FINAL REPORT

to

THE FLORIDA DEPARTMENT OF TRANSPORTATION
ROADWAY DESIGN OFFICE

on Project

"Field Data Collection and Analysis for Freeway Work Zone Capacity Estimation"

FDOT Contract BD-545, RPWO #82 (UF Project 67207)

June 25, 2008

The University of Florida

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METRIC CONVERSION CHART

U.S. UNITS TO METRIC (SI) UNITS

LENGTH

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km

METRIC (SI) UNITS TO U.S. UNITS

LENGTH

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi

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16. Abstract

A previous FDOT project (FDOT BD 545-51) developed analytical models for estimating the capacity of freeway work zones based entirely on simulated data. Simulation was used because there were no freeway work zone field data available at the time. As that project was nearing completion, it was determined that field data could be obtained from a recently installed freeway work zone along I-95 in Jacksonville, Florida, using the Jacksonville Traffic Management Center (TMC) cameras. Therefore this project was initiated to collect field data and based on these re-calibrate the models previously developed. To achieve the objectives of the project, field data were collected at the freeway work zone identified, for a total of 15 days. Various capacity-related measures were obtained from the field data, including the maximum pre-breakdown flow, the breakdown flow, and the maximum and average discharge flow during congested conditions. The following were concluded from the research:

- The average discharge flow had the smallest standard deviation of all the capacity measures. The other three measures showed higher variability.
- The average per lane discharge flow (i.e., capacity during congested conditions) at the study site under good weather conditions was found to be 4,013 vehicles per hour (vph), or 2,007 vehicles per hour per lane (vphpl).
- Rainy conditions reduced the average discharge flow in the work zone by 10-29 percent; heavy rain had a much greater impact on capacity than moderate rain.
- It was concluded that the operations model developed under FDOT BD 545-51 can reasonably predict the capacity of the work zone (difference less than 1 percent) while the planning model under-predicts it by 8.8 percent. The effect of rain is not captured well by either of these models. The existing FDOT lane analysis method underestimated the discharge flow for that site by approximately 10 percent.

The following are recommended:

- The operations model from FDOT BD 545-51 provided good estimates of the discharge flow for the study site over several days of observation. Since the data were collected only at one site, the model should be evaluated in future freeway construction sites, and adjusted if necessary based on additional field data, before it is officially adopted by FDOT.
- The planning model from FDOT BD 545-51 may also be further tested in future construction sites, however it does not seem to provide results as close as those of the operations model.

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EXECUTIVE SUMMARY

A previous FDOT project (FDOT BD 545-51), titled “Impact of Trucks on Arterial LOS and Freeway Work Zone Capacity,” developed analytical models for estimating the capacity of freeway work zones based entirely on simulated data. Simulation was used because there were no freeway work zone field data available at the time. The models developed estimate the capacity of various freeway work zone configurations as a function of prevailing traffic, design, environmental, and work zone characteristics. As that project was nearing completion, it was determined that field data could be obtained from a recently installed freeway work zone along I-95 in Jacksonville, Florida, using the Jacksonville Traffic Management Center (TMC) cameras. Therefore this project was initiated to collect field data to evaluate, and if necessary re-calibrate the models formulated using simulation.

To fulfill the objectives of the project, the research team collected field data at a freeway work zone along I-95 in Jacksonville, Florida, and extracted capacity values for a total of 15 days. Existing TMC cameras were used in conjunction with AUTOSCOPE™ devices, which were installed at the TMC and used to automatically obtain field data. The data collection consisted of 10 days of lane closures with the left-most lane closed, and 5 days with the right-most lane closed. Various capacity-related measures were obtained from the field data, including the maximum pre-breakdown flow, the breakdown flow, and the maximum and average discharge flow during congested conditions. The field site operations were next simulated using CORSIM to compare the field results to those obtained by CORSIM, which was the simulator used in the FDOT BD 545-51 project. The main objective of this analysis was to evaluate the CORSIM simulator with respect to its ability to replicate work zone operations and assess its flexibility to evaluate the impacts of various factors that affect work zones. The capacity estimates from the field data and the CORSIM simulation were compared to the models proposed in the previous project, as well as to the HCM2000 and the existing FDOT lane closure methodology. The objective of these comparisons was to determine which model(s) best estimated the capacity of the work zone.

The following were concluded from the research:

- The average discharge flow had the smallest standard deviation of all the capacity measures. The other three measures showed higher variability.

- The average per lane discharge flow (i.e., capacity during congested conditions) at the study site under good weather conditions was found to be 4,013 vehicles per hour (vph), or 2,007 vehicles per hour per lane (vphpl).
- Rainy conditions reduced the average discharge flow in the work zone by 10-29 percent; heavy rain had a much greater impact on capacity than moderate rain.
- There was no significant difference in the work zone capacity measures between a left- and a right-lane closure.
- CORSIM appears to over-predict the pre-breakdown flow, while the differences for the remaining three capacity measures are relatively low. With respect to lane utilization, CORSIM does not predict very accurately the percent of traffic on each lane, and it does not have the flexibility to allow the user to enter these as inputs into the simulation for a particular site.
- An operations and a planning model were developed under FDOT BD 545-51. That project defined capacity as the average discharge flow based on the CORSIM output. Therefore, that capacity measure from the field data was compared to the results provided by the two models. It was concluded that the operations model can reasonably predict the capacity of the work zone (difference less than 1 percent), while the planning model under-predicts it by 8.8 percent. The effect of rain is not captured well by either of these models. The existing FDOT lane analysis method underestimated the discharge flow for that site by approximately 10 percent.

The following are recommended:

- The operations model from FDOT BD 545-51 provided good estimates of the discharge flow for this site over several days of observation. Since the data were collected only at one site, the model should be evaluated in future freeway construction sites, and adjusted if necessary based on additional field data, before it is officially adopted.
- The planning model from FDOT BD 545-51 may also be further tested in future construction sites; however it does not seem to provide results as close as those of the operations model.
- As additional data are gathered, it may be possible to develop and apply a “Rain

Factor” in traffic operations applications around work zones.

The following recommendations are provided regarding possible improvements to CORSIM with respect to freeway work zone simulation:

- The software should consider developing algorithms specifically applying to work zones, and replicating the use of taper sections.
- Guidance should be provided regarding the use of the “rubbernecking” factor and its relationship to worker and equipment presence in the work zone.
- Various geometric elements (such as lane width and shoulder width) are currently not considered within CORSIM. Its algorithms should be modified to consider such factors generally, as well as with respect to work zones.

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1. INTRODUCTION

Chapter 10 of the FDOT Plans Preparation Manual (PPM) titled “Work Zone Traffic Control” contains a lane closure analysis procedure (pp. 10-30 – 10-43) that calculates the restricted capacity for roadway segments with a lane closure. This procedure applies capacity reduction and other factors to the basic capacity flow rate to determine the capacity of the work zone. Comparing this estimated capacity to the expected hourly traffic demand, restrictions may then be placed on the time of day/night that a lane can be closed. This capacity estimation procedure was developed approximately 10 years ago and it is the desire of the Department to evaluate and update it against more current publications including the Highway Capacity Manual 2000 (HCM2000) and other pertinent recent research.

A previous FDOT project (FDOT BD 545-51), titled “Impact of Trucks on Arterial LOS and Freeway Work Zone Capacity,” developed analytical models for estimating the capacity of freeway work zones based entirely on simulated data. Simulation was used because there were no freeway work zone field data available at the time. The models developed estimate the capacity of various freeway work zone configurations as a function of prevailing traffic, design, environmental, and work zone characteristics. As that project was nearing completion, it was determined that field data could be obtained from a recently installed freeway work zone along I-95 in Jacksonville, Florida, using the Jacksonville Traffic Management Center (TMC) cameras. Therefore this project was initiated to collect field data and based on these re-calibrate the models formulated using simulation.

1.1 Research Objectives

The objectives of this project are to:

a) Collect field data at a freeway work zone along I-95 in Jacksonville, Florida, using the infrastructure of the Jacksonville TMC;

b) Compare the field-measured capacity of the freeway work zone to the respective capacity estimates from project FDOT BD 545-51; and

c) Compare the field-measured capacity to that obtained by the HCM2000 and the existing FDOT procedure, and d) Re-calibrate the previously developed models as necessary, and provide a recommended freeway work zone analysis method.

1.2 Methodology

To fulfill the objectives of the project, four tasks were performed, which are briefly described in this section.

1.2.1 Field Data Collection

The research team collected field data at a freeway work zone along I-95 in Jacksonville, Florida, and extracted capacity values for a total of 15 days. There are currently two lanes open and one lane closed through the work zone, which is 2.5 miles long, and will result in the addition of one lane in each direction of the freeway.

Existing TMC cameras were used in conjunction with AUTOSCOPE™ devices, which were installed at the TMC and used to automatically obtain field data. The data collection consisted of 10 days of lane closures with the left-most lane closed, and 5 days with the right-most lane closed. Data collection was conducted during non-congested and congested conditions, and includes a total of 20 transition periods (i.e., breakdowns). Approximately 45 hours of field data were obtained. This task is described in detail in Chapter 2.

1.2.2 Data Analysis

Various capacity-related measures were obtained from the field data, including the maximum pre-breakdown flow, the breakdown flow, and the maximum and average discharge flow during congested conditions. Statistical analysis verified that the number of samples obtained were adequate for estimating the mean capacity flows to within 100 vehicles per hour (vph), with a confidence interval of 95 percent. The data analysis is presented in Chapter 3.

1.2.3 Re-creation of the Field Work Zone in CORSIM

The field site operations were next simulated using CORSIM to compare the field results to those obtained by CORSIM, which was the simulator used in the previous FDOT project. The main objective of this analysis was to evaluate the CORSIM simulator with respect to its ability to replicate work zone operations and assess its flexibility to evaluate the impacts of various factors that affect work zones (such as left vs. right-lane closures). The simulation effort is summarized in Chapter 4.

1.2.4 Comparison and Recalibration of Original Models

The capacity estimates from the field data and the CORSIM simulation were compared to the models proposed in the previous project, as well as to the HCM2000 and the existing FDOT lane closure methodology. The objective of these comparisons was to determine which model(s) best estimated the capacity of the work zone. Based on these findings, a final lane closure methodology for freeways is proposed. Chapter 5 presents the comparisons and discusses the results, while Chapter 6 presents the project reports and recommendations.

2. DATA COLLECTION

This section describes the study site selected for data collection and summarizes the data collection activities.

2.1 Study Site Description

The criteria for selecting a suitable freeway work zone were as follows:

1) A work zone with a lane closure;
2) Demands that exceed capacity for a significant amount of time each day, so that capacity can be measured; and
3) Existing cameras in the vicinity of the work zone that would allow for data collection at the approach to the work zone and within the bottleneck.

The selected site is located on the north side of Jacksonville, along I-95 Northbound, approaching the Trout River Bridge widening/bridge reconstruction project. Figure 1 shows the location of the work zone in the Jacksonville area.

