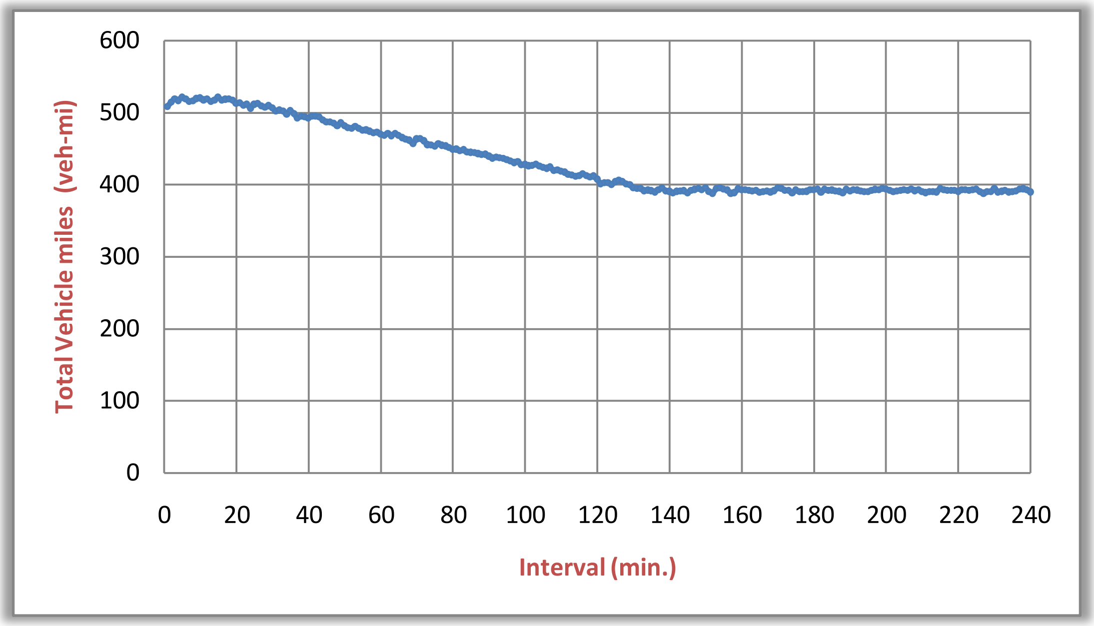

Figure 10. Total Vehicle Miles Traveled

Figure 7 shows that there is practically no delay on the network during the simulation, which is to be expected since there is no incident simulated. Also this indicates that the network operates below capacity and every vehicle travels at the driver's preferred speed. From Figure 8 can be seen that the average speed remains constant on the network during the course of the simulation, which is another indicator that the network is operating below capacity. Figure 9 shows that the total travel time decreases further into the simulation and levels out after about 130 minutes. At 130 minutes the traffic demand of the network is reduced to reflect the ending of rush hour and at this time the travel time throughout the network remains the same. Figure 10 shows a similar plot for total vehicle miles traveled as for total travel time. With the reduction of cars on the network the total vehicles miles traveled also go down until rush hour is over and the volume of cars remains constant.

Along with the output of various MOEs, CORSIM also produces an animation file of the simulated traffic. This animation file is used for a visual assessment of the simulation. For this simulation without incident, no remarkable observations were made as can be seen from figure 12. Traffic enters and exits the network without experiencing visible causes of delay, like congestion. At the entry ramps there are also no visible problems. No queue build-up can be observed on the ramps in figure 11, to indicate merging problems.

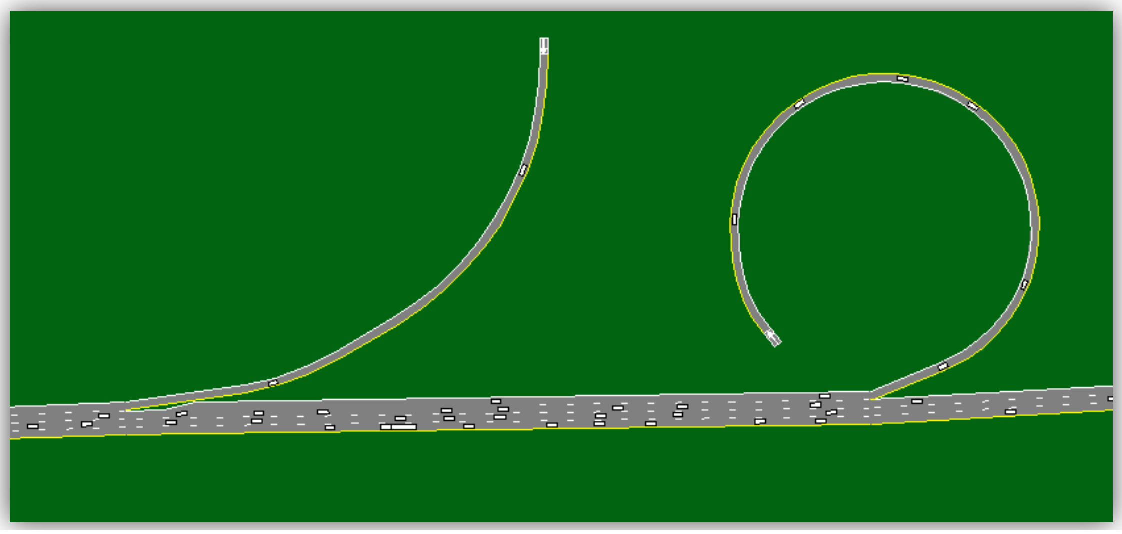

Figure 11. Freeway section Buckman Bridge

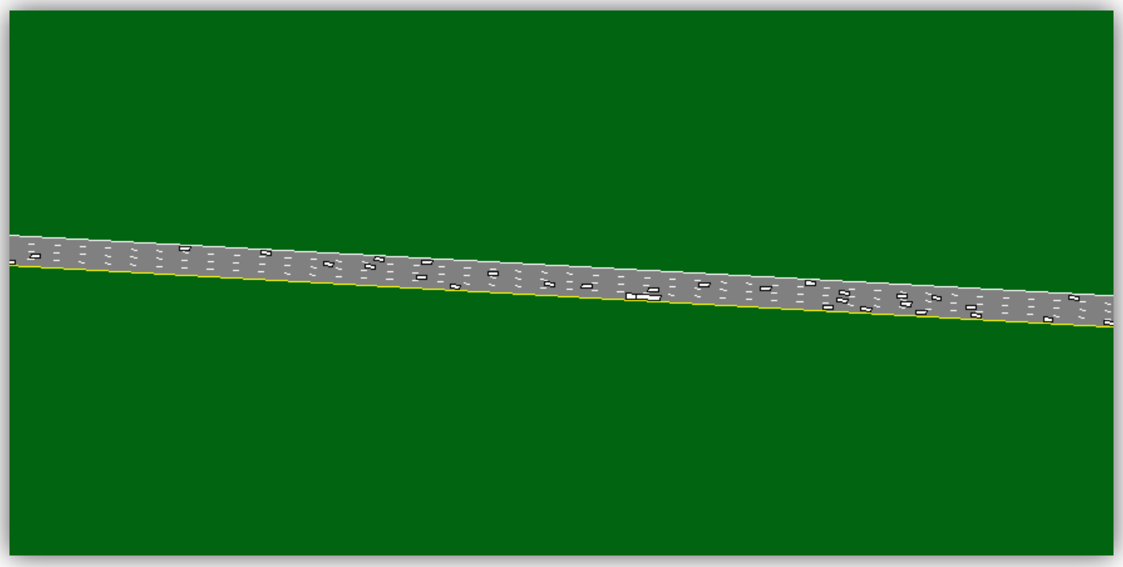

Figure 12. Entry ramps

5.7.3 Incident on network

In this simulation experiment, the incident as described in section 5.3 was coded into CORSIM. The input values of this simulation are described in section 5.7.1. The simulation will provide results for the simulation of an incident on the network. The results for the simulation are shown in figure 13 through 16. The same outputs were used as with simulation under normal conditions, namely Total Delay travel, Average speed, and Total Travel Time and Total Vehicle-Miles Traveled.

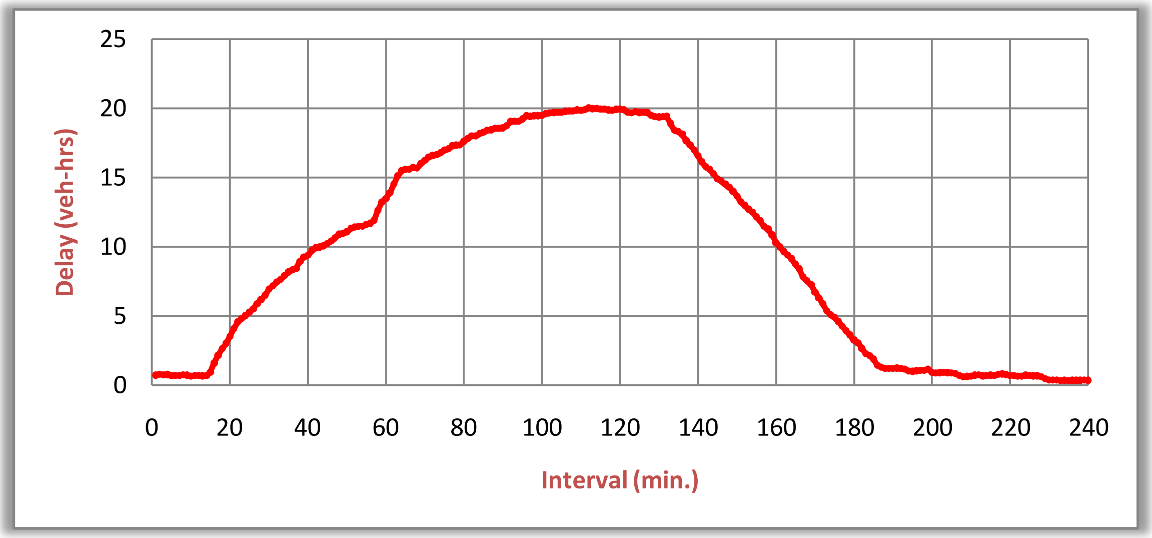

Figure 13. Total Travel Delay

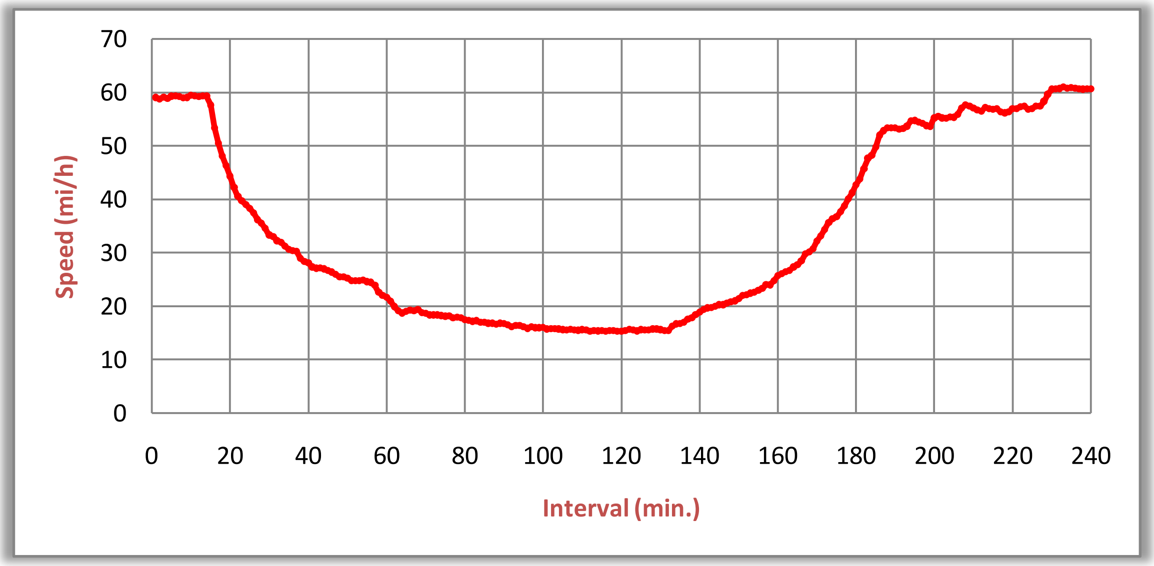

Figure 14. Average Speed

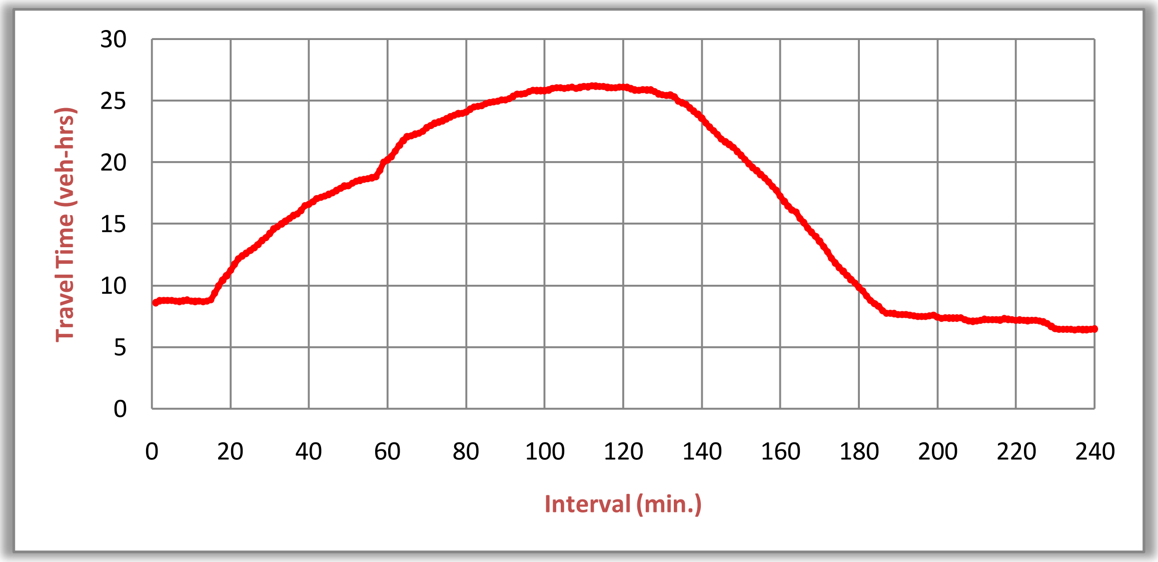

Figure 15. Total Travel Time

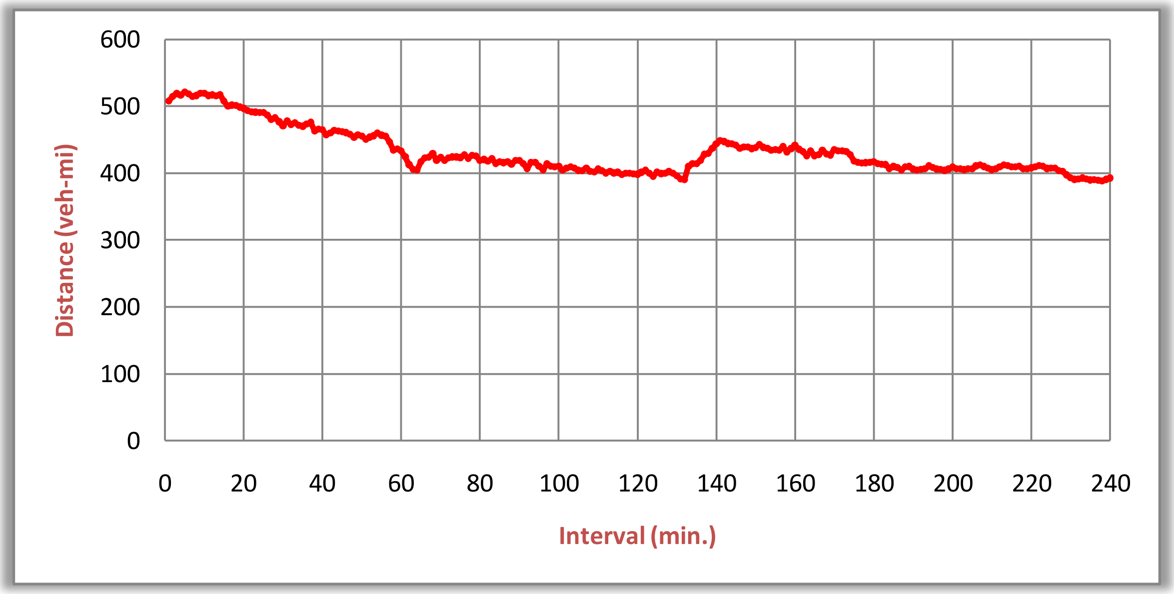

Figure 16. Total Vehicles Miles Traveled

From figure 13 it is clear that the incident is causing delay on the freeway, because a distinct peak can be observed from the simulation. The incident was set to start after 15 minutes and from the graph it can be observed after approximately 15 minutes the curve starts to rise and delay starts on the network, which is as to be expected. After 56 minutes the incidents starts blocking an extra lane of the freeway for two minutes. This extra lane being blocked can be easily seen, because the slope of the delay graph starts to increase more at this point for a few minutes, which is logical since the blockage only lasts for two minutes. Figure 13 shows a decrease in delay after approximately 130 minutes, which corresponds with the opening of the blocked lane on the freeway and with the decrease in traffic demand as the peak traffic demand was assumed to be over at 7:00 p.m. The total travel delay decreases until the point is reached where only the rubbernecking for the shoulder blockage causes delay. When the shoulder blockage is over as well at approximately 185 minutes, delay decreases further until almost no delay occurs on the network.