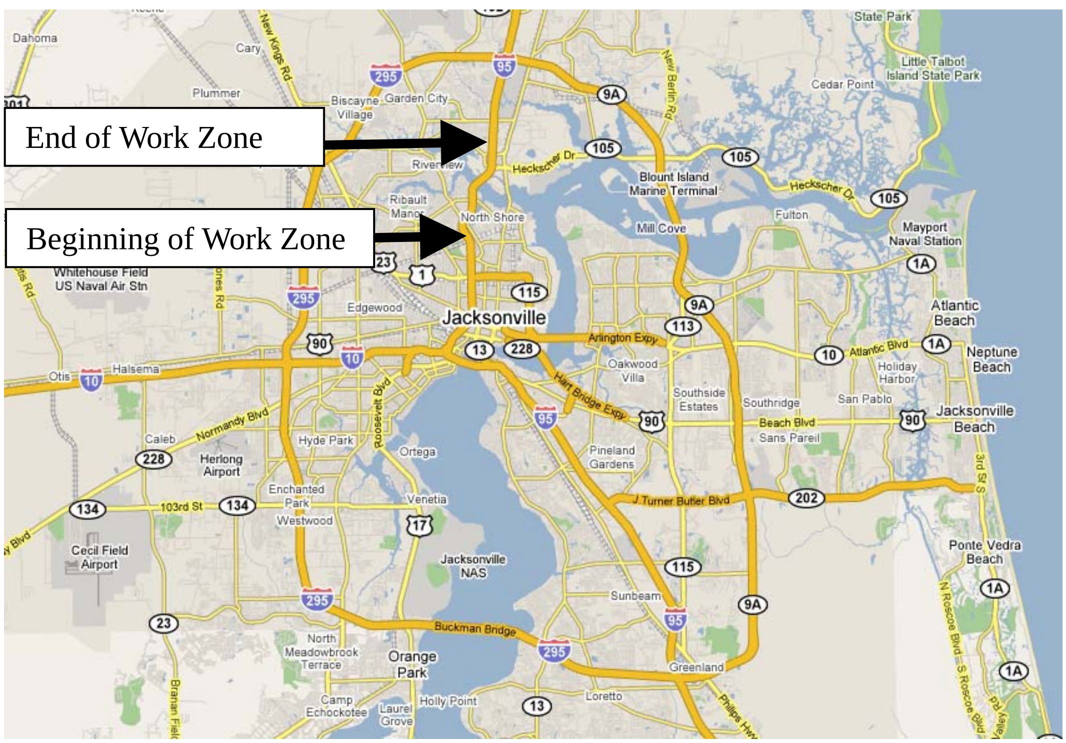

Figure 1: Map of Jacksonville Indicating the Work Zone Location

Figure 2 provides a diagram of the site indicating the data collection points, while

Figure 3 shows a more detailed sketch of the geometry of the site and data collection points (squares in the travel lanes) during the left lane closure. Data collection point 1 is located at the beginning of the work zone and was used to provide discharge flows (i.e. capacity flows) from the work zone.

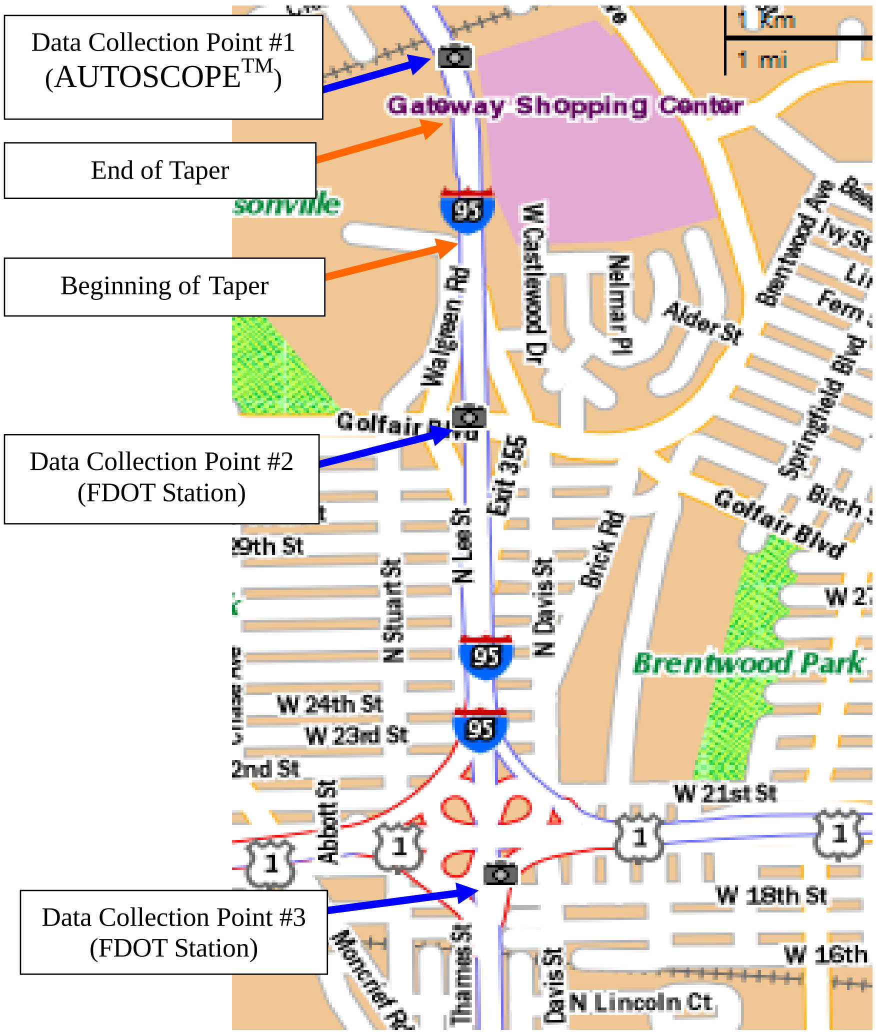

Figure 2: Data Collection Site Diagram for the Left Lane Closure

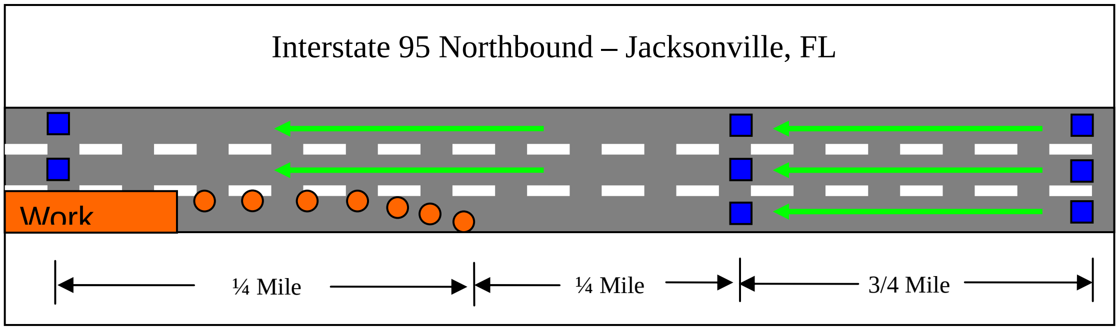

Figure 3: Layout of the Study Site for the Left-Lane Closure

The data at point 1 were collected via the SUNGUIDE ITS camera system in Jacksonville's TMC. Data were collected using existing camera equipment along the I-95 corridor. Cameras are located approximately every ¾ mile, and they have the ability to pan, tilt and zoom. To automate the data collection and reduction, an AUTOSCOPE™ data collection device was installed at the Jacksonville TMC and used to process video coming in from the TMC cameras. Figure 4 shows a snapshot of the camera view used to collect speed and volume data. The other two data collection points are FDOT permanent count stations, which provide speed and flow upstream of the work zone. Data collection point 2 is located at the first orange warning sign indicating a work zone ahead (1 mile upstream of the beginning of the taper to the work zone). Data collection point 3 is located after the first work zone notification sign (variable message sign), approximately ¾ of a mile from point 2. Data were collected at these two locations because the speed and volume data provide lane utilizations and information regarding queue presence, which are necessary in simulating this site and comparing the performance in the field to simulation.

The posted speed limit on the freeway in advance of the work zone is 60 miles per hour (mph). Free-flow speeds during off-peak time periods were found to range between 65 mph and 75 mph. In addition, the area where the work zone is located regularly experienced congestion even prior to the work zone installation. During the study period, the work zone experienced heavy congestion during weekday afternoon peak periods and it was not uncommon for congested conditions to persist for several hours.

Figure 4: View from the FDOT Camera at the Beginning of the Work Zone

The work zone had the following geometric and operational characteristics during the observation periods:

- There was an eight-foot shoulder on the right and a three-foot shoulder on the left of the freeway mainline;
- There was no presence of police other than routine patrols of the site;
- The lane widths were at least 12 ft throughout the segment;
- Truck percentages averaged about 5 percent;
- The data were collected during weekdays, when commuter traffic is expected to be present at the site.

Data were collected in the spring and fall of 2007, for a total of 15 weekdays and for several hours each day. Of these, 10 days of data collection were completed when the work zone had a left lane closure and 5 weekdays when the work zone was reconfigured as a right lane closure. For this later one, the taper section approaching the work zone was shorter than that of the left lane closure. During the data collection effort, the two permanent count stations (Data collection points 2 and 3) were functional only during two days; therefore adequate data could not be collected, and no relationship could be established between capacity measures and lane distributions. However, the data obtained for those two days provided some information on the lane distribution upstream of the work zone. To supplement the information provided by data points 2 and 3 regarding queue lengths upstream of the work zone, the area was visually inspected during the data collection using the TMC cameras upstream of the work zone. The data collection is discussed in the following sections.

2.2 Left-Lane Closure Data Collection

Data were collected over several hours during the PM peak period over 10 days (from 3/27/2007 to 6/14/2007). The data collection periods ranged from four to six hours per day. The data were obtained using the AUTOSCOPE™ device and closely examined for erroneous detector readings. The AUTOSCOPE™ provided volumes and speeds at data collection point 1. A test was conducted to compare the results from the AUTOSCOPE™ to manual data collection. Researchers conducted manual counts from recorded data for two hours to determine the accuracy of the cameras. It was found that the accuracy of the AUTOSCOPE™ was within 2 percent of the hourly flows. The field data were entered into a spreadsheet, which includes the speed, volumes, and flow rates for each five minute period of data collection.

Most data collection periods began around 3:00 p.m. and lasted until the congestion subsided. Typically breakdowns (i.e., the beginning of the congested period) occurred sometime between 3:00 and 6:00 p.m. There were three data collection periods where congestion started before the data collection period began. The data collected includes 14 congested time periods, for which breakdown and the transition to congested flow was observed 11 times. For most data collection periods, congestion started at the bottleneck, i.e., immediately upstream of the two lane section. Two occurrences were notable in the data collection: a) On one day, congestion started within the work zone and extended upstream; b) On another day there was heavy rain that caused congestion. The other 12 breakdowns were caused by demand exceeding the capacity of the work zone. A summary of the field data collected and the capacities measured is provided in Chapter 3.

2.3 Right-Lane Closure Data Collection

Data collection continued at the same location in the fall of 2007 when the right most lane of the same site was closed. Figure 5 illustrates the geometry of the site along with the data collection points indicated by squares in the travel lanes. The collection methods for these data were identical to the methods used for the left lane closure and described above. Data were again collected during the PM peak period for 5 days (from 9/19/2007 to 10/3/2007) and for time periods ranged from four to six hours per day.

Typically, data collection started around 3 PM, since congestion occurred between 3:00 PM and 6:00 PM. There were three data collection periods where the congestion occurred before the data collection period began. The data collected include six breakdowns. During one data collection period, there was very heavy rain, with 4.55 inches (recorded at the National Weather Service at Jacksonville Naval Air Station; Source: www.weatherunderground.com) during that day. The heaviest rain occurred during the data collection and precipitated the breakdown. The remaining five breakdowns were caused by demand exceeding capacity at the work zone. A summary of the field data collected and the capacities measured is provided in Chapter 3.

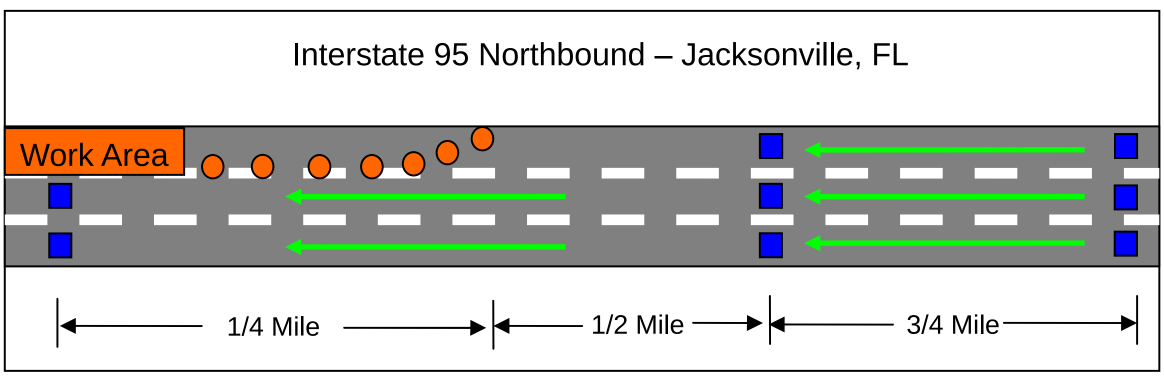

Figure 5: Layout of the Study Site for the Right-Lane Closure

3. ANALYSIS OF FIELD DATA

This section describes the methodology used to obtain capacity values from the field data, and presents the data obtained for each day of the data collection.

3.1 Capacity Analysis Methodology

Five-minute intervals were used in the data analysis. For each day of data obtained, time series plots of flow and speed were generated to identify the breakdown (i.e., the transition from non-congested to congested conditions), and to obtain the maximum flows measured at various times throughout the data collection. The data analysis examined the flows collected before, during, and after the transition from non-congested to congested flow, because previous research has shown that the maximum flow at a particular bottleneck may occur during any one of these three time periods. Furthermore, the actual numbers of the maximum flows vary from day-to-day, therefore it was important to obtain field data over several days.

In this project the analysis was conducted in accordance to a procedure detailed partly by Elefteriadou and Lertworawanich (2002). The following process was undertaken:

1. Identify and quantify each transition interval from non-congested to congested flow, i.e., breakdown event, and document the corresponding **breakdown flow**.
2. Identify and document the **maximum pre-breakdown flow**.
3. Identify and document the **maximum discharge flow**. This flow is the maximum observed at the site after the occurrence of breakdown, and prior to recovery to non-congested conditions.
4. Identify and document the **average discharge flow**. This flow is the average observed at the site between the start and end of congestion.

Figure 6 presents a time-series plot of speed and flow during a breakdown event at a ramp merge junction, and illustrates the first three variables defined above. The purple line (scale on the right of the graph) shows speed dropping sharply around 19:15 PM, indicating breakdown, and the beginning of congestion. The blue line (scale on the left of the graph) shows the corresponding average flows for each time interval. Similar plots were developed for the data obtained in this project to obtain the four flows defined above.

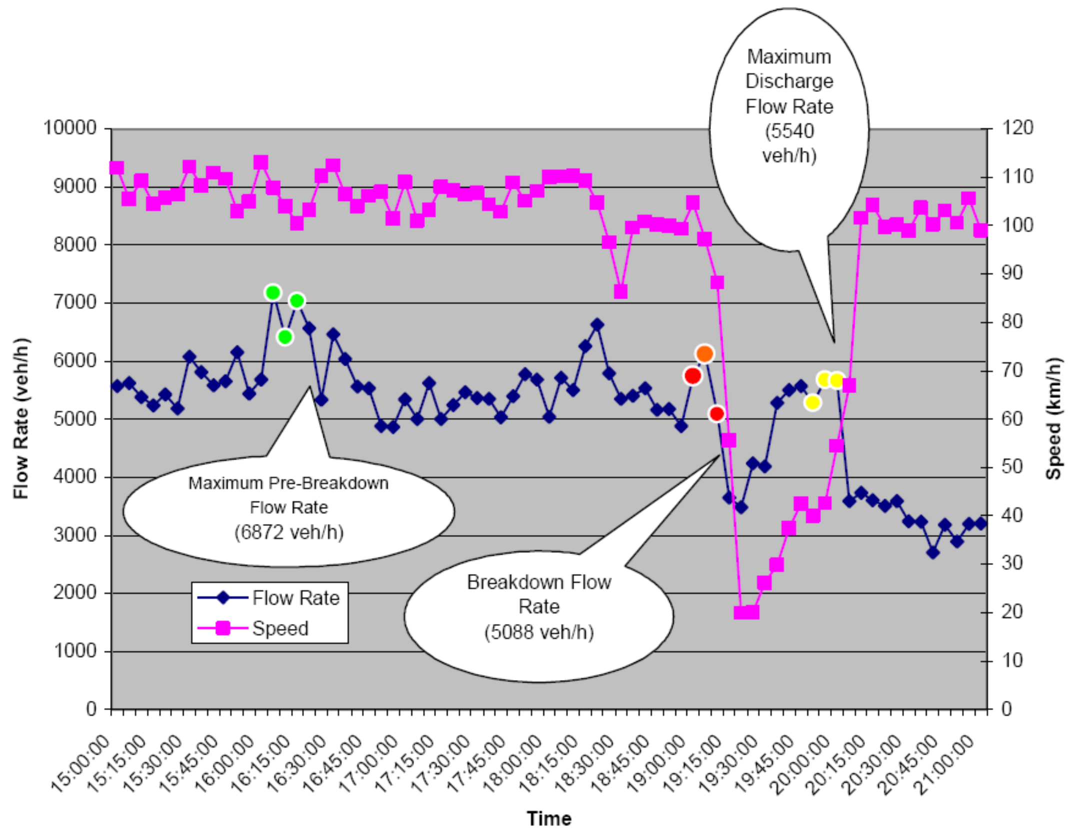

Figure 6: Illustration of the Three Parameters on Time Series Plot of Flow and Speed (Source: Elefteriadou and Lertworawanich, 2003)

For this project breakdown was defined as 15 minutes (3 – five-minute observations) of speeds below 55 mph. This value was chosen because it was observed that when the speed was below 55 mph queuing was present. This also represented a 10-15 mph drop in speed from the free flow speeds of 65-70 mph. Return to non-congested conditions was defined to occur when the average speed reached 55 mph and remained there for at least 15 minutes. To obtain capacity for the study site, each of these four flow rates (the maximum pre-breakdown, the breakdown flow, the maximum discharge flow, and the average discharge flow) were obtained for each breakdown event. Average values of each of these measures were obtained separately for the left-lane closure and the right-lane closure work zone. The remainder of this chapter presents the field data analysis summary, while comparisons to other methods and techniques are discussed in Chapter 5.

3.2 Left Lane Closure Field Data

This section presents the analysis of the field data collected when the left lane of the study segment was closed. These consist of capacity-related measures at the work zone (data collection point 10) and lane utilization data collected upstream (data collection points 2 and 3). First, time series plots of the data are presented for each day of data collection, followed by lane utilization data. A summary of the field data is presented at the end of the section.

In Figures 7 through 16 the time series plot of flow vs. speed is presented for each of the data collection periods. As shown in Figure 7, on March 27, 2007, congestion began just after 3 PM and continued until approximately 6 PM. Visual inspection by the research team using TMC cameras indicated that at 5:00 PM the queue extended more than a mile upstream.

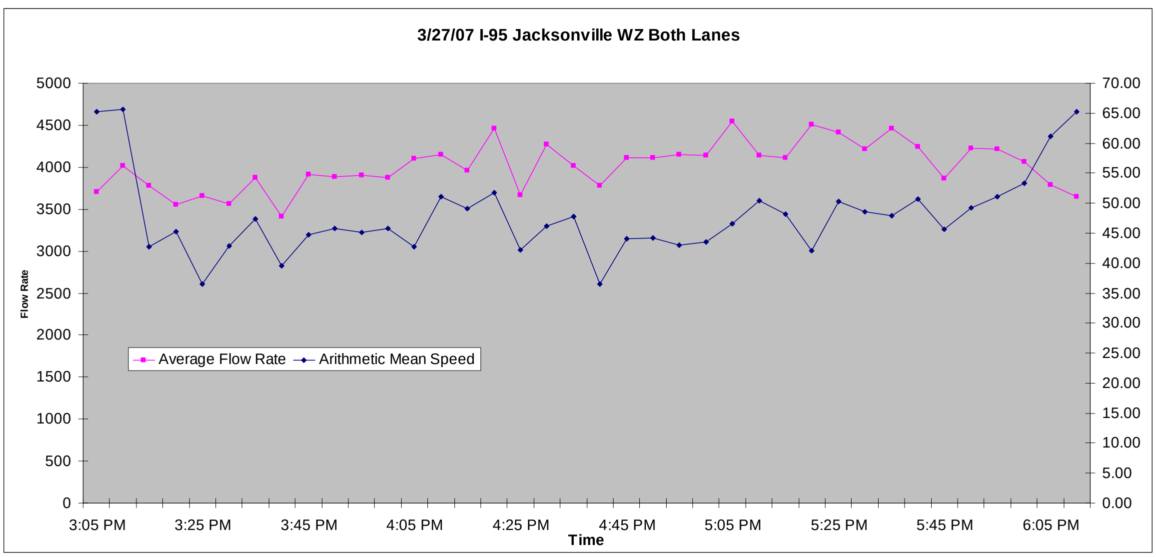

Figure 7: Plot of Flow and Speed for 3/27/07

The data shown in Figures 8, 9, and 10 do not include a breakdown, as it occurred before the beginning of the data collection. Thus the data in Figure 8 all represent congested conditions and visual inspection from TMC cameras indicated that the queue extended more than a mile upstream at 4 PM. During the data collection on April 13 (Figure 9), a backup from within the work area occurred around 5:30 PM resulting in a significant speed drop upstream. The event was not visible on the cameras, but there was significant queuing from within the work zone. On April 19 (Figure 10) there was a speed drop at 3:45 PM. It was not visible from the TMC cameras what caused it, but it is possible that it was triggered by significant activity within the work zone. The speed flow pattern that day was unusual in that there are noticeable speed and flow drops throughout the data collection period. Visual inspection using TMC cameras indicated that the queue extended more than a mile upstream at 4 PM.