Figure 14 shows a similar pattern for the average speed as for the delay, only the curve descends when the incident begins. Otherwise the same properties stand out, such as the short time when the freeway is blocked for two lanes and the point where the incident is reduced to a shoulder blocking with the demand reduction at the same time. The two-lane blockage causes a sudden drop in average speed for a few minutes, but speeds continue to decline until 130 minutes. This corresponds with the increase in delay at figure 13 and is caused by the loss of capacity at the incident location. After the freeway mainlines are cleared and the traffic demand is lowered, the average speed starts to increase again. The end of the graph is very uneven, at the point where only the shoulder blocking is present. This is probably because the queue, which builds up behind the incident, is dissipating and the traffic is being restored to normal operations. The sudden increase in average speed to the point where it was before the incident is a sign that the queue is dissipated and traffic is restored to normal operations.

The total travel time in figure 15 displays similar results as the total delay in figure 13. The two lane blocking period is also visible for the travel time, as is the ending of the incident. Also the point where normal traffic operation are restored on the network is visible, as the travel time drops at this point to its normal value. The difference with the travel time is that the total travel time is smaller at the end of the simulation than at the beginning. However this is easily explained, because there are fewer vehicles on the network and therefore the combined travel time of all the vehicles is smaller.

Figure 16 displays the total vehicle miles traveled during the incident. The incident can be clearly identified in the plot. When the incident starts the vehicle miles traveled go down, which indicates that cars are not able to move freely. At the point of the two lane blockage after 56 minutes, the same effect as at the start of the incident is identified. This means that even more cars are stopped at this point. The vehicle miles start to rise again when the two lane blockage is reduced again to a one lane blockage, but only shortly and they start to decline again until 130 minutes. At 130 minutes the incident is reduced to the shoulder blockage and traffic is able to travel along the three mainlines again. This with the decrease in traffic demand at this point in the simulation, cause the vehicle miles to increase to let the queue dissipate, but falls again after a short time, because the total vehicles on the network will decrease.

The visual analysis of the simulation with an incident present gives a good impression of how CORSIM handles the incident. The red lanes in figure 17 represent the blocked lanes by the incident for the distance that was specified, and the yellow lanes represent the lanes that are affected by the incident due to rubbernecking. CORSIM sees the incident as blocked lanes and lanes where capacity is affected by a rubberneck factor that was assigned before simulation. Upstream of the lanes that were affected by the incident, blocked or otherwise, a queue build up can be seen. This queue extends all the way up the freeway section on the Buckman bridge, shown in figure 18. This queue build up corresponds with the queue that was observed from pictures during the real incident. Although the traffic demand data does not correspond to the same day of the incident, the results appear to be reasonably similar However, there is a problem that occurs at the merging of the on-ramp before the incident and in the lane behind the blocked mainline. The merging behind the blocked lane is realistic. Traffic behind the incident is stuck in the right lane and cannot seem to find an adequate gap in the adjacent lane to merge into. This also causes the traffic on the on-ramp to stop, since they cannot merge onto the freeway. In reality, a merging process will be started where vehicles from the right lane, behind the incident, are allowed to merge into the left lanes. CORSIM does not seem to be able to duplicate this behavior, despite the lane-changing parameter that should allow traffic to merge better for mandatory lane changes, namely the percentage of drivers yielding the right-of-way to lane-changing vehicles attempting to merge ahead. Another simulation was made with the percentage set at 100% instead of 80%, but this did not make a difference for the merging process. This merging problem has a negative effect on CORSIM's ability to simulate incidents on a freeway. The problem causes vehicles to be on the network longer and can let vehicles stop for a longer period of time, which could influence the results obtained from the simulation.

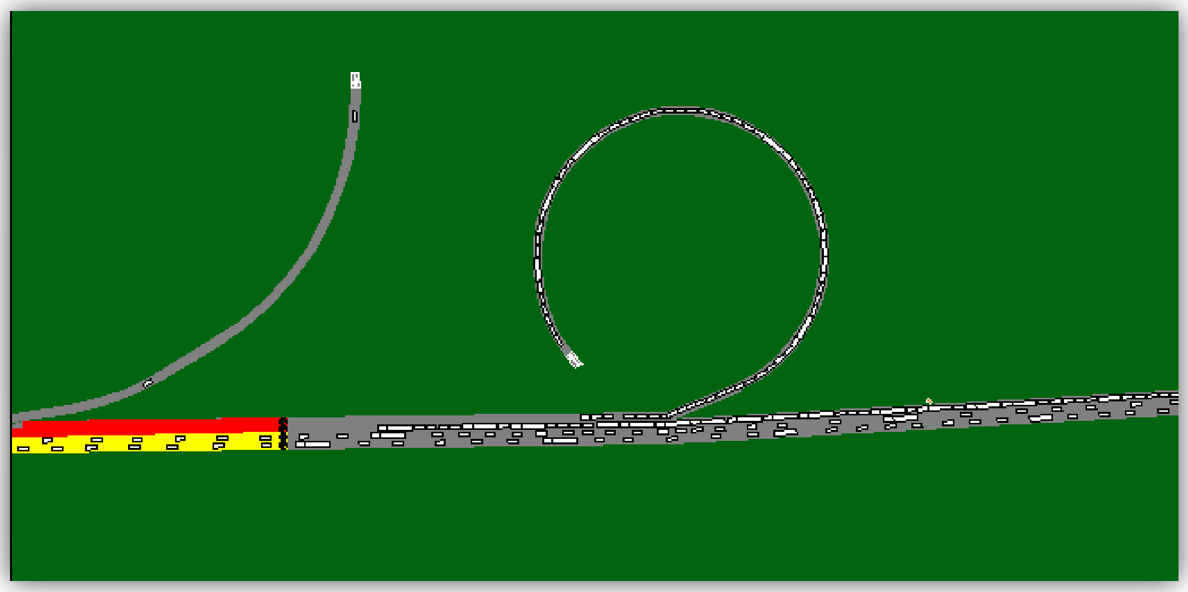

Figure 17. Incident and merge location

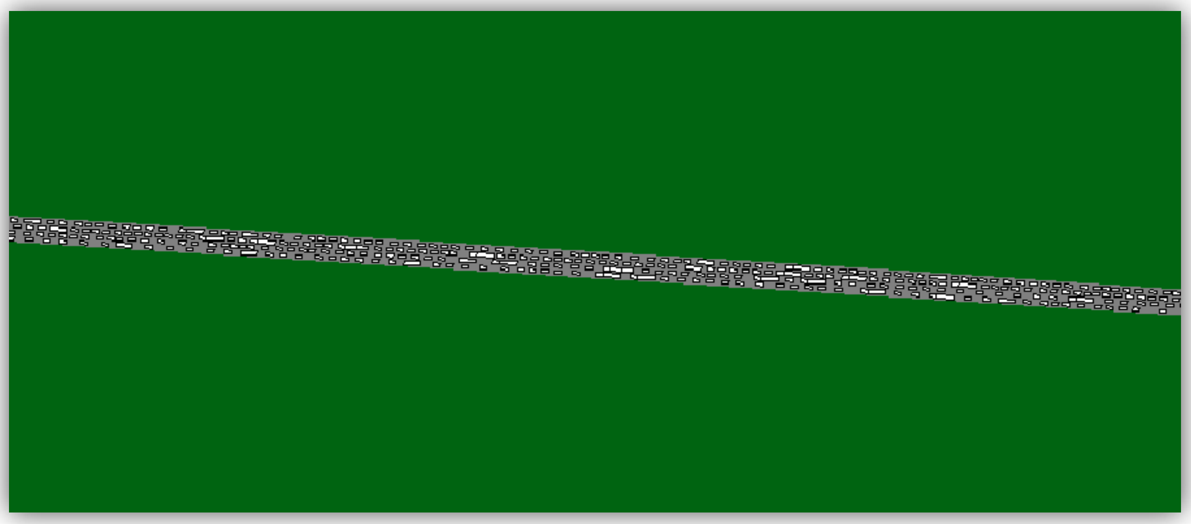

Figure 18. Buckman Bridge section

5.7.4 Comparison of the results

In this section, the simulation results from both experiments are plotted together, which gives a good comparison for the reference simulation under normal conditions and the simulation with the incident. In the graphs, the blue line represents the simulation with normal conditions and the red line represents the simulation with an incident.

The first impression of the graphs is that the incident is clearly visible from the peaks in the red lines. This indicates that CORSIM is able to simulate an incident that is modeled on the freeway, but the question is how well CORSIM can model the incidents. The incident described in section 5.3 was a complex one to model in CORSIM, but with a few adjustments, it was possible. The complex nature of the incident for simulation was the fact that it had different events over the course of the incident.

All these events had to be modeled, and from the output in the simulation, it can be observed that these events are simulated in CORSIM and produce logical outcomes. The only problem in the simulation is the merging process behind the incident. CORSIM does not let the cars merge in a manner that is expected when an incident occurs. The cars behind the blocked lane of the incident do not merge into the adjacent open lane, which normally does happen in reality.

With both results plotted in the same graph, the impacts of the incident on traffic flow are very evident. These outputs were selected because they are good indicators for breakdown on a freeway. Since the cause of the breakdown is known to be the incident, they are good indicators for the influence of the incident on traffic operations. In the results logical expectations would be for the delay and travel time to increase as a consequence of the incident on the freeway, because traffic is impeded at the incident which should have consequences for the entire network. Average speed and vehicle miles traveled on the other hand are expected to decrease, when traffic is impeded by the incident. In figure 19, it can be seen that in the case of normal operations there is practically no delay and at the peak the total delay under incident conditions is maximally 20 vehicle-hours. With the average speed falling below 20 mi/h, the difference between normal operations and during the incident is more than 40 mi/h in average travel speed at the maximum. The results from the total travel time in figure 21 shows that the travel time is at least four times as high at the maximum difference. Figure 22 shows the difference for the vehicle miles traveled and gives very interesting results. The results show that when the incident is reduced to a shoulder blockage and vehicles are able to travel along the three mainlines again, the vehicle miles start to increase above the level of the vehicle-miles without an incident and indicates that the queue is dissipating. This means that the network is trying to restore normal (free flow) operating conditions. All of these results indicate that the incident caused major congestion on the freeway, which was generally consistent with the observations from the real incident. These problems can be seen in the images attached in appendix 7.2. CORSIM seems to represent the incident logically during the simulations, with all the events input into model being represented in the results and traffic being affected as was expected from the incident in reality.