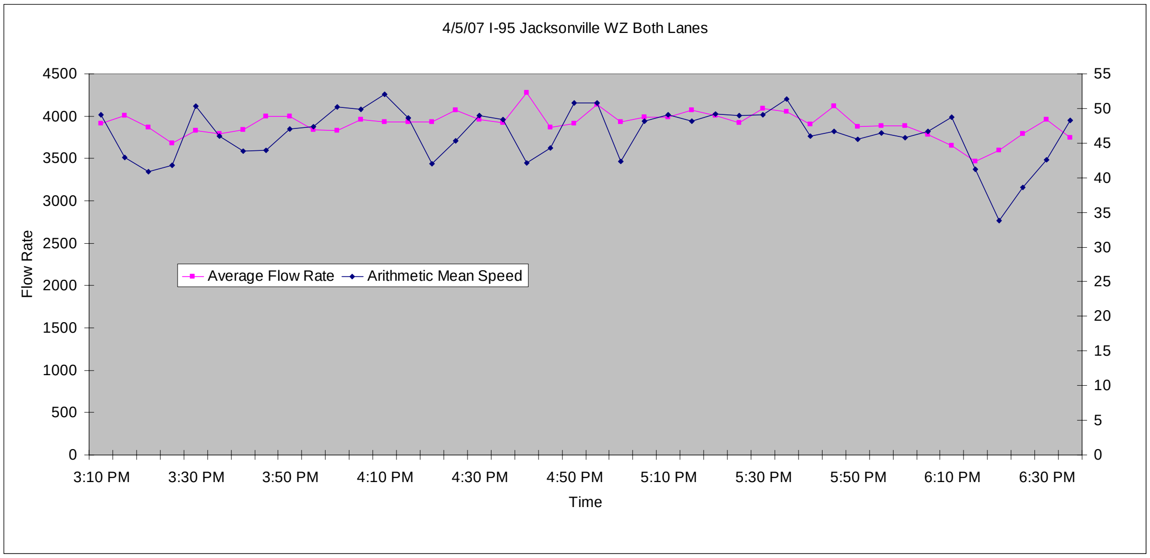

Figure 8: Plot of Flow and Speed for 4/5/07

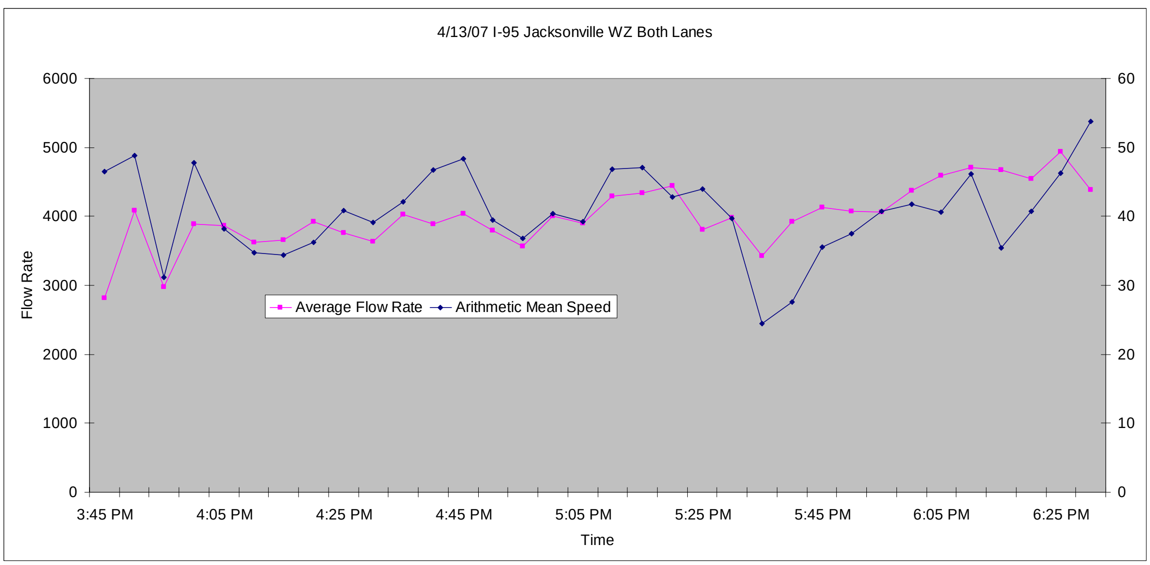

Figure 9: Plot of Flow and Speed for 4/13/07

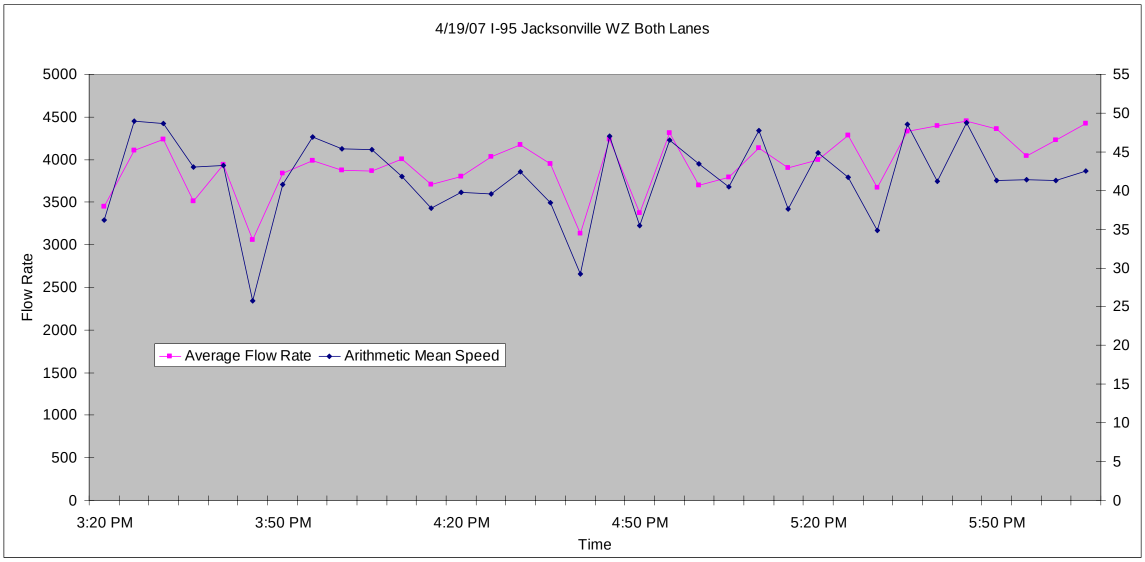

Figure 10: Plot of Flow and Speed for 4/19/07

On April 26 (Figure 11) congestion began about 3 PM and recovered around 3:30 for a short time. After 4 PM another breakdown occurred, and congested conditions continued through the peak hours until 6 PM. Visual inspection using TMC cameras indicated that the queue extended more than a mile upstream at 5 PM.

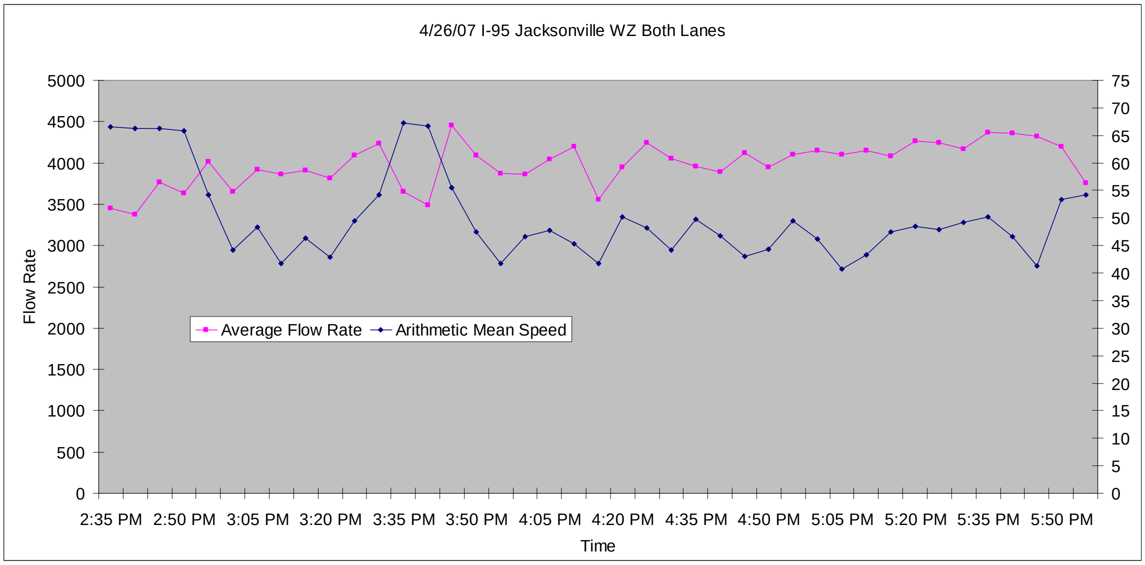

Figure 11: Plot of Flow and Speed for 4/26/07

Congestion on May 14 (Figure 12) began about 3:45 PM, recovered around 4:30

until just before 5 PM, and then another breakdown occurred with congestion lasting until 6 PM.

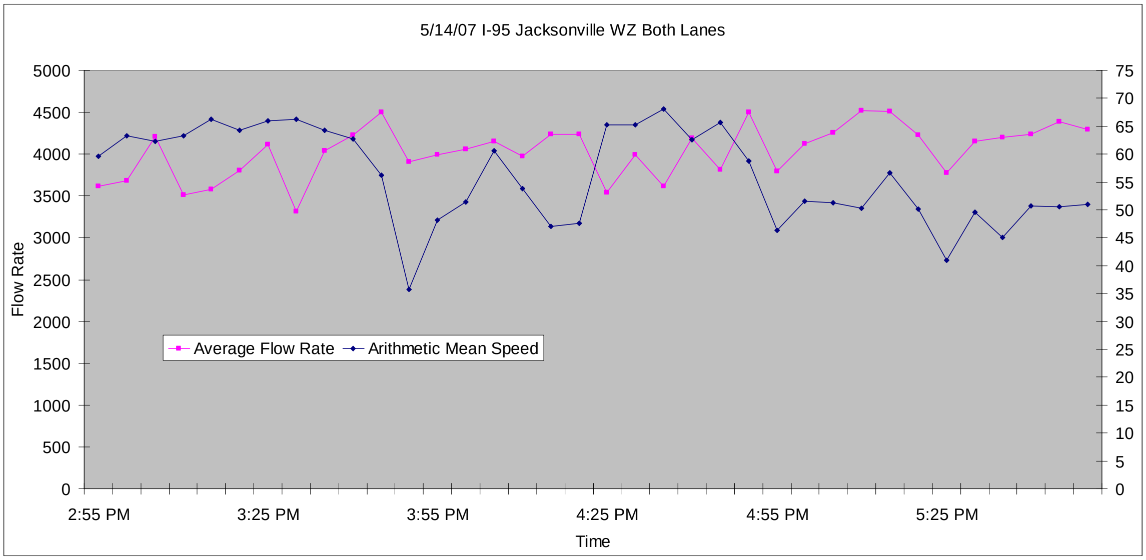

Figure 12: Plot of Flow and Speed for 5/14/07

On May 22 (Figure 13) a breakdown occurred later than in previous days (about 4:45 PM) because demand that day was much lighter.

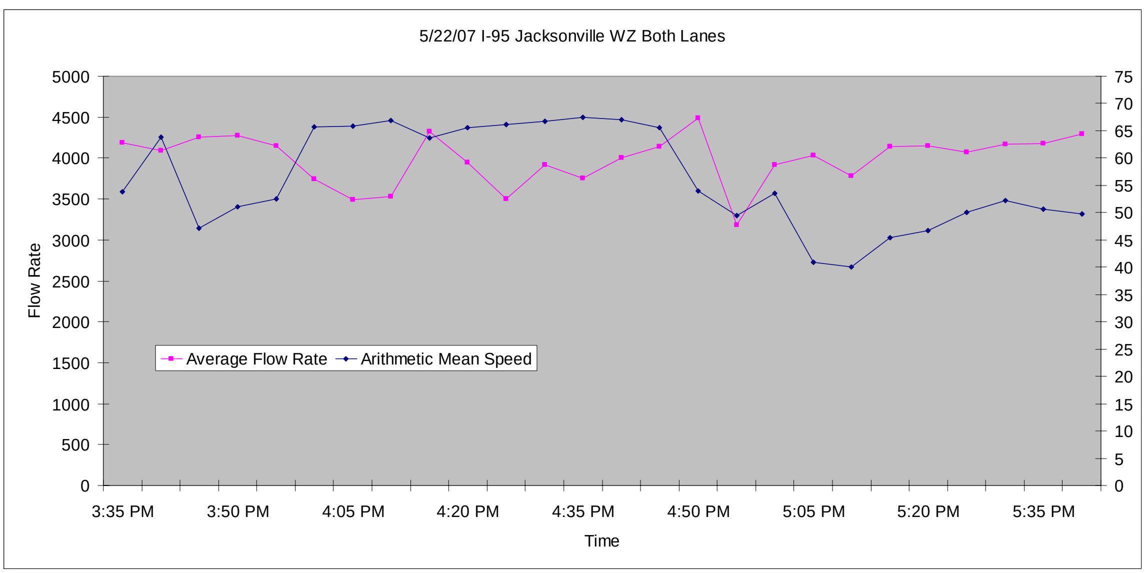

Figure 13: Plot of Flow and Speed for 5/22/07

On May 31 (Figure 14) there were two breakdowns. The first one occurred around 4:15 PM with a recovery around 5 PM. A second breakdown occurred around 5:15 PM, with congestion lasting until 6 PM.

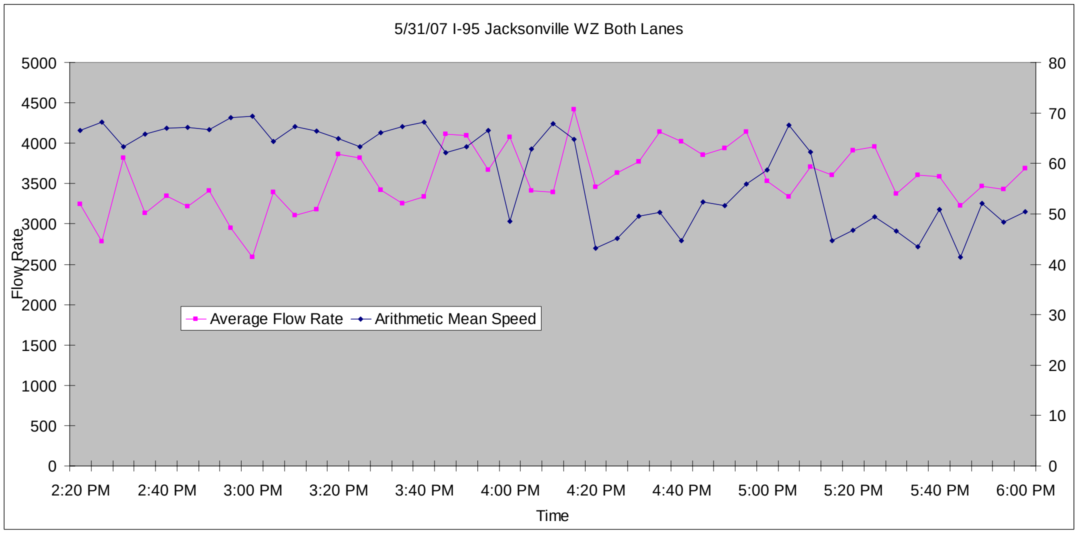

Figure 14: Plot of Flow and Speed for 5/31/07

Similarly to the data collected on May 22, congestion on June 4 (Figure 15) began about 4:45 PM and recovered by 5:30 PM. The demand on this day was much lighter than previous days.

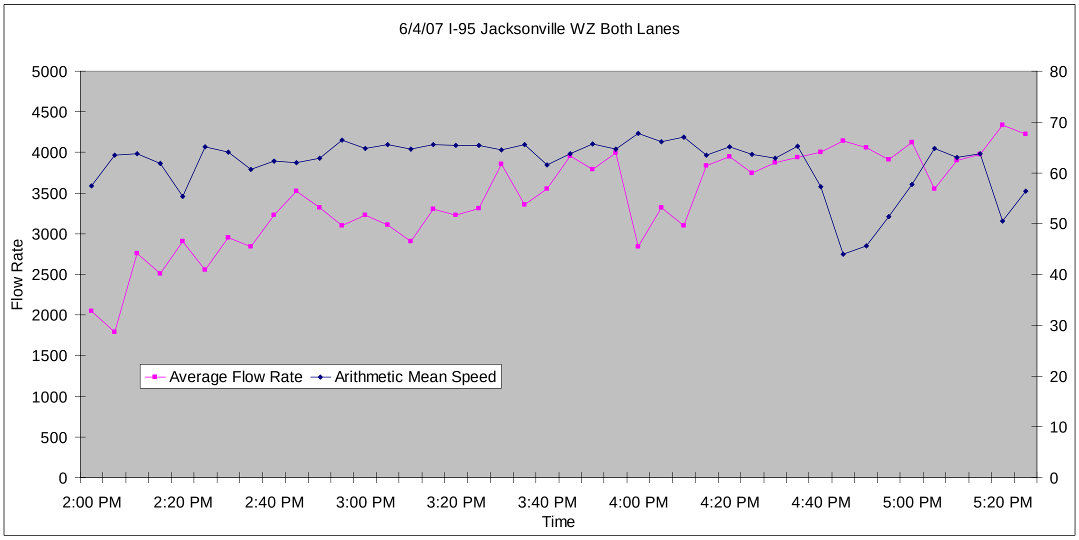

Figure 15: Plot of Flow and Speed for 6/4/07

On June 14 (Figure 16) congestion began before 4 PM. That day there was heavy rain which slowed the traffic down considerably during the data collection.

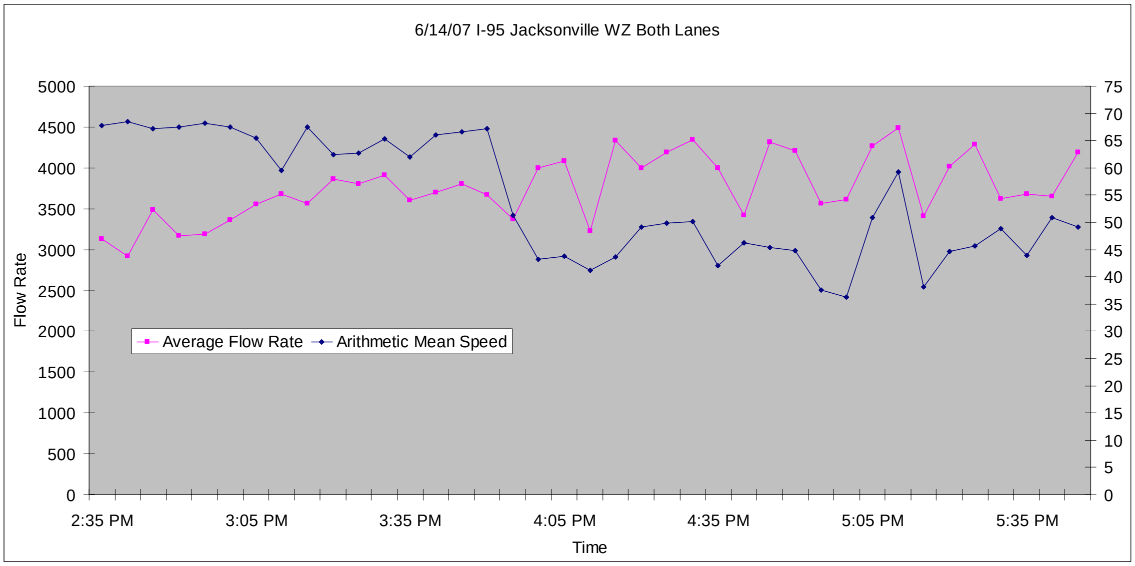

Figure 16: Plot of Flow and Speed for 6/14/07

Table 1 presents the four flow values for each of the 14 breakdown events observed during the data collection. The pre-breakdown and breakdown flow rates were not available (denoted by N/A) for three of the breakdowns, as discussed above (Figures 7-9).

Table 1: Capacity-Related Measures for Each Breakdown (Left-Lane Closure) in VPH

Breakdown	Date	Max Pre-Breakdown Flow	Breakdown Flow	Max Discharge Flow	Average Discharge Flow
1	3/27/07	3078	4020	4548	4040
2	4/5/07	N/A	N/A	4272	3910
3	4/13/07	N/A	N/A	4944	4004
4	4/19/07	N/A	N/A	4452	3950
5	4/26/07	3768	3636	4236	3939
6	4/26/07	3648	4452	4368	4079
7	5/14/07	4224	4500	4236	4068
8	5/14/07	4188	4500	4524	4180
9	5/22/07	4188	4092	4272	4228
10	5/22/07	4320	4140	4488	4035
11	5/31/07	4116	4416	4140	3830
12	5/31/07	4140	3708	3960	3584
13	6/4/07	3996	4008	4140	4036
14	6/14/07	3912	3672	4344	3899

Table 2 presents the minimum and maximum values, as well as the mean and standard deviation for each capacity measure for a 5-min aggregation interval. The maximum discharge flow rates were the highest, with the breakdown flows the lowest. The average discharge flow values had the lowest standard deviation (i.e., lowest variability). The pre-breakdown flows had the highest range at 1350 vph, while the breakdown flows had a range of about 850 vph.