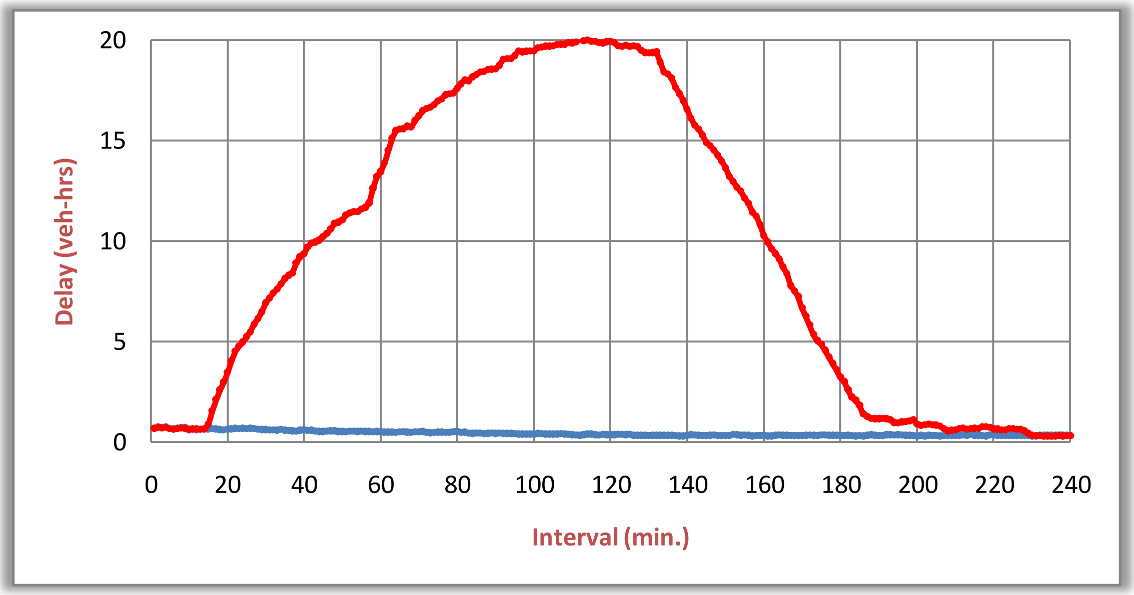

Figure 19. Total Travel Delay for both simulations

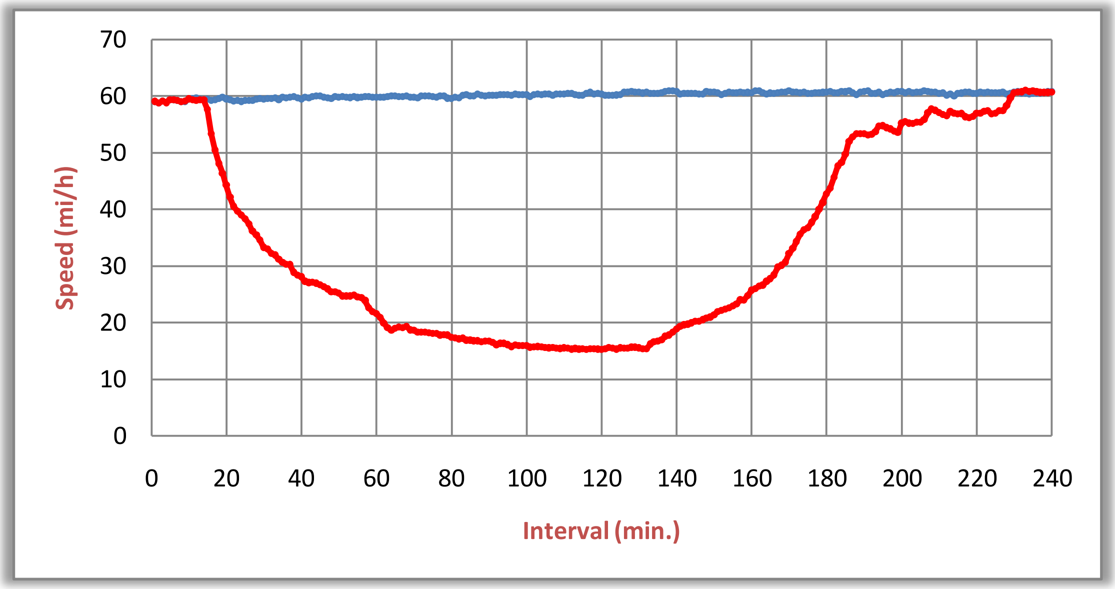

Figure 20. Average Speed for both simulations

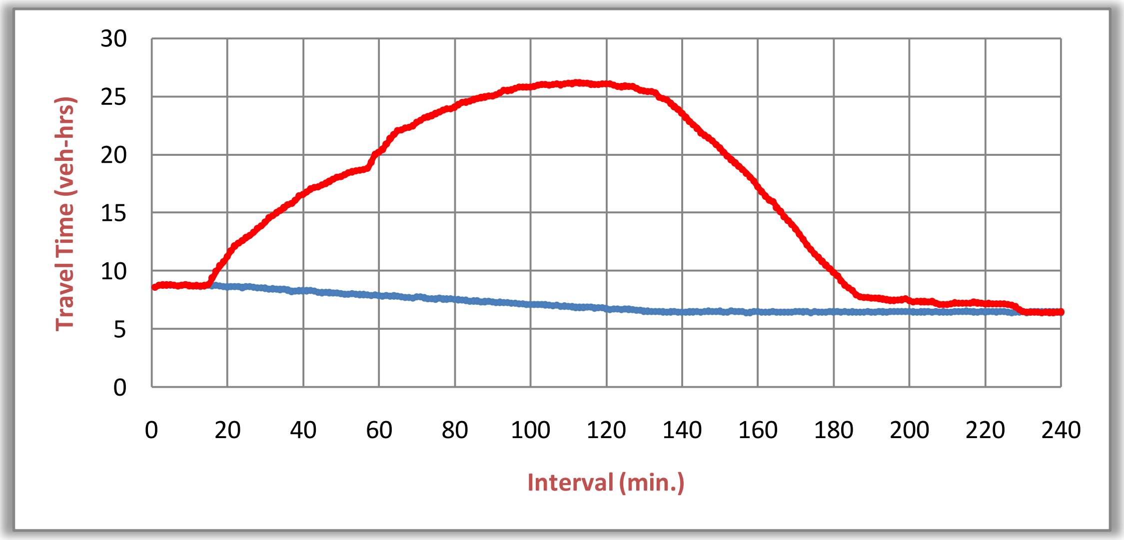

Figure 21. Total Travel Time for both simulations

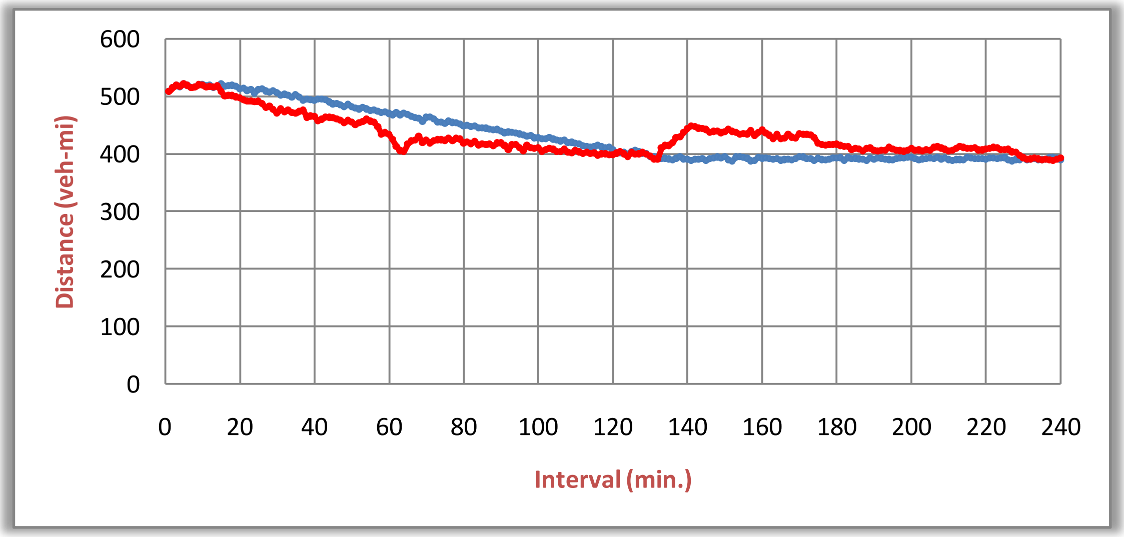

Figure 22. Total Vehicle Miles Traveled for both simulations

5.8 Sensitivity analysis

Previous sections show how CORSIM handles the simulation incidents within its input possibilities, despite a problem with the merging of cars behind the incident. For the input options it is important to establish what input parameters are important and therefore need attention and extra care when inputting values. The importance of an input option is obtained by performing an sensitivity analysis on important input parameters.

5.8.1 Analysis process

The complexity of input for the incident on I-295 in CORSIM makes it difficult to perform a useful sensitivity analysis on the different parameter values. To overcome this complexity the incident input was reduced from six incidents to one incident. For this one incident the right lane and part of the acceleration lane are blocked and the capacity on the two remaining lanes on the freeway are affected by rubbernecking of the vehicles passing the incident. The duration of the incident is kept constant so that the freeway is blocked for three hours. The reduction of complexity allows changing one parameter, while the others remain constant. All the input values for the sensitivity analysis are attached in appendix 7.9. By changing only one parameter value the effects of the change can be observed in the results and on that basis a judgment can be made on the importance of that input value.

From CORSIM's input options, parameters were selected for the sensitivity analysis. These parameters had to have a relation with the traffic flow around the incident. This means that parameters relating to time are dismissed from the selection. The parameters related to time are dismissed, because they will not produce useful information for traffic flow. They will only affect the duration of the impeded traffic flow. The list below displays the parameters selected:

- Length of incident
- Lane configuration
- Rubberneck factor
- Warning sign
- Free-flow speed
- Percentage of drivers yielding the right-of-way to lane-changing vehicles attempting to merge ahead
- Entry volumes

As mentioned these parameters were selected for their effect on traffic flow past the incident. A brief description of the expected effect will help in understanding the results of the sensitivity analysis that may give some unexpected results for the simulation capabilities of CORSIM. The length of the incident causes the capacity of the freeway to be reduced for a longer section of the freeway. This could have an effect on traffic flow, although the bottleneck is the same for every length of the incident. The lane configuration can be important, because the acceleration lane is located on the right side of the freeway. This means that more vehicles are expected to change lanes at an incident from the right lane than with an incident on the left lane. The rubberneck factor indicates remaining capacity on the lanes past the incident, what could make it a very important parameter since it affects all traffic upstream of the incident. The warning sign marks the place where motorists know that an incident has occurred downstream of their location and they need to merge, so it is expected to affect traffic flow by changing the merging process upstream of the incident. Speed is an important variable for traffic flow, so it can be expected that changes in the free flow speed have consequences on traffic flow past the incident. Another parameter with an influence on the merging process behind the incident is the percentage of drivers yielding to lane-changing vehicles that want to merge to avoid the incident. When the merging process changes by either going smoother or more difficult the traffic flow is affect. Entry volumes specify the amount of vehicles entering the network per hour, thus determining the traffic demand at of the vehicles wanting to pass the incident. Changes in this parameter are expected to have big consequences on the results.

5.8.2 Results sensitivity analysis

The results for the sensitivity analysis will be discussed for every parameter by assessing the influence changes of the parameter input has on traffic flow. After this assessment a judgment can be made for the importance of the parameter in relation to input modeling into CORSIM and if this is in accordance with expectations on real life situations. To obtain the influence of changes to parameter values, results of the simulation are plotted. The results of the simulation that are being used, is the simulation output of total delay of travel of the entire network. These results will show a good spread when the parameter is sensitive to changes and little spread when the parameter is not.

Lane configuration

For the parameter of lane configurations two simulations were made to determine its effects on traffic flow. One simulation is run with the right lane being obstructed by an incident and the other with a left lane obstruction of the incident. Although the freeway has three mainlines, only left and right lane obstructions were simulated. This was because it is very unlikely a middle lane will be closed by itself on a freeway. Either multiple lanes are obstructed or the incident is moved to one side of the freeway. The results for these simulations are shown in figure 23.

The results of the simulation in figure 23 show very interesting results. The results show that left lane obstruction causes much more delay than a right lane obstruction on the simulated network. The delay is so high that the entire network behind the incident is congested and therefore reaches its maximum delay. This can be observed by the flat top of the graph. The big difference in delay seems odd, since the most logical result would be when both the simulations would show similar levels of delay or the right lane configuration shows a bit more delay, since more traffic has to merge from the right due to the location of the on-ramp. An explanation for the results can be the fact that at the incident location an on-ramp with acceleration lane enters the freeway and CORSIM is not able to handle the merging from the left lane and the acceleration lane onto the open freeway lanes simultaneously. The left lane simulation does not seem realistic compared to what should be expected in real life. Therefore no real conclusions can be made from the results.

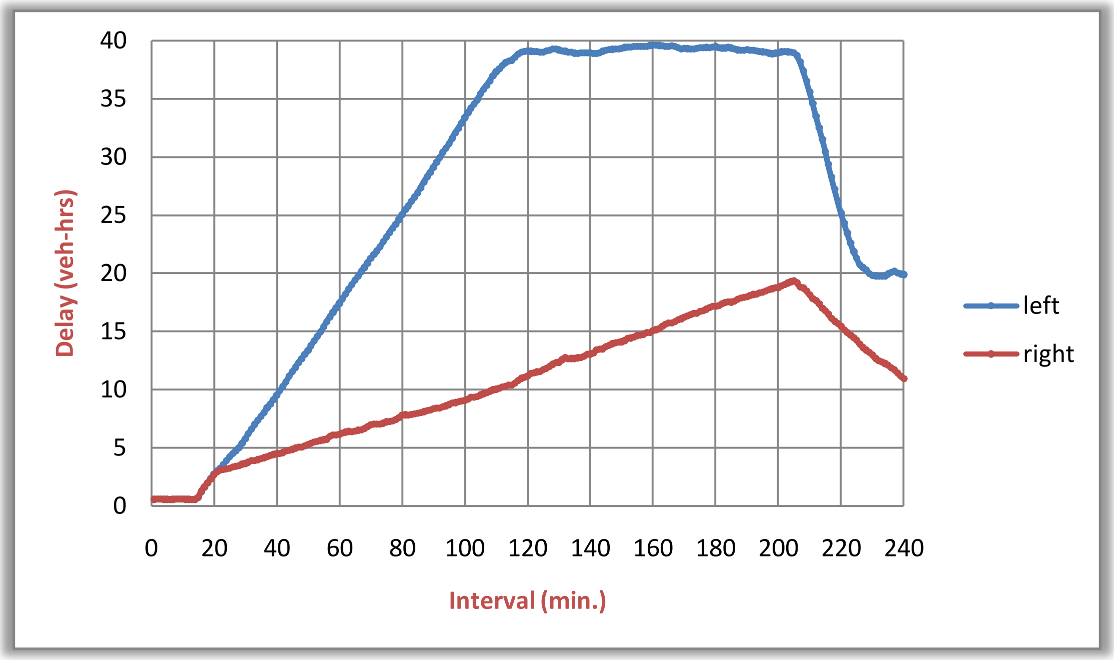

Figure 23. Lane configuration simulations

Incident length

To determine the importance that variations in incident length have on the simulation results, five simulations with different simulations lengths were executed. The different lengths for the incident were chosen to be 200ft, 400 ft, 600 ft, 800 ft, and 1000 ft. These lengths are a wide range of possible incident lengths. The results of the simulations are plotted in figure 24.

The results show that the incident length has an effect on traffic flow. For incident lengths below 800 ft the graph shows a spread in its results. For every increase in incident length the delay on the network also increases. This indicates that the incident length affects traffic flow on the network. However at 800 and 1000 ft the graphs are very similar. This indicates that at these lengths a maximum of influence on traffic flow is reached. An increase in incident will most likely not cause a further increase in delay on the network. So a spread of the results for different lengths can be seen till an incident length of 800 ft. This means that for incident up to a length of 800 ft will have an influence on traffic flow around the incident. Furthermore a large difference in delay can be observed between an incident with length 400 ft and an incident with length 600 ft, which means that changes in incident length in this range will have more influence on traffic flow, than for other values of the incident length.

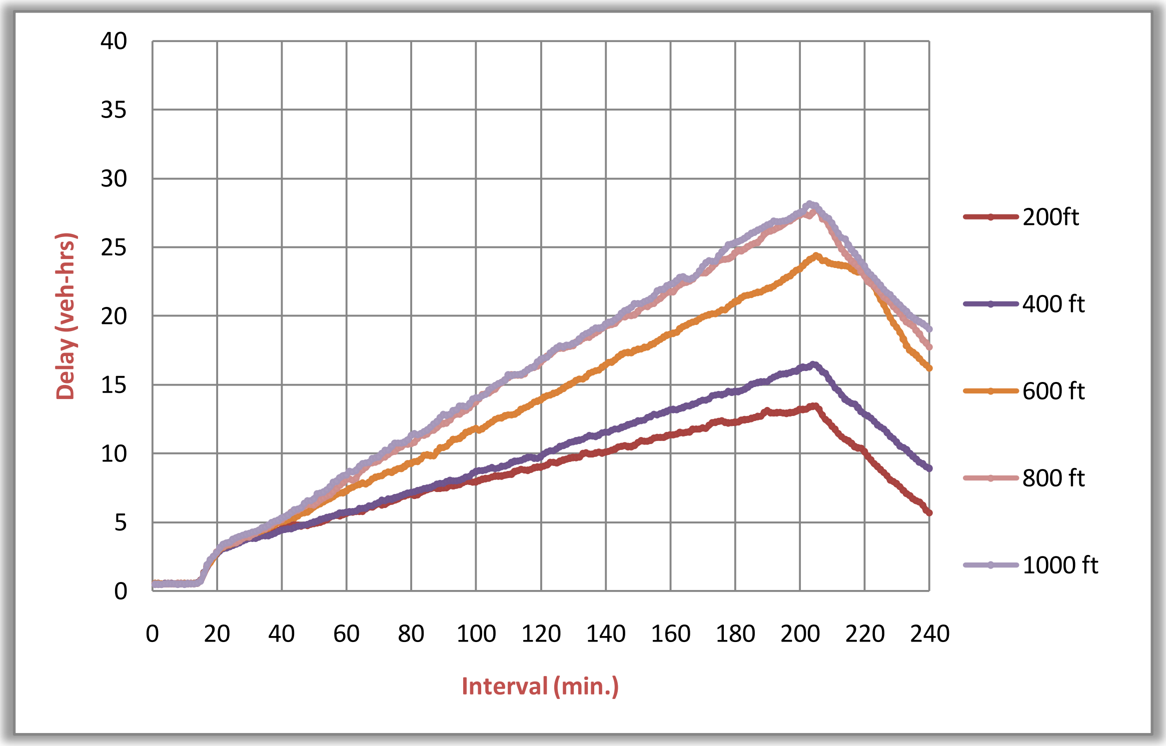

Figure 24. Incident length simulations

The rubbernecking factor

The importance of the rubbernecking factor is determined by performing eight simulations with different values for the percentage of capacity reduction on a single lane. For the eight simulations the capacity reduction was set at successively 2, 4, 6, 8, 10, 12, 14, and 16 percent. These small changes of the values is done, because the rubbernecking factor is expected to be sensitive to these changes. The results of these simulations are plotted in figure 25.

The graph of the rubbernecking factor is characterized by a spread between the different percentages of capacity reduction. It was to be expected that assigning a reduction in capacity has an effect on the results of the simulation. So the question in this case was not if changing the parameter would affect the traffic flow past the incident and thus the results of the simulation, but how much do the changes affect the results. Figure 25 shows that every increase in the percentage of the rubbernecking factor causes a considerable increase in delay. This means that for every increase of the rubbernecking factor, the traffic flow in the simulation is affected. Only the lowest capacity reductions of 2% and 4% do not because an increase in delay, because the traffic flow is probably more affected the lane blockage and the merging process behind it. The last value for the rubbernecking factor of 16% still has an increase in delay, but the top of the graph is flat. This is being caused by the same phenomenon as described with the lane configuration results. Congestion has occurred on the entire roadway network behind the incident, so the peak cannot rise any further. Otherwise the peak of the graph for the 16% rubbernecking factor would still have given an increase in delay. So the results of the simulations are affected and sensitive to changes in the rubbernecking factor.