Table 2: Aggregate Capacity-Related Measures for Left-Lane Closure (in VPH)

Breakdown	Max Pre-Breakdown Flow	Breakdown Flow	Max Discharge Flow	Average Discharge Flow
# of Observations	11	11	14	14
Min Value	3078	3636	3960	3584
Max Value	4320	4500	4944	4228
Mean	3962	4104	4352	3985
Std. Dev.	357	334	237	157

In addition to field data collected at the work zone, a limited amount of data were collected upstream (data collection points 2 and 3). Table 3 summarizes the lane utilizations observed during two of the days of data collection. As shown, lane utilization is very similar between those two days; therefore it is assumed that these numbers are fairly typical for this particular work zone configuration. In a subsequent chapter of this report, these numbers are compared to the respective numbers observed in CORSIM.

Table 3: Lane Utilization at Data Points 2 and 3

	Left Lane	Center Lane	Right Lane
Field data (03-27-07)	21%	45%	34%
Field data (04-05-07)	19%	45%	36%

3.2.1 Left Lane Closure Data Collection Summary

Figure 17 provides a summary histogram of the four capacity measures observed at the study site. The maximum pre-breakdown flows seem to be generally lower than the maximum discharge flows. Both resemble a normal distribution, with the maximum pre-breakdown flow centering around 4,250 vph and the maximum discharge flow centering around 4,500 vph. The average discharge flow has a maximum value of about 4,250 vph.

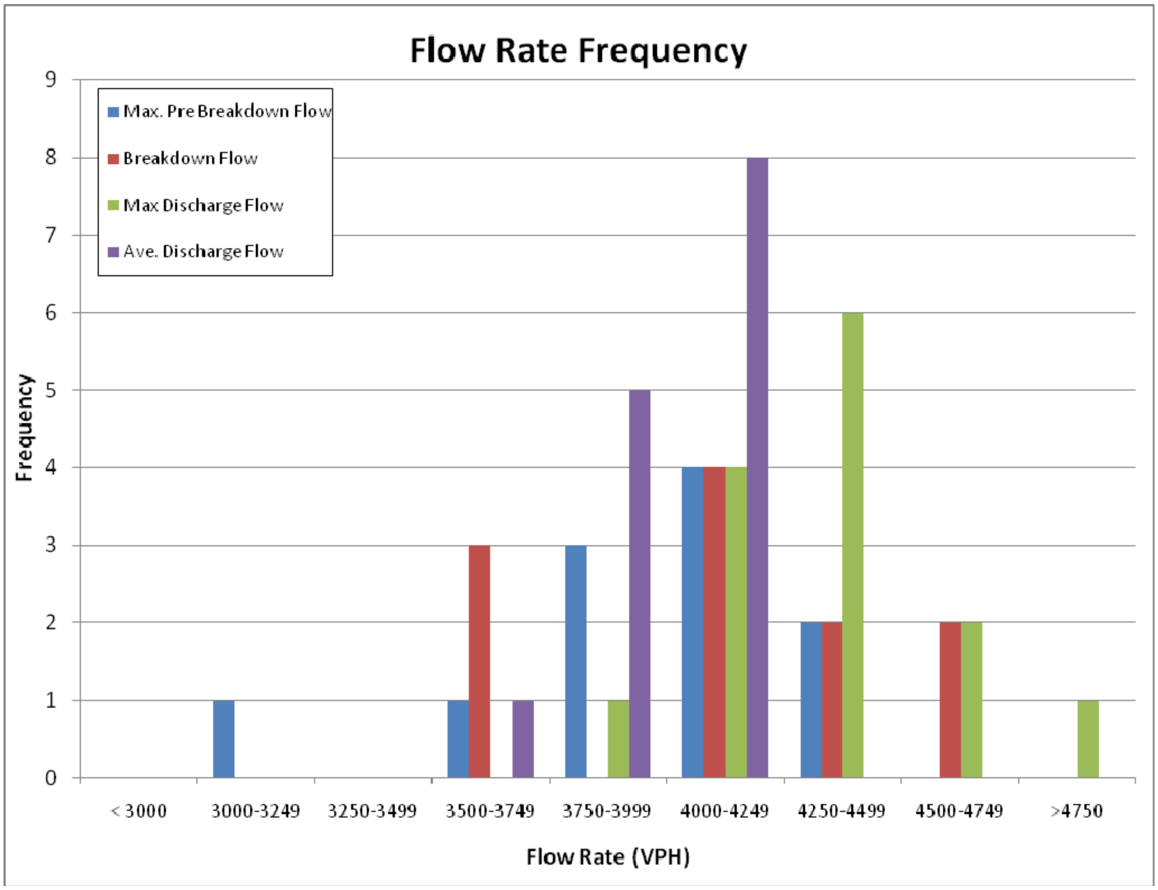

Figure 17: Histogram of Capacity Measures Observed for the Left-Lane Closure

3.3 Right Lane Closure Field Data

The results of the right lane closure data collection and capacity analysis are presented in this section. In Figures 18 through 22 the time series plot of flow vs. speed is presented for each of the data collection periods. As shown in Figure 18, on September 19, 2007, congestion began just after 5:15 PM and continued until approximately 6 PM. Visual inspection using TMC cameras indicated that at 5:30 PM the queue extended approximately one mile upstream.

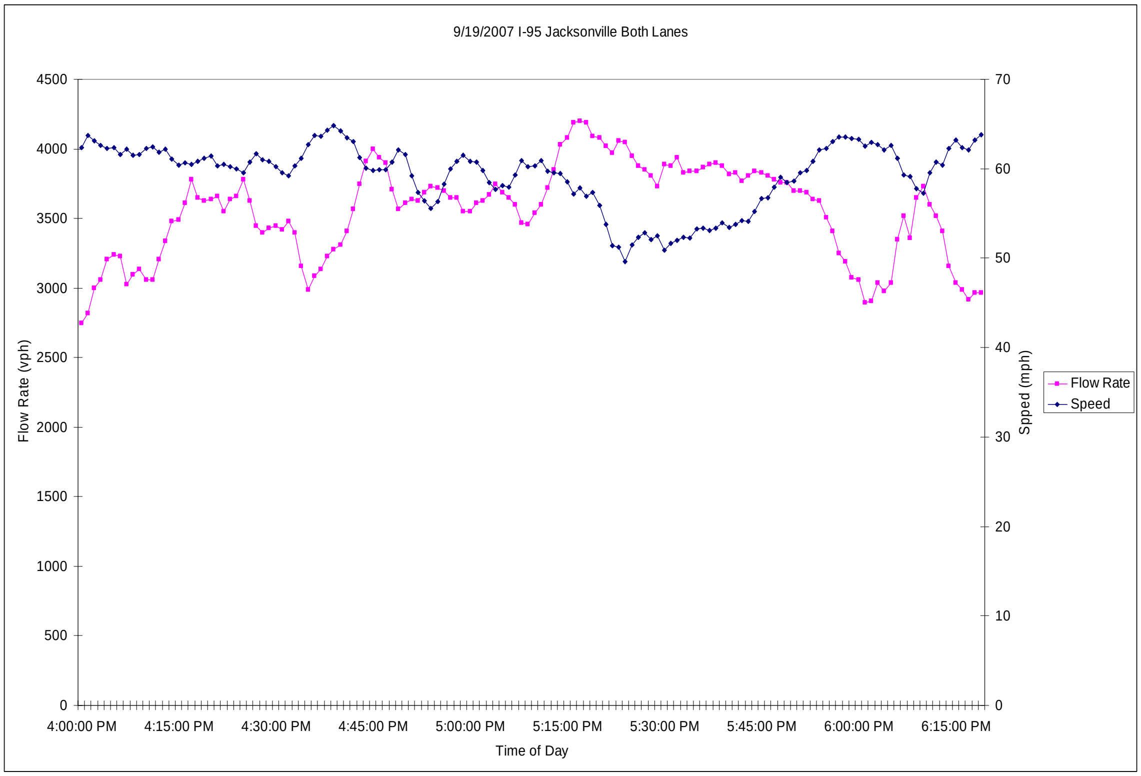

Figure 18: Plot of Flow and Speed for 9/19/07

On September 20 (Figure 19) congestion began about 4:45 PM and recovered around 5:00 PM for a short time. After 5:15 PM, another breakdown occurred, and congested conditions continued through the peak hour until 5:45 PM. Between breakdowns there was a significant decrease in the amount of demand indicating that there may have been an incident upstream that caused demand at the study site to drop in between the breakdowns. Visual inspection using TMC cameras indicated that the queue extended more than a mile upstream during the second breakdown.

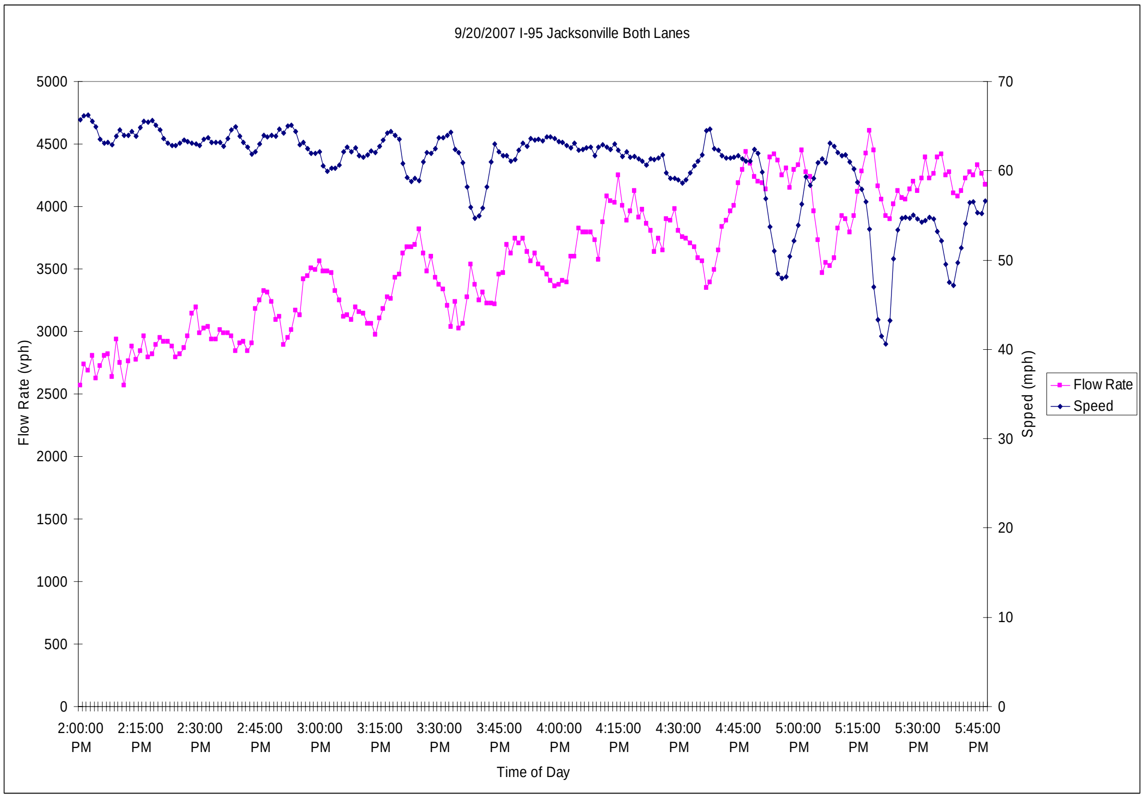

Figure 19: Plot of Flow and Speed for 9/20/07

On September 28 (Figure 20) congestion began about 3:30 PM and recovered around 5:00 PM for a short time. The breakdown was nearly continuous with two near-recoveries between 4:15 and 4:30 that were not sustained. Visual inspection using TMC cameras indicated that the queue extended more than three miles upstream during the congested period.