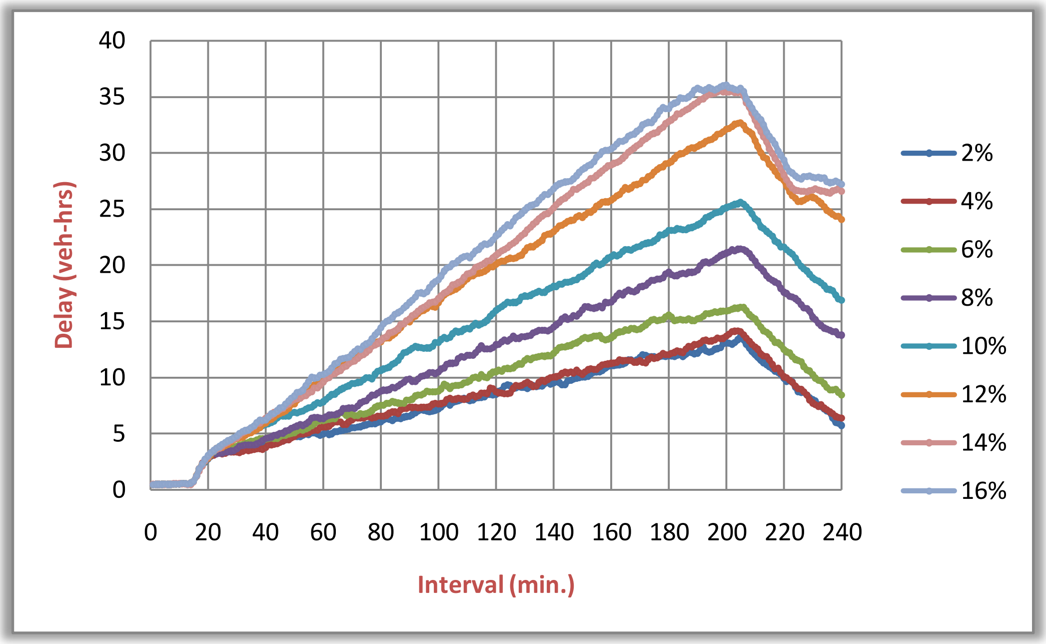

Figure 25. Rubbernecking factor simulations

Warning sign location

In the sensitivity analysis the influence of the warning sign location was tested by simulating the incident in CORSIM, for six different locations of the warning sign. The location of the warning sign was set at 1 ft (because 0 ft was not allowed by CORSIM), 300, 600, 900, 1200 and 1500 ft. The results for the simulation are shown in figure 26.

The simulations for the warning sign locations show very erratic results, especially when the warning sign is put further upstream of the incident location. For the locations of 1 ft and 300 ft the differences in delay can be explained. When the warning sign is 1 ft upstream of the incident location vehicles have no room to accelerate and will not be able to merge to the left lanes easily, whereas with 300 ft this acceleration space is available. The results for the other locations are best explained by CORSIM's inability to simulate the merging process upstream of the incident properly. So vehicles are merging irregularly and that is what gives the erratic results for delay.

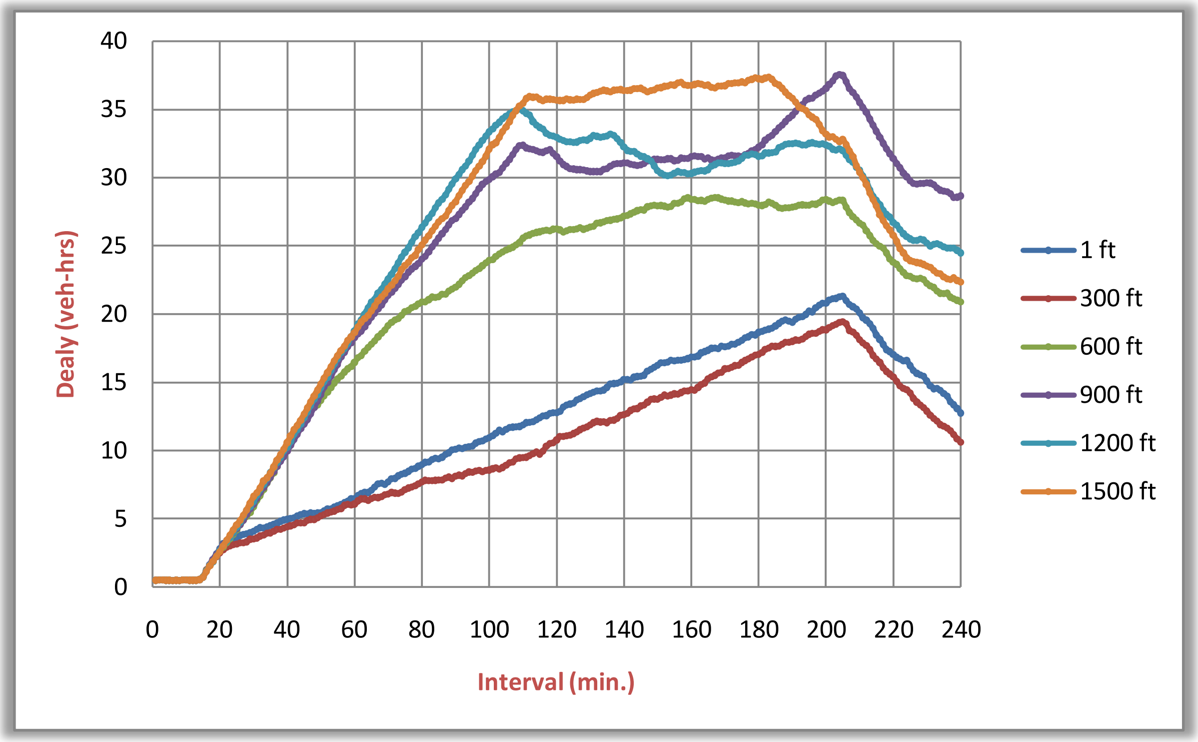

Figure 26. Warning sign location simulations

Percentage of drivers yielding to merging vehicles

For the sensitivity analysis of the "percentage of drivers yielding the right-of-way to lane-changing vehicles attempting to merge ahead" five simulations were carried out. The percentages were chosen to be 20%, 40%, 60%, 80% and 100%, in order to get results for a wide range of possibilities for the parameter. The results of the simulations are plotted in figure 27.

The results plotted in figure 27 look very different from the other results. Where the other results show variation between the different simulations that were performed, the results for the percentage of drivers yielding to merging vehicles do not show this variation. This means that the influence of this parameter is very limited on the traffic flow past the incident. This is surprising since the purpose of this parameter is to improve the merging process, due to mandatory lane changing in case of incidents or other obstructions. This lack of influence of the parameter can be part of the fact that CORSIM has trouble with the merging process behind the incident. If the parameter does not influence the simulation it is possible that this is caused by the merging difficulties in CORSIM, since this parameter should improve the merging.

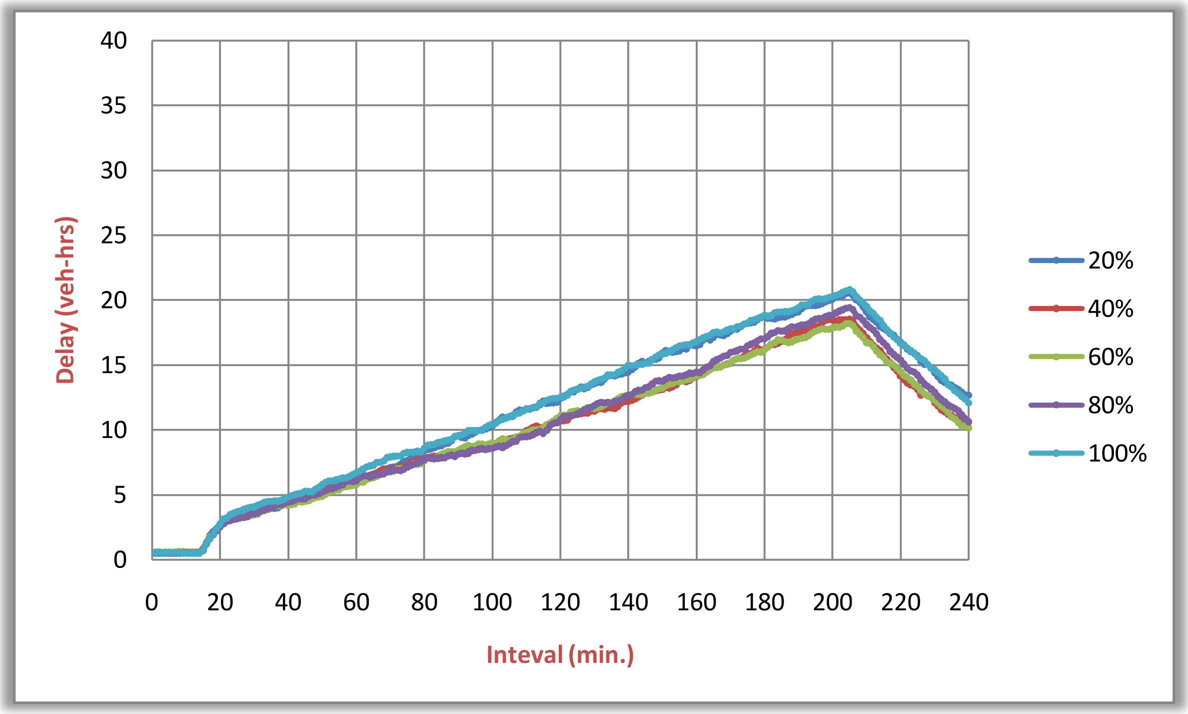

Figure 27. Percentage of drivers yielding to merging vehicles simulations

Traffic demand

Traffic demand is not directly an incident related parameter, but could have major consequences on traffic flow on the network, when an incident occurs. The importance of traffic demand is determined by running simulations with changes in the entry volumes for the network. The entry volumes that are used in the simulations were set to be 5600, 5800, 6000, 6200 and 6400 vehicles per hour. The results of the simulation are shown in figure 28.

As is to be expected the results for the traffic demand simulations show a big spread for changes in to the entry volumes. This spread means that changes in the entry volumes and thus a variation of traffic demand cause big changes in traffic flow on the network with an incident present. It can be observed from figure 28 that a difference of 800 vehicles per hour for the entry volumes can cause the difference between a little delay with practically no consequences on the network, and maximum delay with congestion reaching all the way back to the endpoint of the modeled network. The great spread in results means that when modeling incidents, changes in entry volumes has big consequences on the results of the simulations.

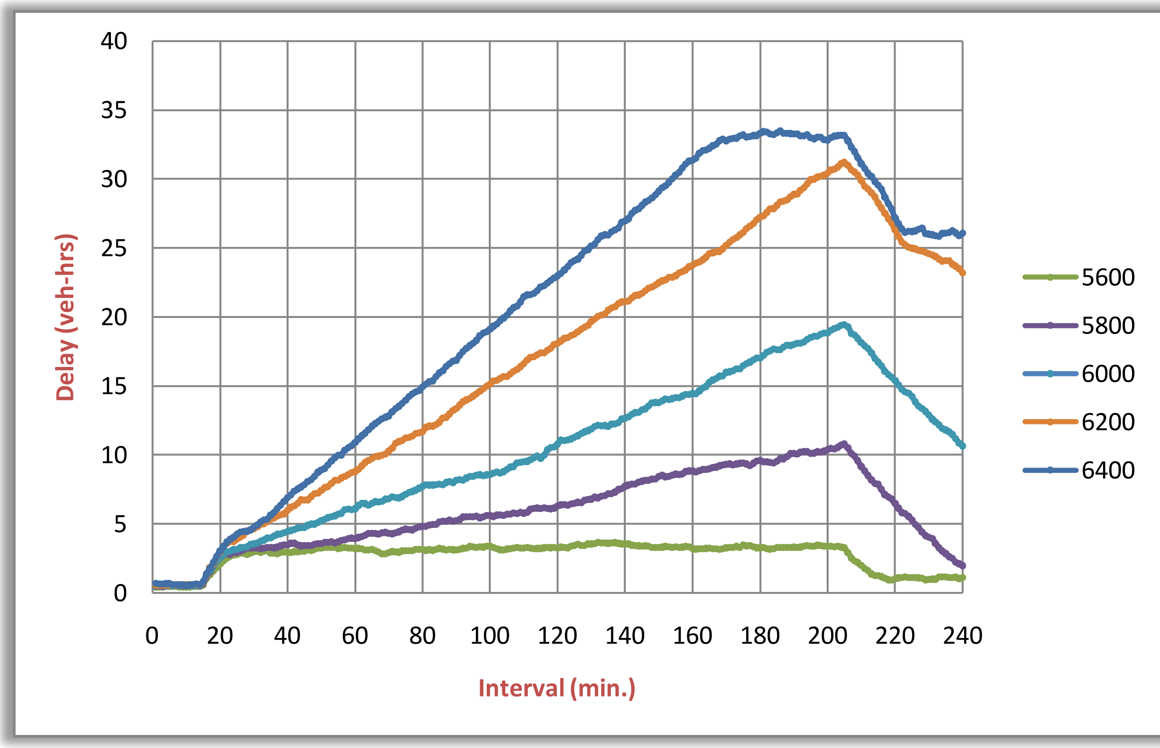

Figure 28. Traffic demand simulations

Free flow speed

Free flow speed is a parameter that is not directly related to incidents. Under conditions without an incident free flow speed influences the traffic flow, so for an incident situation it was examined if changes to free flow speed had an influence. For the simulations with changes to free flow speed the speeds were set at 50, 55, 60, 65 and 70 mph. The results are plotted in figure 29.

The results for the variation of free flow speed show little spread. This means that the influence of the free flow speed on the traffic flow during the incident is minimal. This is logical, because during the incident traffic probably operates below the free flow speed. Although it can be determined from the results that a low free flow speed in the simulation at the start of an incident will result in more delay during the course of the incident. In figure 29 can be seen, despite a small spread of the results that with an increased free flow speed, comes a lower total delay on the network.

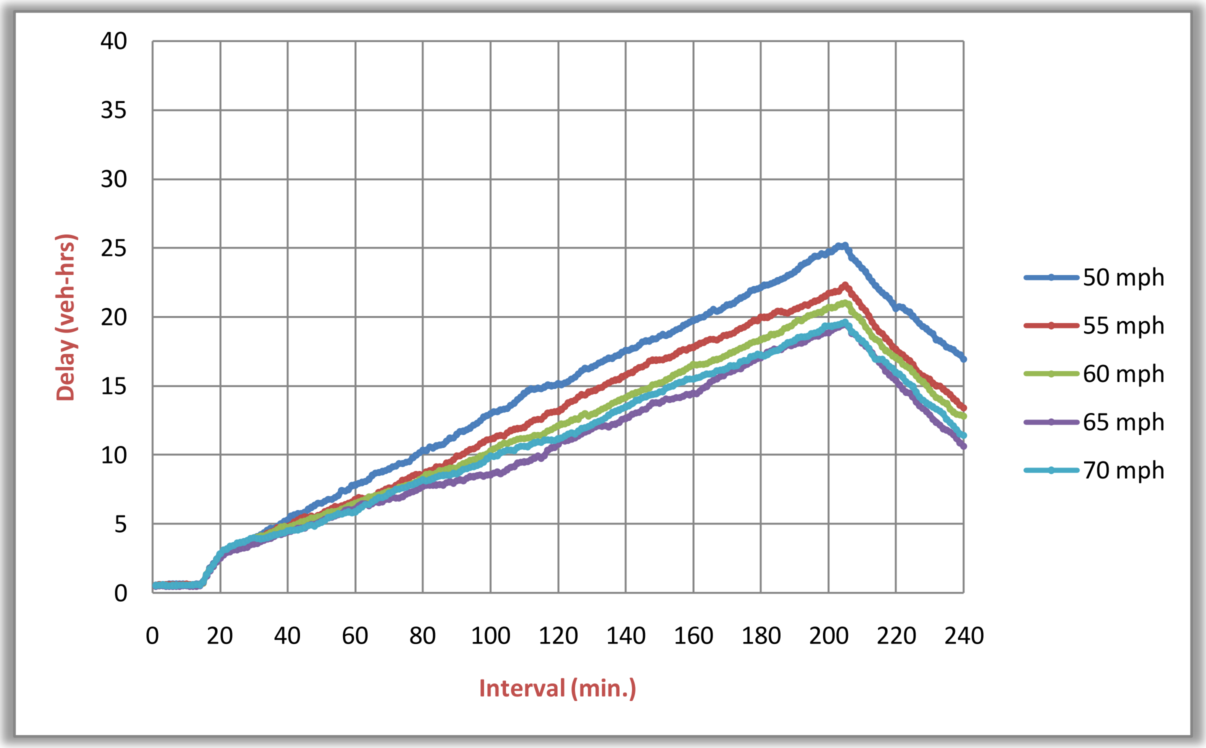

Figure 29. Free flow Speed simulations

5.8.3 Important parameters

In the results of the sensitivity analysis for the different parameters were discussed in the previous section. From these results the important parameters can be determined and what influence this has on the modeling of incidents.

The results of the sensitivity analysis show that the most important parameters for the input of CORSIM are the rubbernecking factor, incident length, and traffic demand. Of these three parameters the rubbernecking factor and traffic demand are a bit more important than the incident length. Because of the sensitivity of these parameters in simulations with CORSIM, their input values have to be determined with care. So in order to simulate an incident in CORSIM good, reliable data and/or validated assumptions, for the capacity reduction from rubbernecking and the traffic demand upstream, are needed. Otherwise the simulation could give inaccurate results for the effects of the modeled incident. The incident length is another important parameter, although not as important as the other two. Because the incident length is not an attribute that is often measured at the scene, an estimate has to be made. This estimate has to be done carefully, since the results could be affected.

The parameter for free flow speed has little influence on the results of the simulations. This is the result of the fact that during the incident the operating speed on the network falls below the free flow speed. The parameter related to the yielding of motorists to traffic trying to merge has limited influence on the simulation. This raises the question that maybe the parameter is not working properly in the simulation with CORSIM. Since the parameter should allow motorists to change their lane more easily, when there is a mandatory lane change required (in the case of a lane blockage).

The final two parameters showed incomprehensible results. It should be expected that the simulations for lane blockage on the right and on the left lane, would produce similar results or at least results that are closer together. However, the difference between results that were obtained from the simulations is certainly not what could be expected. An answer can be sought in the acceleration lane of an on-ramp joining the freeway at the incident location and CORSIM's inability to handle the merging from the on-ramp and the left lane simultaneously. Otherwise it is inexplicable how these results differ so extensively. The location of the warning sign also produced very peculiar results, with the very unstable results. These are best explained by the problems that were observed with the merging behind the incident. The merging of cars starts at the warning sign, as the motorist is alerted at this point of the need to make a lane change to avoid the lane blockage. Cars making a lane change only occurs occasionally now and that causes the delay to drop and also gives the unstable results. So the location of the warning sign does not affect the results of the simulation too much, since the underlying cause is the trouble CORSIM has with the merging process behind the incident.

5.9 CORSIM's modeling capabilities

By using the analysis from the previous sections on the possibilities for inputting incidents into CORSIM, the results for the incident simulations and the results sensitivity analysis an assessment can be made for the modeling capabilities of CORSIM for freeway incidents. This assessment presents the strengths and limitations that CORSIM has for both the input and simulating capabilities. With the outcome of the assessment recommendations can be made for what would be preferred option for simulating freeway incidents.

The analysis for the input options show, that almost all the specified model requirements could be entered into the model of CORSIM via the input options. However not all requirements could be entered directly. For some requirements it was necessary to use different parameters to obtain the same effects for traffic flow in the model as could be expected for traffic flow in reality. The model requirements that could be inputted directly were:

- Incident location
- Incident duration
- Lane blocking
- Entry-ramp blocking
- Capacity reduction due to rubbernecking
- Traffic demand changes
- Allow merging from the on-ramp

For all of these requirements an entry box or screen was present in the network editor of CORSIM, except for the merging from the on-ramp, since CORSIM handles this option automatically by allowing vehicles to merge from the acceleration lane. So There is no option that needs to be changed for this requirement. The model requirements that could not be inputted directly in CORSIM were:

- Shoulder blockage
- (Law enforcement presence)
- Changes in incident status

- Forced merging upstream of the lane blocking

Two of the requirements that could not be entered directly caused some difficulties in the simulation with CORSIM, the other two requirements could be modeled using other input options and gave logical results. The requirements causing problems in CORSIM were law enforcement presence and Forced merging upstream of the lane blocking. The requirements that did not cause problems were the shoulder blockage and the changes in incident status.

No direct input option for a shoulder blockage on the network was given. In order to get the effects of a shoulder blocking in the simulation the rubbernecking factor can be used, since rubbernecking is what in reality occurs during a shoulder blockage. So the use of the rubbernecking factor is an excellent and maybe even better substitute for the direct input of a shoulder blockage, because now the effects of the shoulder blockage can be adjusted. The changes in incident status could be entered by modeling multiple incidents, instead of modeling one incident on the network. So for every change of the incident a new incident was specified in the model. This did not cause any problems in the simulation and gave the results that were to be expected.

Law enforcement presence was an option that could not be entered into CORSIM. There was only an indirect possibility for entering law enforcement presence. Since the effects of law enforcement presence on traffic especially involves better visibility of the incident, adjusting the warning sign location was used to enable the better visibility. By placing the warning sign further upstream in the model the increased visibility by law enforcement was imitated. However traffic did not start merging at this point, instead they stopped at the location of the warning sign and occasionally a vehicle would change lanes to make its way past the incident. This problem with lane changing of vehicles is related to that of the next model requirement. The fourth option that could not be modeled directly was the forced merging behind the incident, although the merging process could be influenced by changing a parameter for the lane changing characteristics. This parameter was the "percentage of drivers yielding the right-of-way to lane-changing vehicles attempting to merge ahead" and should let traffic merge more easily behind the incident, but this proved to be not the case from the simulations. Traffic did not merge onto the left lanes in order to move past the incident. Only occasionally a vehicle would merge, the rest of the vehicles remained in queue behind the incident at the location of the warning sign. The sensitivity analysis for this parameter showed that it has no effect on the simulation whatsoever. So this seems to be a real limitation in CORSIM for the simulation of freeway incidents.

Even though CORSIM has trouble handling the merging behind the incident, the behavior of the simulation in CORSIM was good. Every event that occurred during the incident that was put into CORSIM could be traced in the results of the simulation. These events could be for instance the start and ending of the incident, changes in lane configuration and changes in traffic demand. So CORSIM is able to simulate incidents on freeways. Only the problems with the merging can influence the results of the simulation. Most likely the delay will be valued greater, than it would be in reality. The greater delay is caused by traffic being stopped behind the incident.

For a good simulation in CORSIM the most important parameters with an effect on the traffic flow and therefore the parameters with a big effect on the results are the rubbernecking factor, traffic demand and incident length. It is vital for simulations of incidents that these parameter values are chosen carefully, because they can greatly affect the results of simulation incidents on the freeway. For the other parameters this great care with the input values is less important. The parameter for the percentage of drivers yielding to cars merging ahead and the free flow speed do not even affect the results. For flee flow speed this is logical, since the speed is expected to drop below free flow values. But for the percentage of drivers yielding to cars merging ahead the lack of influence on the simulation is a restriction of CORSIM, that most likely need to be fixed.

From the assessment of CORSIM's modeling capabilities recommendations can be made for simulating incidents with CORSIM. The major entry necessities are present within CORSIM, incident duration, incident location and rubbernecking. However some other options could be added. For instance different events within one incident cannot be modeled as one incident. Now it is necessary to specify multiple incidents, but it could be more orderly when different time steps were allowed for one incident. For each of these time steps the characteristics of the incident can be changed, so that the events during an incident are modeled. Furthermore an option for adjusting the lane changing characteristics of vehicles at the incident location should be provided. It would be best if this option was separated from the lane changing characteristics for the entire network. Although CORSIM has the option to change the lane changing characteristics for vehicles on the network, it does not work properly. Changes to the parameter have no effects on the results for the simulation of the incident, where a change in delay could be expected due the increased or reduced resistance to lane changing. This problem for the merging process is most likely a bug in the FRESIM simulator that needs to be repaired. By repairing the bug in FRESIM the erratic results due for the warning sign location will probably be solved, because a more fluent merging at the warning sign will smooth out the delay differences. Still the location of the warning sign is a substitute for the presence of law enforcement, based on the increased visibility generated from the police car and its blue flashing light. In reality the presence of law enforcements can have more influences on traffic, such as an extra reduction of speed. It would be best if CORSIM had an option to include police presence, but imitating the presence with other parameters will work for the simulation. The parameters that could imitate the police presence would then be the warning sign location and/or the rubbernecking factor.

To conclude the statement can be made that CORSIM is able to simulate incidents on a freeway, but the problem with the merging has to be solved. When the problem with the merging is solved more reliable results can be obtained from simulation performed with CORSIM.

6. Conclusion

The major impact of traffic incidents on traffic operations on freeways can be seen in statistics that show that freeway incidents cause more than one-third of traffic delay in urban areas of the United States. (U.S. Department of Transportation Federal Highway Administration Office of Operations, 2008) The tendency in the field of transportation nowadays is to first improve traffic operations to increase capacity, instead of increasing capacity by producing more roads. By concentrating on the effects that incidents have on capacity, a contribution can be made to find methods that improve traffic operations and reduce delay caused by incidents.

The premier reference in the United States regarding capacity related information is the Highway Capacity Manual 2000 (HCM). The manual lists outdated and limited information on capacity reduction due to incidents for its analysis procedure on freeway facilities. The information is outdated, because the research that forms the basis for the material in the HCM is more than 35 years old. The biggest limitations of the HCM are that no distinction is made for the severity of an incident, no information on rubbernecking in the opposite direction is presented and road characteristics are not factored into the capacity reduction. The advantage of using the information in the analysis procedure for freeway facilities is that it is very straightforward to use and can be applied easily.

The limitations and age of the material in the HCM make it very desirable for the Highway Capacity and Quality of Service Committee (HCQSC) of the Transportation Research Board (TRB) to update the information on the effects on capacity from freeway incidents. The synthesis in this reports shows that very little research on the topic of capacity reduction due to incidents has been done to this date. The research found dealing directly with capacity reduction from incidents, presented the same type of adjustment factors at the HCM. Only the studies were more recent and therefore better represent the current traffic conditions better in their results. A good addition to the HCM could be the research performed by Masinick & Teng, 2004 on the effects of rubbernecking for the opposite direction of travel. However it is vital that more research is being performed on the topic, so that results can be generalised. With more research on the topic a better update of the HCM can be realised with better and more complete information.

To reduce delay on the roadways due to incidents, incident management systems are in place. To test different strategies of these incident management systems field studies and traffic simulators can be used. Traffic simulators are a cost-effective method for performing these evaluations. Another benefit of traffic simulators is that they can be used to test the different strategies before implementation, whereas field studies can only evaluate the strategies after implementation. CORSIM is a microscopic traffic simulator that is a very useful traffic simulator for simulating incidents on a freeway. CORSIM provides a special option for modeling incidents on the freeway, that is very easy to use. Within the special incident option in CORSIM the most important inputs for modeling the incident on the freeway network are provided, such as the location, duration, lanes affected and rubberneck factor. The rubberneck factor is the extra capacity reduction on the remaining lanes caused by the incident. CORSIM does however have a few limitations for simulating incidents. So does CORSIM not allow the law enforcement presence to be modeled. Also, CORSIM does not give the possibility to overwrite the merging process on the network when an incident occurs, so that another merging algorithm is used for the queue behind the incident. The problem with the merging in CORSIM is that vehicles arriving at the incident on the lane that is blocked are stuck behind the incident. They do not make a lane change to continue their travel along the freeway and this will give distorted results for the simulation in comparison to reality. However when this problem is repaired by fixing the algorithm, or even better by providing special merging process for incidents, CORSIM should be able to simulate incident correctly and represent reality reasonably well.

In CORSIM the rubberneck factor is an important parameter to influence the capacity as a result of the incident. The parameter value has to given in by the modeler. This can either be done by obtaining field data, or literature on capacity reduction due to incidents. The most important source for this information is the HCM, where outdated information was presented. Thus, the outdated information in the HCM could be used in evaluating alternatives for incident management strategies and provide the evaluation with distorted results.

So more research has to be done to improve the knowledge on how incidents affect freeway capacity. This will also contribute to better simulating results. For these simulations the traffic simulator CORSIM is a good tool, but some improvements can be made and problems need to be fixed, to represent reality better. With more research done and the improvements made, a better understanding of the effects of incidents on capacity can be obtained.

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7. Appendix

7.1 Incident report

The Sunguide intelligent transportation system of Florida's Department of Transportation records all information related to the incident. This includes general information on the incident such as the date, incident description, incident location, time of onset, the notifier agency of the incident and conditions. From the report can be extracted that the incident involved two trucks and took place on I-295 NB with a road ranger detecting the incident. The other part of the report specifies the actions that were taken to handle the incident, such as the arrival of law enforcement and towers.

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION

Event Chronology

SUNGUIDE™ Florida's Intelligent Transportation System

Created On:	September 19, 2008 07:16:32
Center:	District 2
Filter Parameters Selected:	[From Event ID]: 14422, [To Event ID]: 14422
Period:	September 18 2008
Event(s) Found:	1
Event ID Range:	14,422

Event #: 14422 **Event Type:** Accident **Report Date:** 09/18/2008 16:59:00

Status:	Closed	**County:**	Duval	**Organization:**	FDOT TMC
Last Status Time:	09/18/2008 20:10:21	**Road:**	I-295 NB	**Notifier Agency:**	D2 Road Rangers
Duration (mnt):	191	**Location:**	I-295 NB Entrance from US-17/Roosevelt Blvd NB		
First Notified:	09/18/2008 16:59:00			**Notifier Contact:**	202, 202
Confirmed:	09/18/2008 16:59:00				
First Closed:	09/18/2008 20:10:21	**Rollover:**	False	**Conditions:**	Daylight
Secondary to:		**Fire:**	False	**CCTV ID:**	
FHP Incident Number:		**HAZMAT:**	False	**CCTV Preset:**	
Injury:					
Contacts:					
Involved Vehicles	White OTHER Tractor-Trailer TAG# OH-SB5896, White OTHER Tractor-Trailer TAG# WI-T32985W				

Date	Type	Description
09/18/2008 16:59:00	ARRIVED	D2 Road Rangers: 202
09/18/2008 16:59:00	NOTIFIED	D2 Road Rangers: 202
09/18/2008 16:59:00	OWNER	bdeiter
09/18/2008 16:59:00	STATUS	Active
09/18/2008 16:59:17	LOCATION	Duval on I-295 Northbound, At I-295 NB @ US-17/Roosevelt Blvd
09/18/2008 16:59:26	BLOCKAGE	1 Right Lane (of 3 Lanes) Blocked
09/18/2008 16:59:35	BLOCKAGE	1 Right Lane (of 3 Lanes) Blocked
09/18/2008 16:59:35	BLOCKAGE	No lanes blocked.
09/18/2008 16:59:41	ACTIVITY	D2 Road Rangers: 202 MOT non-specific
09/18/2008 17:02:44	ACTIVITY	D2 Road Rangers: 202 Deploy Cones
09/18/2008 17:19:05	FIRST ARRIVED	JSO
09/18/2008 17:19:10	TMC NOTIFIED	FDOT Maintenance
09/18/2008 17:19:38	FIRST ARRIVED	FHP
09/18/2008 17:19:58	FIRST ARRIVED	Fire
09/18/2008 17:27:04	COMMENT	(Operator) freightliner first vehicle, striking
09/18/2008 17:27:16	COMMENT	(Operator) mac truck second vehicle
09/18/2008 17:40:00	FIRST ARRIVED	Wrecker Driver
09/18/2008 17:41:35	LOCATION	Duval on I-295 Northbound, Ramp From I-295 NB Entrance from US-17/Roosevelt Blvd NB
09/18/2008 17:41:45	BLOCKAGE	1 Right Lane (of 3 Lanes) Blocked, Entry Ramp Blocked, Right Shoulder Blocked
09/18/2008 17:41:53	FIRST ARRIVED	FDOT Maintenance
09/18/2008 17:42:03	DEPARTED	D2 Road Rangers: 202
09/18/2008 17:43:00	BLOCKAGE	1 Right Lane (of 3 Lanes) Blocked, Right Shoulder Blocked
09/18/2008 18:00:00	LAST DEPARTED	Fire
09/18/2008 18:00:00	LAST DEPARTED	JSO
09/18/2008 18:07:34	OWNER	jevans

Created On: September 19, 2008 07:16:32 Version 3.1.2 9/19/2008 **Page 1 of 2**

Event Chronology

Date	Type	Description
09/18/2008 18:07:45	OWNER	jevans
09/18/2008 18:26:16	COMMENT	(Operator) Class C wrecker
09/18/2008 18:41:49	LAST DEPARTED	Wrecker Driver
09/18/2008 18:57:48	BLOCKAGE	Right Shoulder Blocked
09/18/2008 19:30:00	LAST DEPARTED	FHP
09/18/2008 19:30:00	LAST DEPARTED	FDOT Maintenance
09/18/2008 20:10:15	BLOCKAGE	No lanes blocked.
09/18/2008 20:10:21	STATUS	Closed

Figure 30. Incident report

7.2 Accident Images

Several images of the incident are acquired from the 511 motorist information website. This website is for the Jacksonville area and is called jax511.com. The motorist information that is published here reports incidents, construction sites, detours and congestion. All these events can be watched via video feeds from traffic cameras at the interstates in the Jacksonville area. These traffic cameras are part of the Sunguide intelligent transportation system and it is a courtesy of the Florida Department of Transportation that this feed can be used for information purposes.