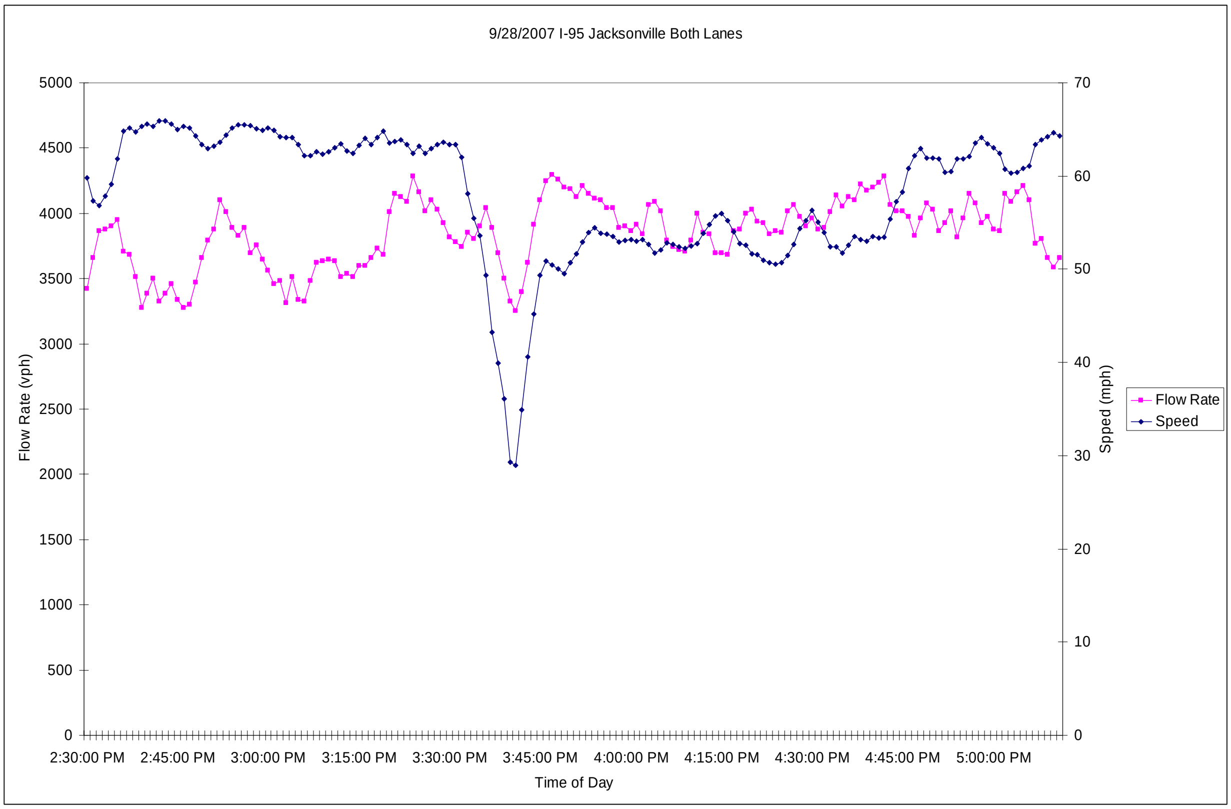

Figure 20: Plot of Flow and Speed for 9/28/07

On October 2 (Figure 21) there was very heavy rain in the Jacksonville area with 4.55 inches of rain recorded for that day at the National Weather Service Station at Jacksonville Naval Air Station (source: www.wunderground.com). The rain was constant throughout the day and affected operations within the work zone. At three times during the data collection (3:00, 5:15, and 6:30) very heavy rain significantly affected the flow and speed within the work zone. Demand was much lower than usual as motorists avoided the roadways. A breakdown occurred just after 5:00 PM and continued until 6:15

PM with one very short recovery resulting by a break in the rain. Visual inspection using TMC cameras indicated that the queue extended more than one mile upstream during the congested period.

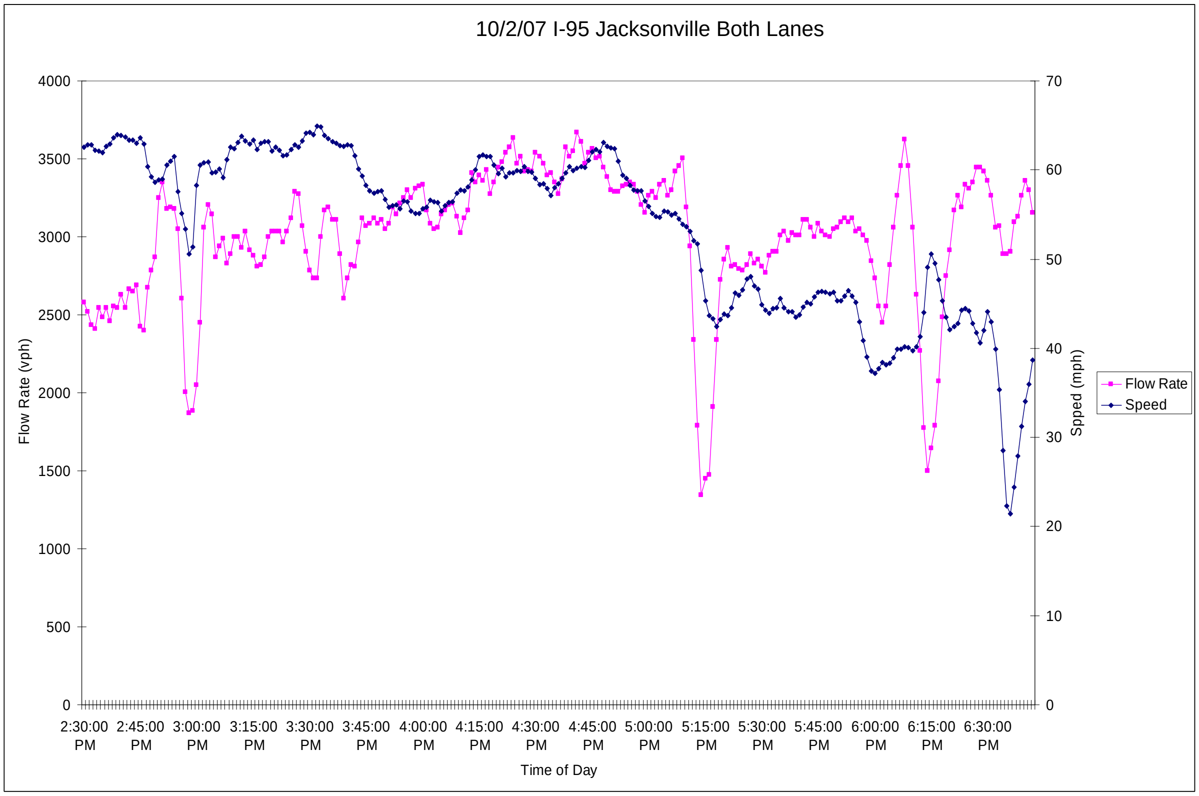

Figure 21: Plot of Flow and Speed for 10/2/07

On October 3 (Figure 22) congestion began about 5:15 PM and recovered around 5:30 PM. Traffic demand was not as high as many motorists were still recovering from the effects of the heavy rain and flooding of the previous day. Visual inspection using TMC cameras indicated that the queue extended approximately a mile upstream at 5:20 PM.

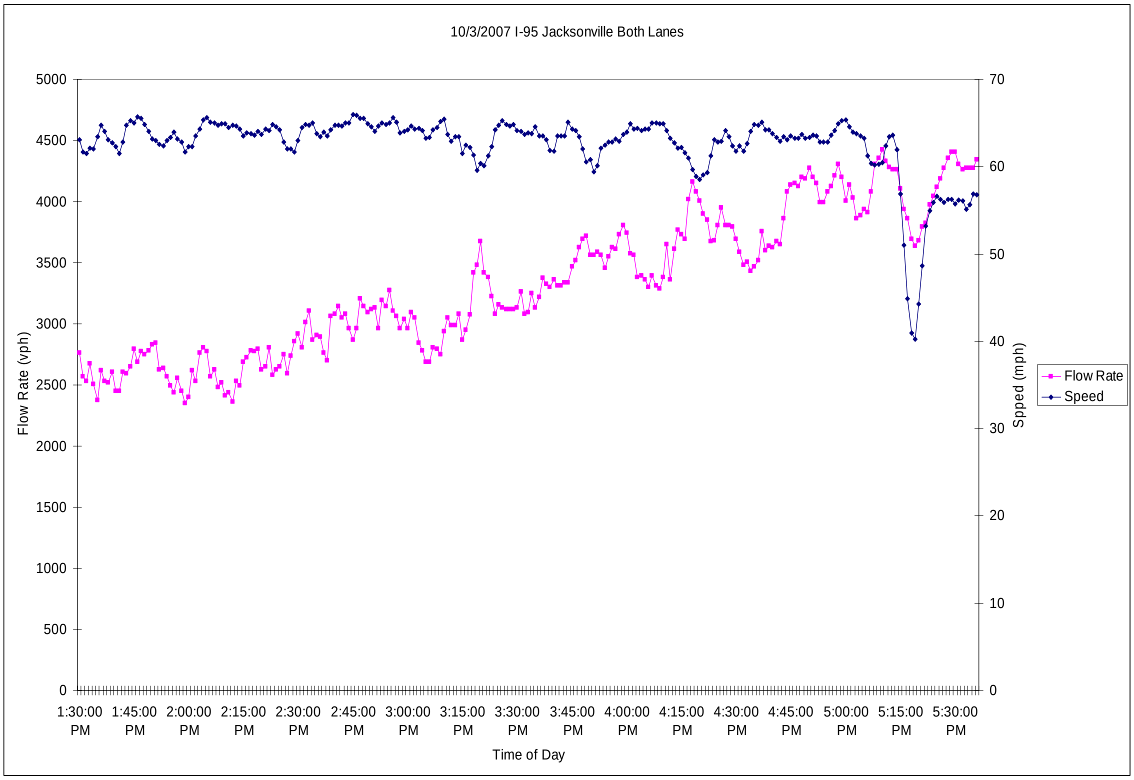

Figure 22: Plot of Flow and Speed for 10/3/07

3.3.1 Right Lane Closure Data Collection Summary

The results of the data collection from the right lane closure are presented in Table 4. Table 4 presents the four capacity measures for each breakdown observed during the data collection. A total of 6 breakdown events were observed. Breakdown 5 is shown in bold because it occurred during heavy rain conditions.