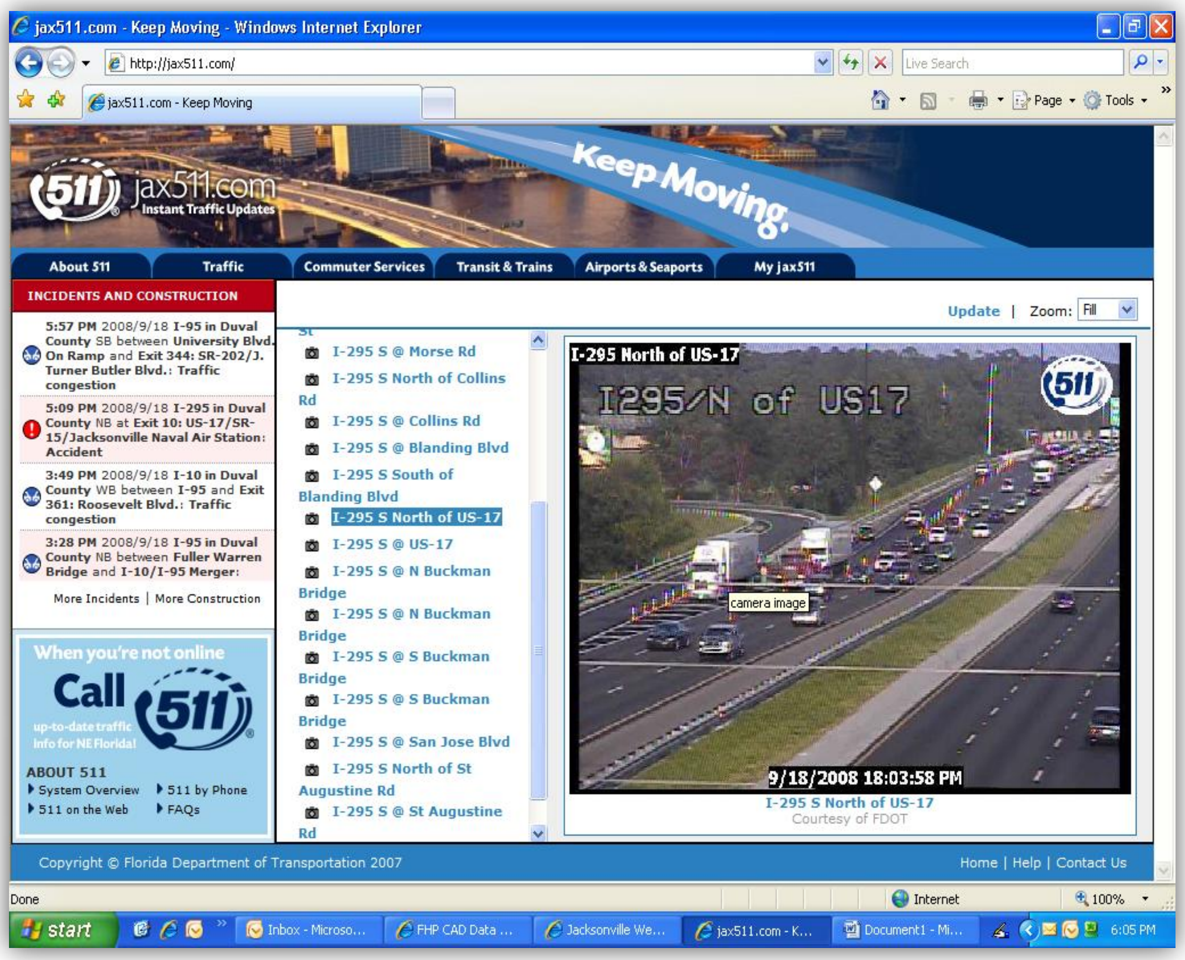

Figure 31. Incident image

This image shows the incident, with the two trucks. The location of the incident can be pinpointed by looking at the road characteristics. A rough description of the location is given by the incident report and was given at the intersection of I295 NB and US-17. Further investigation of the image shows that the incident occurred between two on-ramps leading onto I-295 and coming from US-17.

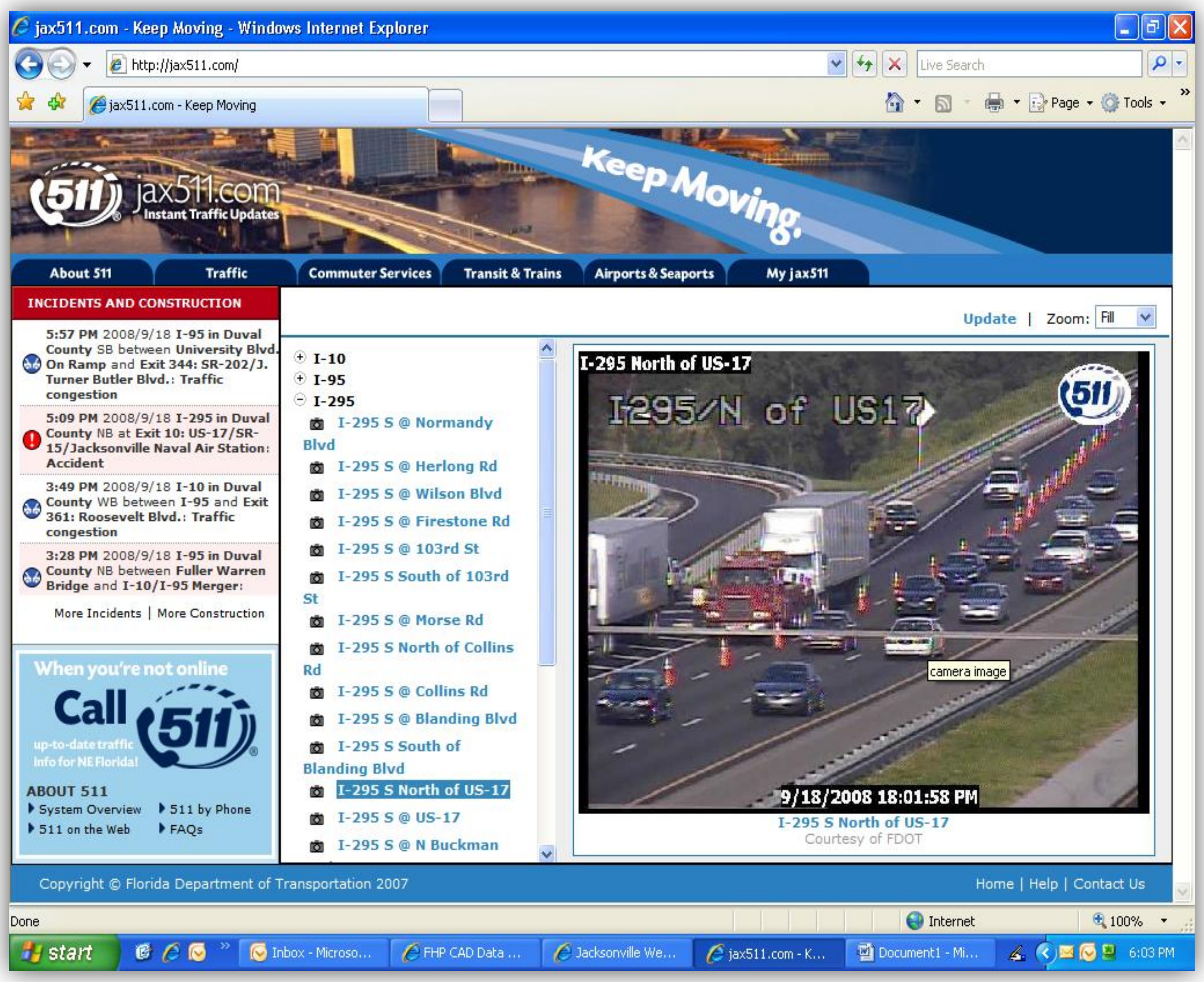

Figure 32. Incident image

On this picture the camera zoomed in on the incident and a couple of things become clearer about the characteristics of the incident. The first thing that stands out are the orange cones that are deployed to mark the lane closure. At the start of the cones the road ranger, who was first to arrive at the incident scene, showed a sign to the motorists alerting them of the lane blockage. With this sign the motorists were informed to merge at the sign. Also the law enforcement car and the tow truck can be identified, so the incident is in the process of being cleared from the roadway.

Figure 33. Web site jax511.com + incident image

The Jax511 website is displayed very well in this image. The image shows the possibilities of motorists to obtain traffic information for their preferred travel routes. Using this information they can alter their routes if necessary. To the left all the recent events on the road network in the Jacksonville area are displayed using an icon. At these icons the time of onset and a short description of the location for every event is given. In the center the user can then select the camera of his or her choice and have a look at the traffic conditions at the roadway of interest. The incident that was used in this report is displayed in the center it can be seen that traffic is definitely affected by it, because of the merging process upstream.

Figure 34. Incident image

The incident on the freeway caused a lane blockage. The lane blockage affected the capacity at the location of the incident and creating a bottleneck. This bottleneck due to the incident originated at rush hour, meaning that major congestion occurred behind the incident. This image is of the Buckman Bridge that is located a few miles upstream of the incident. The Buckman Bridge was totally congested over four lanes of freeway, which indicated that the lane closure had a major impact on the capacity and caused the capacity to drop drastically on the freeway.

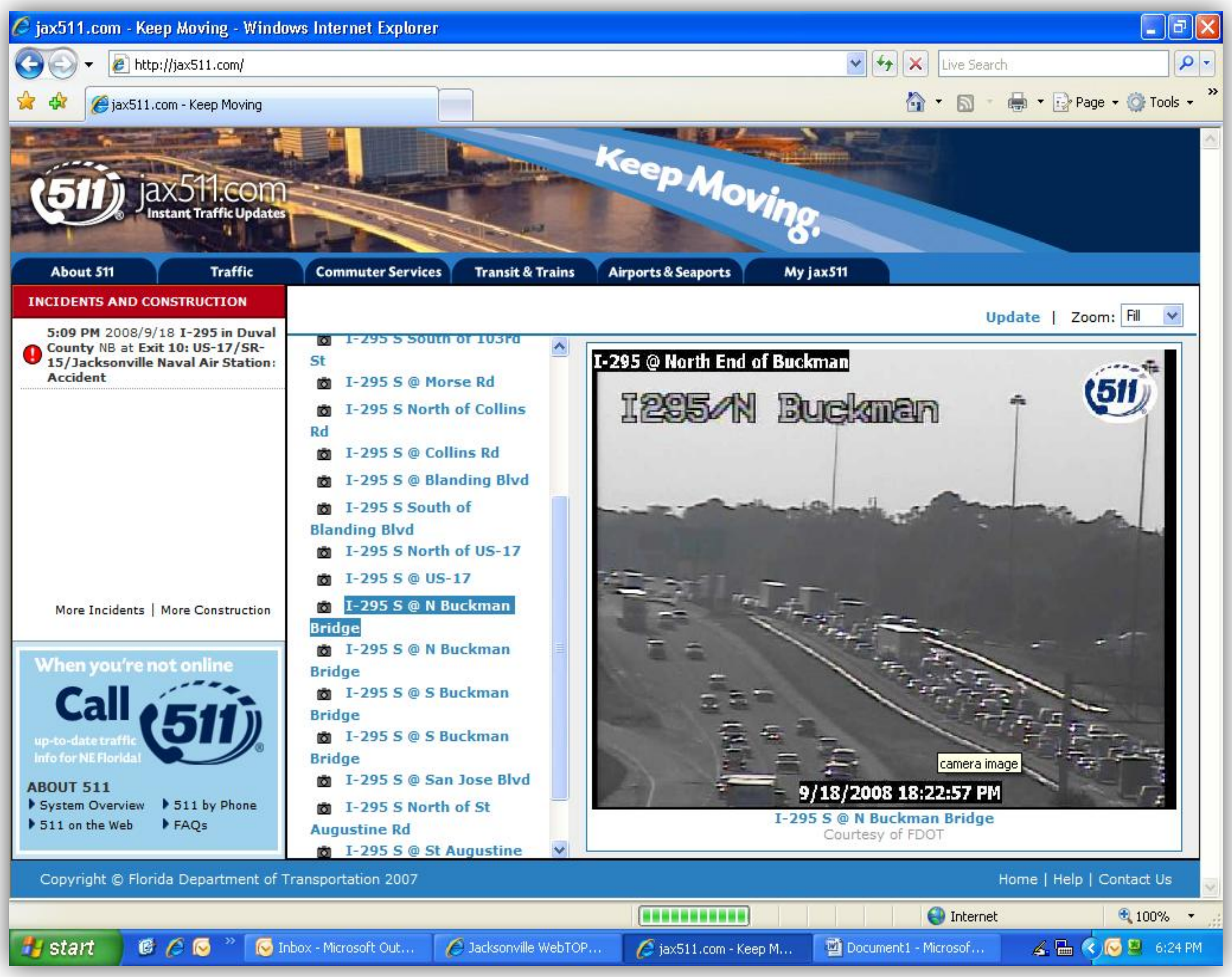

Figure 35. Incident image

Because the Buckman bridge is congested everything between the incident and the bridge is congested as well. This can be seen from this image. A lot of people vehicles were part of the congestion. The incident occurred at the top of the picture. The entry ramp from US-17 can be seen on the right-hand side. This entry-ramp has part of its acceleration lane blocked, because of the incident. With a close look can be seen that the on-ramp is congested as well.

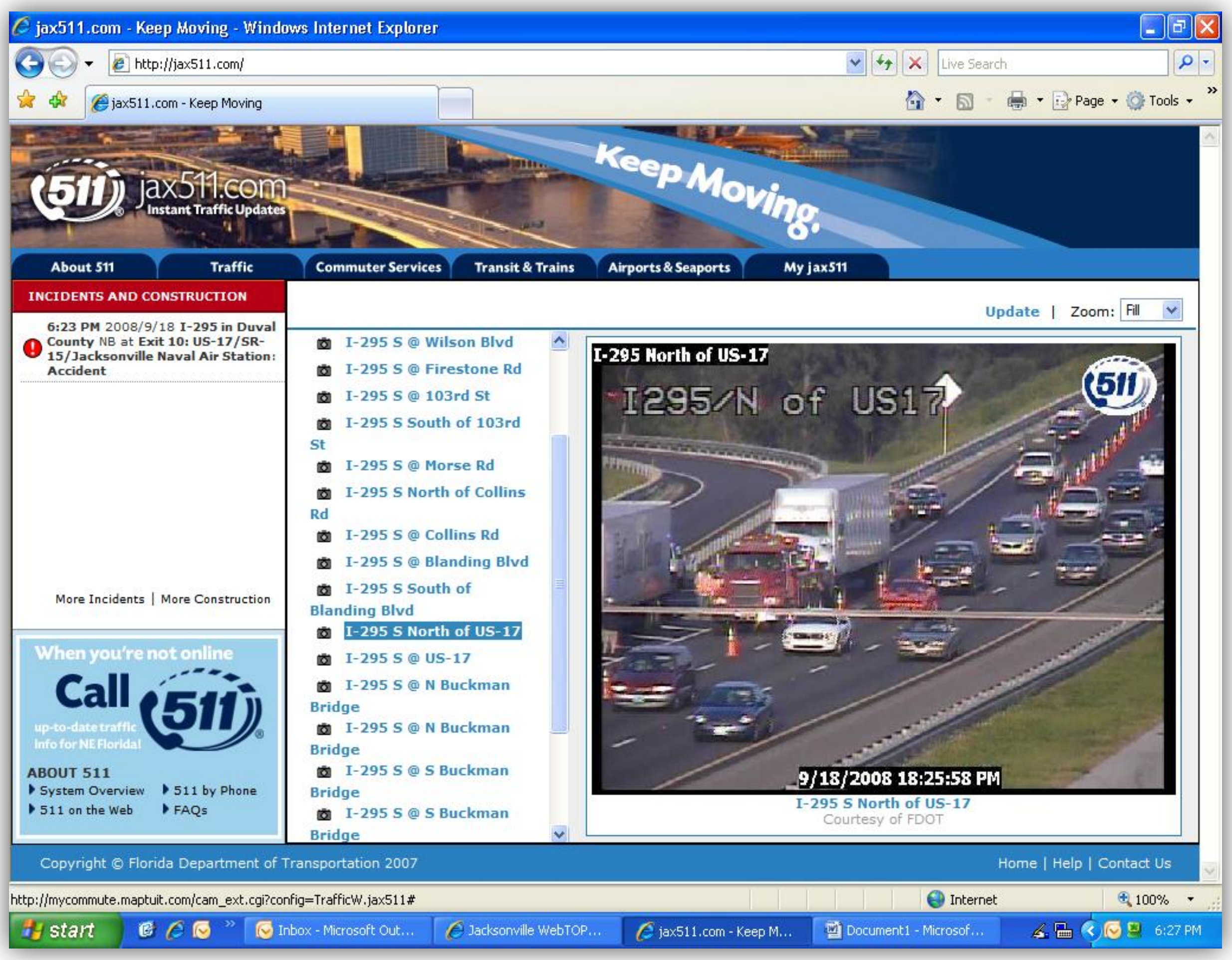

Figure 36. Incident image

This image also zoomed in on the incident. The truck is loaded onto the tow truck and ready to be moved from the road. There is also a second law enforcement vehicle at the scene and parked at the start of the lane blockage. This vehicle probably has its blue flashing light on in order to warn motorists of the incident and make the scene more visible further upstream.

7.3 Incident location and lane configuration

Figure 37. Incident location

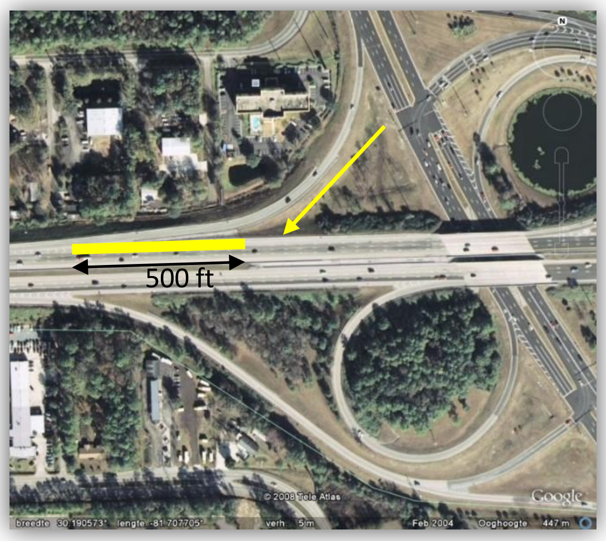

Figure 38. Incident configuration

The road configuration at the incident location is displayed in figure 12. The roadway at the location of the incident consists of three mainlines. At these three mainlines two on-ramps enter the freeway from US-17, with both on-ramps having an acceleration lane. In figure 13 the important characteristics of the incident are displayed. The acceleration lane indicated with the arrow is blocked during the incident. Also the shoulder between the two acceleration lanes is blocked at one time during the incident. The yellow area shows the distance of the freeway that is being blocked during the major part of the incident. The blockage will vary between one lane blocked, two lanes blocked and shoulder blocked. The incident is blocking 500 feet of roadway, which include the shoulder and part of the acceleration lane.

7.4 Detector locations

Figure 14 displays the different detector locations around the Buckman Bridge on I-295 and its on-ramps. Appendix 8.5 displays the traffic data that corresponds with these detectors.

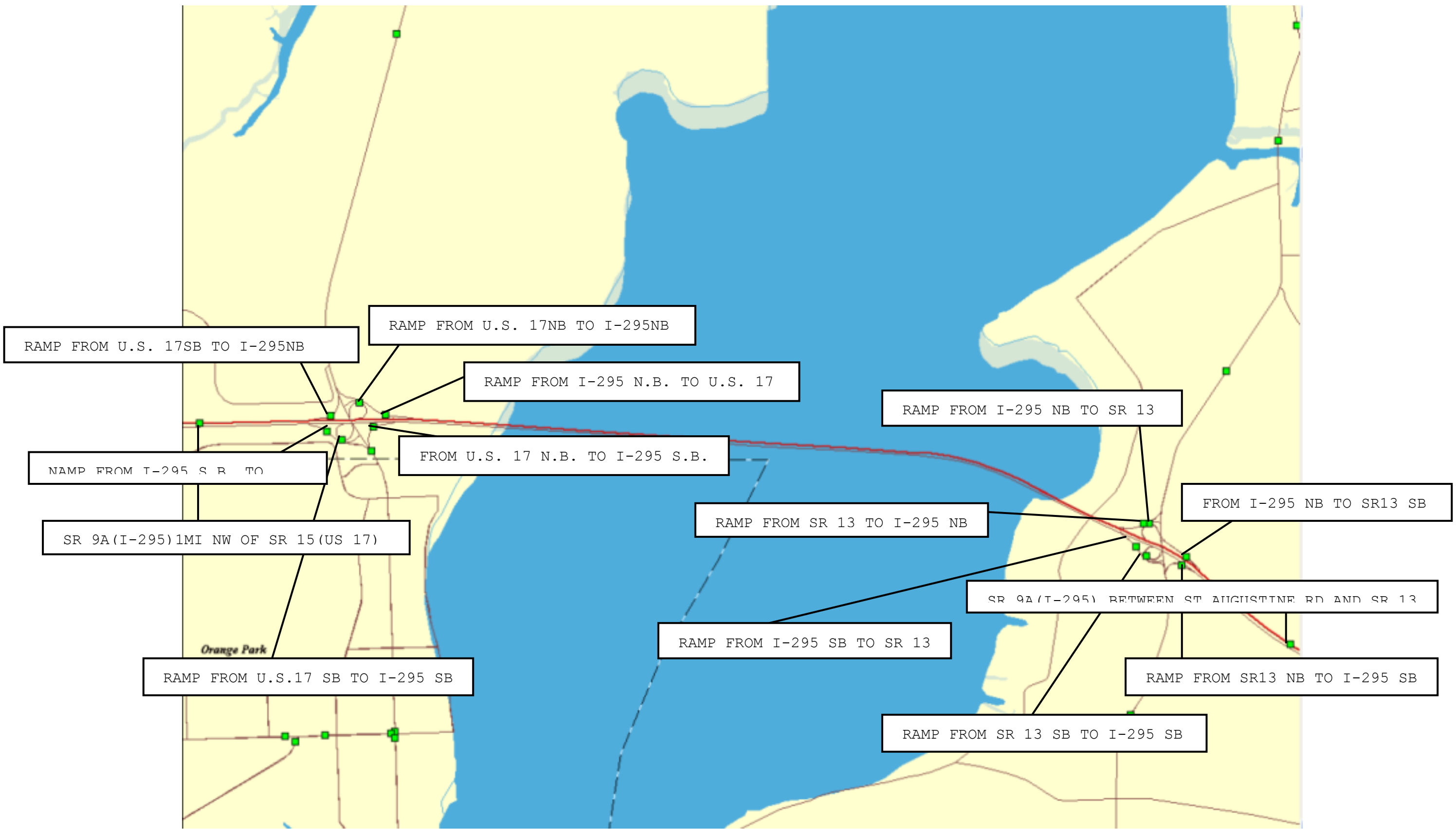

Figure 39. Detector locations with detector names

7.5 Detector Data

FLORIDA DEPARTMENT OF TRANSPORTATION 2006 Annual Average Daily Traffic Report - Report Type: ALL County: 71 CLAY

Site	Site Type	Description	Direction 1		Direction 2		AADT Two-Way		"K" Fctr	"D" Fctr	"T" Fctr
3140		ON SR 15 100' S I295 RAMPS	N	37000	S	33000	70000	C	9.36F	55.56F	7.43F
0895		SR 9A(I-295) BETWEEN ST AUGUSTINE RD AND SR 13	N	59500E	S	58500E	118000	X	10.01F	53.03F	13.36F
0897		SR 9A(I-295)1MI NW OF SR 15(US 17)	N	47500E	S	49500E	97000	S	10.01F	53.03F	13.36F
3896		SR 9A(I-295) 0.6MI NW OF SR 13	N	65000	S	64500	129500	C	10.01F	53.03F	13.36F
4070		RAMP FROM SR13 TO I-295 SB	S	11000		0	11000	C	10.01F	99.99W	13.36F
4071		RAMP FROM I-295 NB TO SR13 SB	N	3600		0	3600	C	10.01F	99.99W	13.36F
4072		RAMP FROM SR 13 TO I-295 SB	S	2700		0	2700	C	10.01F	99.99W	13.36F
4073		RAMP FROM I-295 SB TO SR 13	S	18500		0	18500	C	10.01F	99.99W	13.36F
4074		RAMP FROM I-295 NB TO SR 13 SB	N	9600		0	9600	C	10.01F	99.99W	13.36F
4075		RAMP FROM SR 13 TO I-295 NB	N	18500		0	18500	C	10.01F	99.99W	13.36F
4076		NAMP FROM I-295 S.B. TO U.S.17	S	11000		0	11000	C	10.01F	99.99W	13.36F
4077		RAMP FROM U.S.17 SB TO I-295 SB	S	8400		0	8400	C	10.01F	99.99W	13.36F
4078		RAMP FROM U.S.17 TO I-295NB	N	3400		0	3400	C	10.01F	99.99W	13.36F
4079		RAMP FROM I-295 N.B. TO U.S. 17	N	23000		0	23000	C	10.01F	99.99W	13.36F
4080		RAMP FROM U.S. 17 TO I-295 N.B	N	7400		0	7400	C	10.01F	99.99W	13.36F
4176		RAMP FROM U.S. 17 N.B. TO I-295 S.B.	S	15500		0	15500	C	10.01F	99.99W	13.36F

Site Type : P= Portable; T= Telemetered
AADT Flags : C= Computed; E= Manual Est; F= First Yr Est P= Prior Year; S= Second Yr Est; T= Third Yr Est; X= Unknown
"K/D" Flags : A= Actual; F= Volume Fctr Catg; D= Dist/Func. Class; P= Prior Year; S= State-wide Default; W= One-Way Road
"T" Flags : A= Actual; F= Axle Fctr Catg; D= Dist/Func. Class; P= Prior Year; S= State-wide Default; X= Cross-Reference
30-Apr-2007 16:58:59 Page 1 of 1 622UPD [1,0,0,2] 2_71_CAADT.txt

7.6 Incident events and their relevance to traffic flow

To obtain the data requirements for incident modeling, the events during one incident are reviewed and then examined for their relevance to traffic flow. When an event during the incident has an effect on traffic flow, it is most likely that it has to be used in the modeling of incidents. Table 8 displays the events during the incident on one side and the relevance they have on traffic flow on the other side.

Table 9. Incident events and the relevance to traffic flow

Incident timeline		
Time stamp	**Event description**	**Relevance to traffic flow**
16:59	Incident reported on I-295 at the on-ramp from US-17 by a Road Ranger	The consequence of these events is that by blocking the lane, the physical capacity of the freeway is reduced. This can reduce the traffic flow passing the incident.
16:59	Incident blocks the right lane	
16:59	Road Ranger deploys cones to close the right lane and part of the on-ramp, for handling the incident	The closing of the acceleration lane results in difficulties for the merging of traffic from the on-ramp
17:19	Jacksonville Sheriff's Office arrives at the incident site	Arrival of law enforcement at the incident site gives more visibility to the incident for traffic upstream. Motorists are more aware of 'something' happening on the freeway
17:19	Florida Highway Patrol arrives at the incident site	
17:19	Fire Department arrives at the incident site	
17:19	TMC notifies FDOT maintenance	No direct relevance
17:40	Wrecker arrives at the scene to tow the vehicles for the site	Wrecker blocks the entire entry ramp and shoulder, in order to tow the trucks involved in the incident away from the freeway
17:41	Incident blocks the right lane, the right shoulder, and the entry ramp	
17:41	FDOT maintenance arrives at the incident site	No direct relevance
17:43	Incident blocks the right lane and the right shoulder, and part of the on-ramp	Wrecker does no longer block the entry ramp, which means traffic can merge onto the freeway again
18:00	Fire Department leaves the scene	No direct relevance
18:00	Jacksonville Sheriff's office leaves the incident site	No direct relevance, Florida Highway Patrol is still present at the incident site
18:41	Wrecker leave the incident site	No direct relevance
18:57	Incident blocks right shoulder	The opening of the lane and the entry ramp restores the physical capacity of the freeway, which can influence traffic flow
19:30	Florida Highway Patrol leaves the scene	With the law enforcement leave the incident site and only the shoulder 'blocked', motorist could be less careful, since there is no evidence of a situation that needs their attention.
19:30	FDOT maintenance leaves the incident site	
20:10	Incident cleared	No blocking restores capacity to its original state and traffic flow will not be influenced

7.7 Link-Node diagram

Figure 15 displays the link-node that was constructed to represent the road network of I-295 in the vicinity of the Buckman Bridge. Figure 16 then displays the road network that is being used by CORSIM for the simulation.

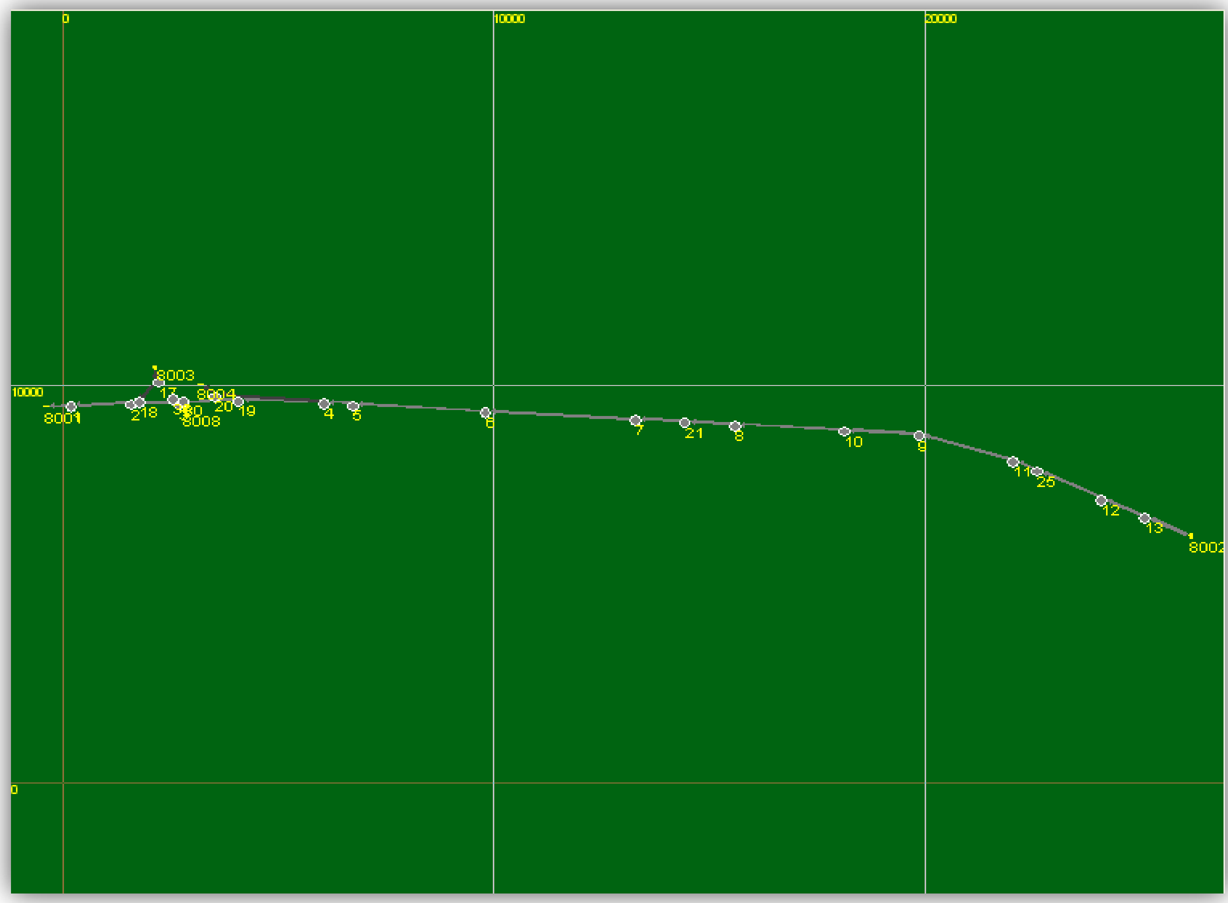

Figure 40. Link-Node diagram

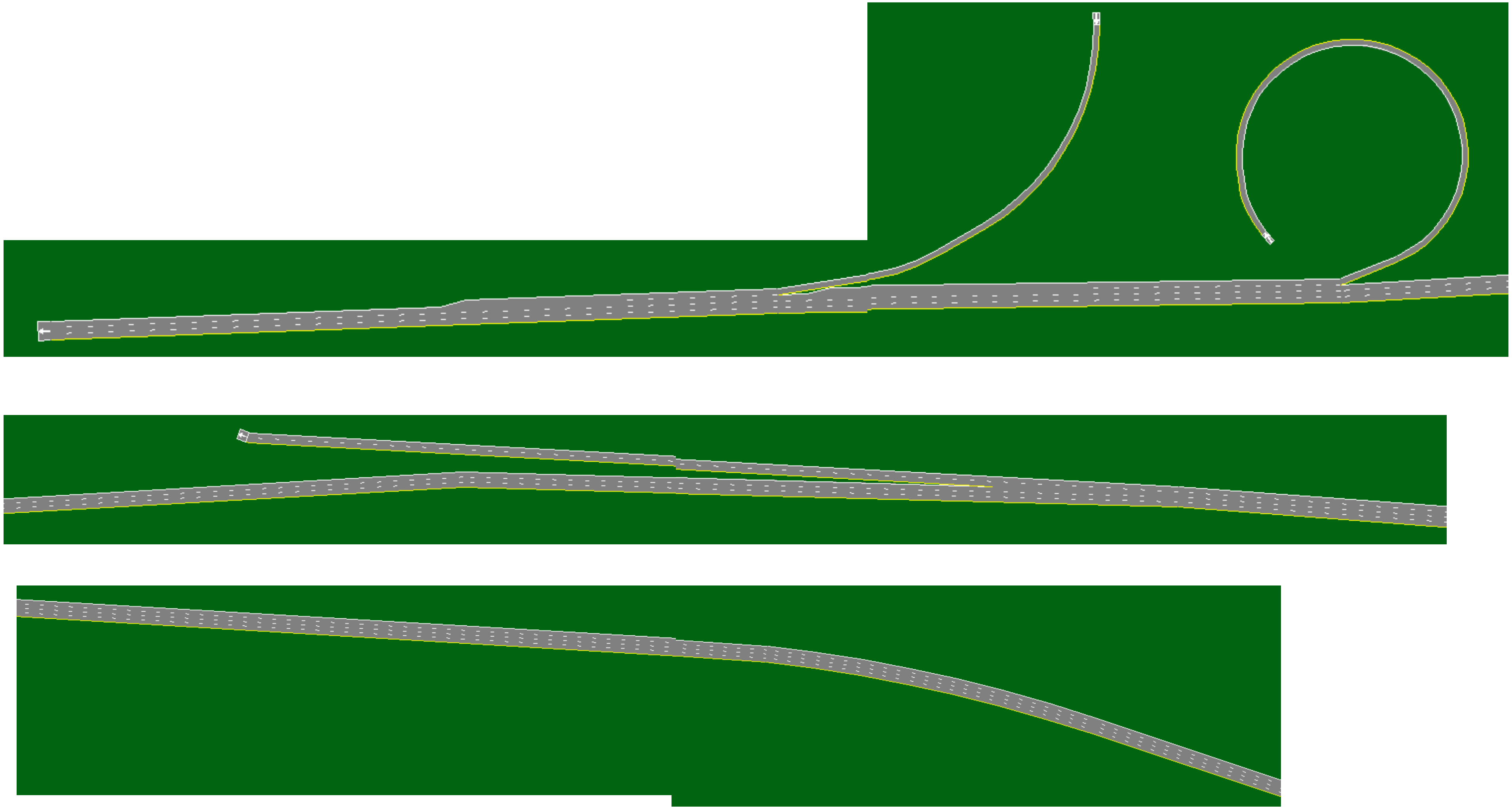

Figure 41. Road network in simulation

7.8 Entry volumes

To test CORSIM's ability for simulating freeway incidents, a real incident was simulated. Unfortunately no traffic data could be obtained for the time of the incident. Therefore historical data was used. But to simulate the incident, traffic demand changes had to be represented in the model. These demand changes occurred as a result of rush hour. The demand changes are also important to see if CORSIM can handle these changes with the incident and see if the results represent the changes with the incident effects.

Traffic demand from historical data is shown in table 10. These are the start values for the simulation for entry volumes onto the constructed network. To represent the end of rush hour a reduction of the entry volumes was applied, to imitate the reduction in traffic demand at this time. The reduction of demand was applied after 134 minutes or at the beginning of time step 6, which represents 7:00 pm. Only the entry volumes of the freeway mainlines was adjusted, not the volumes for the entry-ramps. The entry ramps were not adjusted, because they do not have a major effect on the results, since entry-ramp 1 is congested for the time of the incident and entry-ramp 2 has free flow speed during the entire duration of the incident. The entry volumes after 134 minutes were set at 80% of their initial values, so that a significant change in traffic demand occurs and the behavior of CORSIM can be observed.

Table 10. Entry Volumes

Detector name:	AADT	Peak hour volume	Entry Volumes (time step 1)	Entry Volumes (time step 2)
Ramp from US 17 SB to I-295 NB (entry-ramp 2)	3400	340	340	340
Ramp from US 17 NB to I-295 NB (entry-ramp 1)	7400	741	741	741
SR 9A(I-295) 0.6MI NW OF SR 13 (mainlines)	65000	6507	6507	5206
Ramp from I-295 NB to US 17 (exit-ramp)	23000	2302	35%	35%

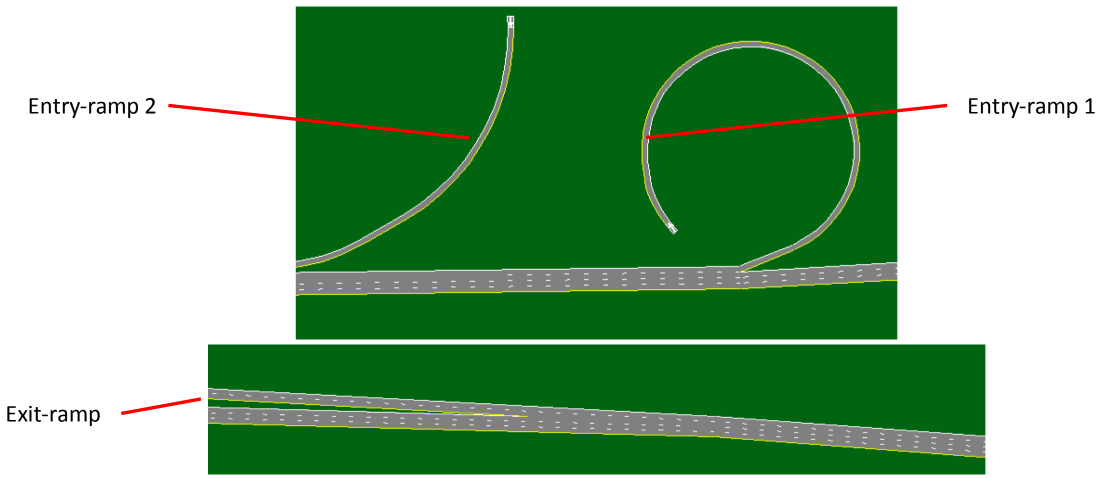

Figure 42. Entry- and Exit-ramps

7.9 Input values

In the table the different parameters are mentioned. For each parameter is determined if the input is mandatory for simulating incidents in CORSIM. If the input is not mandatory the default settings of CORSIM can be used during the simulation of incident, but if required the value can be adjusted according to the modeler's preferences. The final column shows the value that was assigned to the input for the simulation of the incidents.

7.9.1 Network parameters

Table 11. Model inputs incident simulation

Parameter/input	Mandatory input?	Value
Time step	Yes	8
Simulation start time	Yes	1645 hours
Duration of time period	Yes	1: 840 s 5: 4440 s 2: 1200 s 6: 1980 s 3: 1320 s 7: 2400 s 4: 120 s 8: 2100 s
Time interval duration	Yes	60 seconds
Entry volumes time periods 1-5	Yes	6507 vehicles per hour
Entry volumes time periods 6-8	Yes	4880 vehicles per hour
Time to complete lane-change maneuver	No (default settings can be used)	2.0 seconds
Gap acceptance parameter	No (default settings can be used)	1
Percent of drivers yielding the right-of-way to lane-changing vehicles attempting to merge ahead	No (default settings can be used)	80%
Multiplier for desire to make an discretionary lane change	No (default settings can be used)	0.5
Advantage threshold for discretionary lane change	No (default settings can be used)	0.4
Free flow speed	Yes	65 mph
Pavement	Yes	Asphalt
Grade	No (only when present on road network)	Link [8,21] = 4% Link [21,7] = -4%

Grade calculation

The clearance between the water surface and the road deck is 65 feet (about 20 meters) (Jacksonville Boating) in the center. To estimate the vertical gradient the clearance and distance over which the bridge rises need to be known. The clearance was about 20 meters and with the help of Google earth the distance of the rise is estimated at 400 meters. The road deck does not start at the water level, but is already elevated. This means the clearance value needs to be adjusted by about 4 meters.

$Grade = \frac{16}{400} = 0.04$ This leads to a vertical gradient of 4%.

7.9.2 Incident parameters

The parameters and inputs are presented here. Because 6 different incidents need to be specified for each change in events during the incident, the incident inputs are described separately from the model inputs that remain the same throughout the simulation. For all six different time steps for the events a table is presented with the incident related input.

Table 12. Incident time step 1

Parameter/input	Mandatory input?	Value
Incident #	Yes	1
Time of Onset	Yes	840s
Duration	Yes	1200s
Distance from upstream Node	Yes	590 ft
Length	Yes	500 ft
Lanes affected by the incident	Yes	#1 blocked #2 Rubbernecking #3 Rubbernecking #9 Rubbernecking
Rubberneck factor	No	8%
Location of incident warning sign	Yes	160 ft

Table 13. Incident time step 2

Parameter/input	Mandatory input?	Value
Incident #	Yes	2
Time of Onset	Yes	2040 seconds
Duration	Yes	1320 seconds
Distance from upstream Node	Yes	590 ft
Length	Yes	500 ft
Lanes affected by the incident	Yes	#1 blocked #2 Rubbernecking #3 Rubbernecking #9 Blocked
Rubberneck factor	No	8%
Location of incident warning sign	Yes	1000 ft

Table 14. Incident time step 3

Parameter/input	Mandatory input?	Value
Incident #	Yes	3
Time of Onset	Yes	3360 seconds
Duration	Yes	120 seconds
Distance from upstream Node	Yes	590 ft
Length	Yes	500 ft
Lanes affected by the incident	Yes	#1 blocked #2 blocked #3 Rubbernecking #9 Blocked
Rubberneck factor	No	8%

Location of incident warning sign	Yes	1000 ft

Table 15. Incident time step 4

Parameter/input	Mandatory input?	Value
Incident #	Yes	4
Time of Onset	Yes	3480 seconds
Duration	Yes	4440 seconds
Distance from upstream Node	Yes	590 ft
Length	Yes	500 ft
Lanes affected by the incident	Yes	#1 blocked #2 Rubbernecking #3 Rubbernecking #9 Blocked
Rubberneck factor	No	8%
Location of incident warning sign	Yes	1000 ft

Table 16. Incident time step 5

Parameter/input	Mandatory input?	Value
Incident #	Yes	5
Time of Onset	Yes	7920 seconds
Duration	Yes	1980 seconds
Distance from upstream Node	Yes	590 ft
Length	Yes	500 ft
Lanes affected by the incident	Yes	#1 Rubbernecking #2 Rubbernecking #3 Rubbernecking #9 Rubbernecking
Rubberneck factor	No	6%
Location of incident warning sign	Yes	1000 ft

Table 17. Incident time step 6

Parameter/input	Mandatory input?	Value
Incident #	Yes	6
Time of Onset	Yes	9900 seconds
Duration	Yes	2400 seconds
Distance from upstream Node	Yes	590 ft
Length	Yes	500 ft
Lanes affected by the incident	Yes	#1 Rubbernecking #2 Rubbernecking #3 Rubbernecking #9 Rubbernecking
Rubberneck factor	No	6%
Location of incident warning sign	Yes	160 ft

7.10 Sensitivity analysis

Because only one parameter is being changed at the time, a base input exists from where the values are adjusted every time. This base input is shown in table 17. In table 18 all the input values that are going to be changed are shown with the values that were assigned in the sensitivity analysis.

Table 18. Model inputs for sensitivity analysis

Parameter/input	Value
Time of Onset	840s
Duration	11460s
Distance from upstream Node	590 ft
Length	500 ft
Lanes affected by the incident	#1 blocked #2 Rubbernecking #3 Rubbernecking #9 Blocked
Rubberneck factor	8%
Location of incident warning sign	300 ft
Percent of drivers yielding the right-of-way to lane-changing vehicles attempting to merge ahead	80%
Free flow speed	65 mph
Truck percentage for entry volumes	10%

For all other input values the default settings of CORSIM are used.

Table 19. Parameter values used for sensitivity analysis

Sensitivity analysis								
Parameter	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Rubberneck factor (%)	2	4	6	8	10	12	14	16
Length of incident (ft)	200	400	600	800	1000			
warning sign (ft upstream of incident location)	1	300	600	900	1200	1500		
Yielding percentage (%)	20	40	60	80	100			
free flow speed (mph)	50	55	60	65	70			
Traffic demand (vph)	5600	5800	6000	6200	6400			
Lane configuration	left	right						

7.11 Number of model runs

The microscopic simulation tool CORSIM is stochastic in nature, which means that results from the simulations are showing a degree of variance. In order to obtain confidence in the results multiple runs to be executed. The number of runs that need to be executed is calculated from the tolerable error specified by the modeler. With tolerable error set the required sample size can be calculated using the following equation:

$n = \frac{1.96^2 \cdot \sigma^2}{E^2}$, where
n = the required sample size (e.g. number of simulation runs)
1.96 is the Z-value for the Standard Normal Curve for 95% confidence
σ^2 = is the sample variance computed from the simulation results
E = the tolerable error for the sample mean (in same units as the mean)

CORSIM is able to determine the required sample size from test simulation runs that are executed. The output processor from CORSIM calculates the tolerable error term by multiplying the sample mean of each selected MOE by the user input value for percent tolerable error (i.e., "% of Mean"). The required sample size for a 95% confidence interval on the mean is then computed for each MOE and displayed by the output processor. Therefore, when determining the number of simulation runs to perform, the sample size result should be chosen for the MOE of key interest. If the calculated sample size is less than the number of simulation runs made, then no additional runs need to be performed. If, however, the calculated sample size is greater than the number of runs made, the simulation should be run again with at least as many runs as the calculated sample size. Determining the sample size is an iterative process since running the simulation for a different number of runs will produce a different sample variance. The process until needs to be repeated until the number of runs made is greater than or equal to the value calculated for the required sample size. As seen in the equation, the smaller the tolerable error term, the larger the required sample size. (McTrans, 2006)

For the simulation of the incident the following MOE's were chosen and are of interest in acquiring the sample size:

- Total Delay
- Total Travel Time
- Average Speed
- Total Vehicle Miles Traveled

By setting the tolerable error to 10% it was determined that 5 model runs were required for acquiring the results from the simulations with and without the incident.