Table 4: Capacity-Related Measures for Each Breakdown Observed (Right Lane Closure) in VPH

Breakdown Event	Date	Max Pre-Breakdown Flow	Breakdown Flow	Max Discharge Flow	Ave. Discharge Flow
1	9/19/2007	3912	4092	4044	3904
2	9/20/2007	4128	4236	4416	4099
3	9/20/2007	3924	4452	4260	4074
4	9/28/2007	4284	4044	4296	3944
5	**10/2/2007**	**3672**	**3504**	**3624**	**2863**
6	10/3/2007	4308	4428	4260	4014

Table 5 presents the minimum and maximum values, as well as the mean and standard deviation for each capacity-related measure for a 5-min aggregation interval for all days of data collection with a right-lane closure (including the day with heavy rain). The standard deviation for the average discharge flow is relatively high because of the inclusion of the relatively low values observed during the heavy rain. Since this heavy rain is a rare event, subsequent analyses are conducted separating the rain-related data from the other capacity values.

Table 5: Aggregate Capacity-Related Measures for Right-Lane Closure, With Rain Events in VPH

	Max Pre-Breakdown Flow	**Breakdown Flow**	**Max Discharge Flow**	**Ave. Discharge Flow**
# of Observations	6	6	6	6
Min Value	3672	3504	3624	2863
Max Value	4308	4452	4416	4099
Mean	4038	4126	4150	3816
Std. Dev.	247	348	284	473

Table 6 presents the same information as Table 5 but excluding the rain-related data. The average max discharge flow rates was the highest (4255 vph), with the average discharge flow the lowest (4007 vph). The average discharge flow values had the lowest standard deviation (i.e., small variability). The breakdown flows had the highest variability and range between the minimum and maximum values.

Table 6: Aggregate Capacity-Related Measures for Right-Lane Closure, Without Rain Events in VPH

	Max Pre-Breakdown Flow	**Breakdown Flow**	**Max Discharge Flow**	**Ave. Discharge Flow**
# of Observations	5	5	5	5
Min Value	3912	4044	4044	3904
Max Value	4308	4452	4416	4099
Mean	4111	4250	4255	4007
Std. Dev.	189	187	134	83

The data collected meets the required sample size, which was estimated to be 10 samples (for a confidence level of 95 percent and an acceptable error of ±100 vehicles), which is lower than the actual number of samples obtained (20 samples).

Figure 23 provides a histogram of the four flow parameters observed in the work zone (which correspond to the values presented in Table 4).

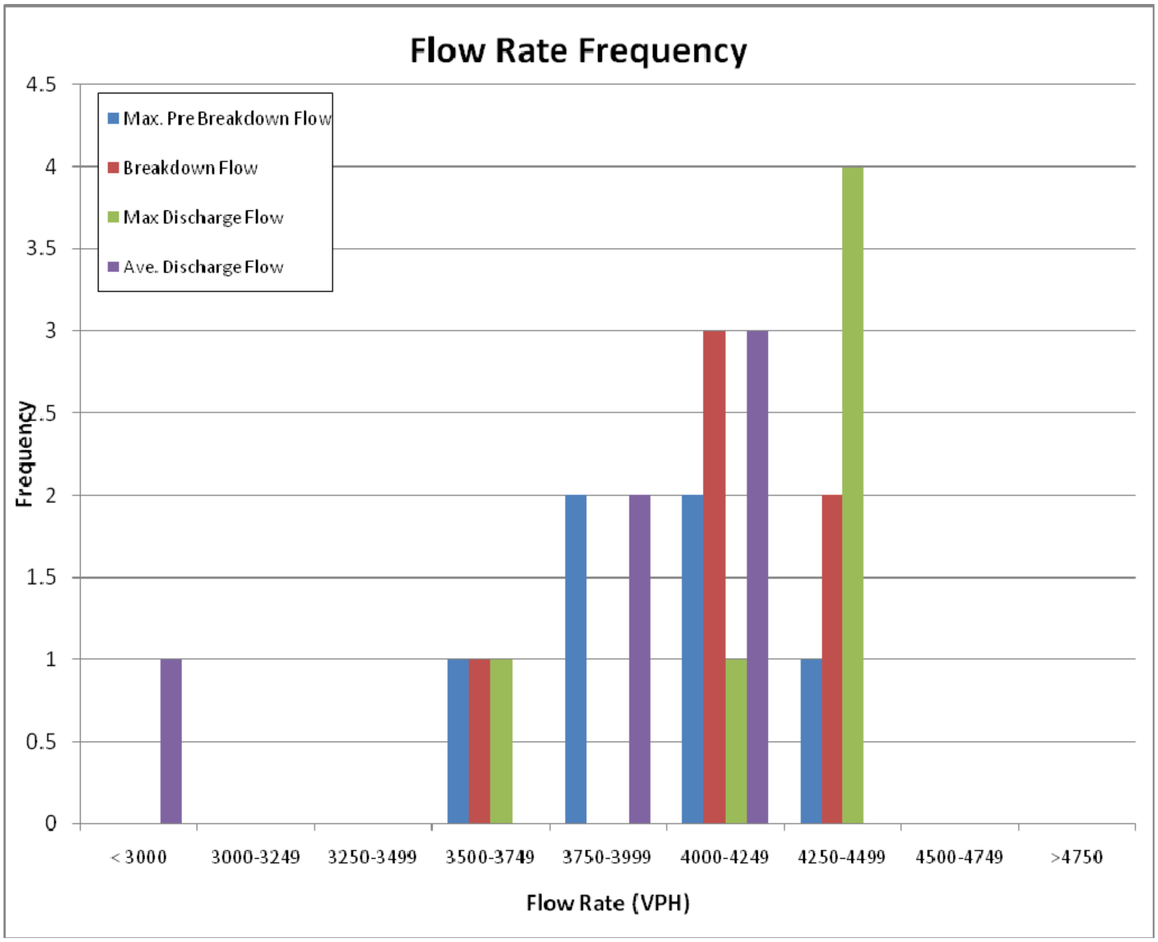

Figure 23: Histogram of Capacity Measures Observed for the Right-Lane Closure (in vph)

3.4 Summary, Comparisons, and Conclusions from the Data Collection

The results of the entire data collection are presented in Table 7. A total of 20 breakdown events were observed during the data collection. The shaded entries represent the right-lane closure data collection. Breakdowns 12 and 19 are in bold because of rain events that occurred on those two days. Breakdown 12 occurred in a light to moderate rain and breakdown 19 occurred during heavy rain.

Table 7: Capacity-Related Measures for Both Work Zone Configurations

Breakdown Event	Date	Max Pre-Breakdown Flow	Breakdown Flow	Max Discharge Flow	Ave. Discharge Flow
1	3/27/2007	3078	4020	4548	4040
2	4/5/2007	N/A	N/A	4272	3910
3	4/13/2007	N/A	N/A	4944	4004
4	4/19/2007	N/A	N/A	4452	3950
5	4/26/2007	3768	3636	4236	3939
6	4/26/2007	3648	4452	4368	4079
7	5/14/2007	4224	4500	4236	4068
8	5/14/2007	4188	4500	4524	4180
9	5/22/2007	4188	4092	4272	4228
10	5/22/2007	4320	4140	4488	4035
11	5/31/2007	4116	4416	4140	3830
12	**5/31/2007**	**4140**	**3708**	**3960**	**3584**
13	6/4/2007	3996	4008	4140	4036
14	6/14/2007	3912	3672	4344	3899
15	9/19/2007	3912	4092	4044	3904
16	9/20/2007	4128	4236	4416	4099
17	9/20/2007	3924	4452	4260	4074
18	9/28/2007	4284	4044	4296	3944
19	**10/2/2007**	**3672**	**3504**	**3624**	**2863**
20	10/3/2007	4308	4428	4260	4014

Table 8 presents the minimum and maximum values, as well as the mean and standard deviation for each flow parameter for a 5-min aggregation interval including the days with the rain events. The average max discharge flow rates were the highest, with the average discharge flows the lowest. The maximum discharge flow values had the lowest standard deviation (i.e., small variability).

Table 8: Aggregate Capacity-Related Measures for Both Work Zone Configurations, With Rain Events (in VPH)

	Max Pre-Breakdown Flow	Breakdown Flow	Max Discharge Flow	Ave. Discharge Flow
# of Observations	17	17	20	20
Min Value	3078	3504	3624	2863
Max Value	4320	4500	4944	4228
Mean	3989	4112	4291	3934
Std. Dev.	316	328	262	286

Table 9 presents the minimum and maximum values, as well as the mean and standard deviation for each flow parameter for a 5-min aggregation interval, without the days with the rain events. The average maximum discharge flow rates were the highest, with the average pre-breakdown flows the lowest. The average discharge flow values had the lowest standard deviation (i.e., small variability). Table 10 presents the comparison of the capacity measures for rain and non-rain events. The table shows that the rain events have lower values than the non-rain events for all capacity measures.

Table 9: Aggregate Capacity-Related Measures for Both Work Zone Configurations, Without Rain Events

	Max Pre-Breakdown Flow	Breakdown Flow	Max Discharge Flow	Ave. Discharge Flow
# of Observations	15	15	18	18
Min Value	3078	3636	4044	3830
Max Value	4320	4500	4944	4228
Mean	4000	4179	4347	4013
Std. Dev.	325	283	202	102

Table 10: Comparison of Capacity Measures for Rain and Non-Rain Events

Rain Events Summary				
	Max Pre-Breakdown Flow	**Breakdown Flow**	**Max Discharge Flow**	**Ave. Discharge Flow**
# of Observations	2	2	2	2
Min Value	3672	3504	3624	2863
Max Value	4140	3708	3960	3584
Mean	3906	3606	3792	3224
Std. Dev.	331	144	238	510
Non-Rain Events Summary				
	Max Pre-Breakdown Flow	**Breakdown Flow**	**Max Discharge Flow**	**Ave. Discharge Flow**
# of Observations	15	15	18	18
Min Value	3078	3636	4044	3830
Max Value	4320	4500	4944	4228
Mean	4000	4179	4347	4013
Std. Dev.	325	283	202	102

A statistical comparison was conducted to determine whether the four capacity measures are affected by the side of the work zone closure (left vs. right). The two sample t-test assuming unequal variances was used at the 95 percent confidence level. Based on this test it was concluded that there is no significant difference in capacity measures between the left- and right-lane closures.

The total sample size for rain events was too small (only two data points) to conduct a meaningful statistical test between two samples. A statistical test (t-test of means for one sample) was conducted to compare the average values for the four capacity-related measures during non rain events to the corresponding average values during the rain events. It was concluded that there is a significant difference in three of the four capacity measures at the 95 percent confidence level between the rain and non-rain events. The only capacity measure that was not shown to be statistically different was the pre-breakdown flow.

Figure 24 provides a histogram of the four capacity measures observed in the work zone. The maximum discharge flow resembles a normal distribution centered at 4500 vph. The breakdown flows also approximate the normal distribution centered at 4250 vph.

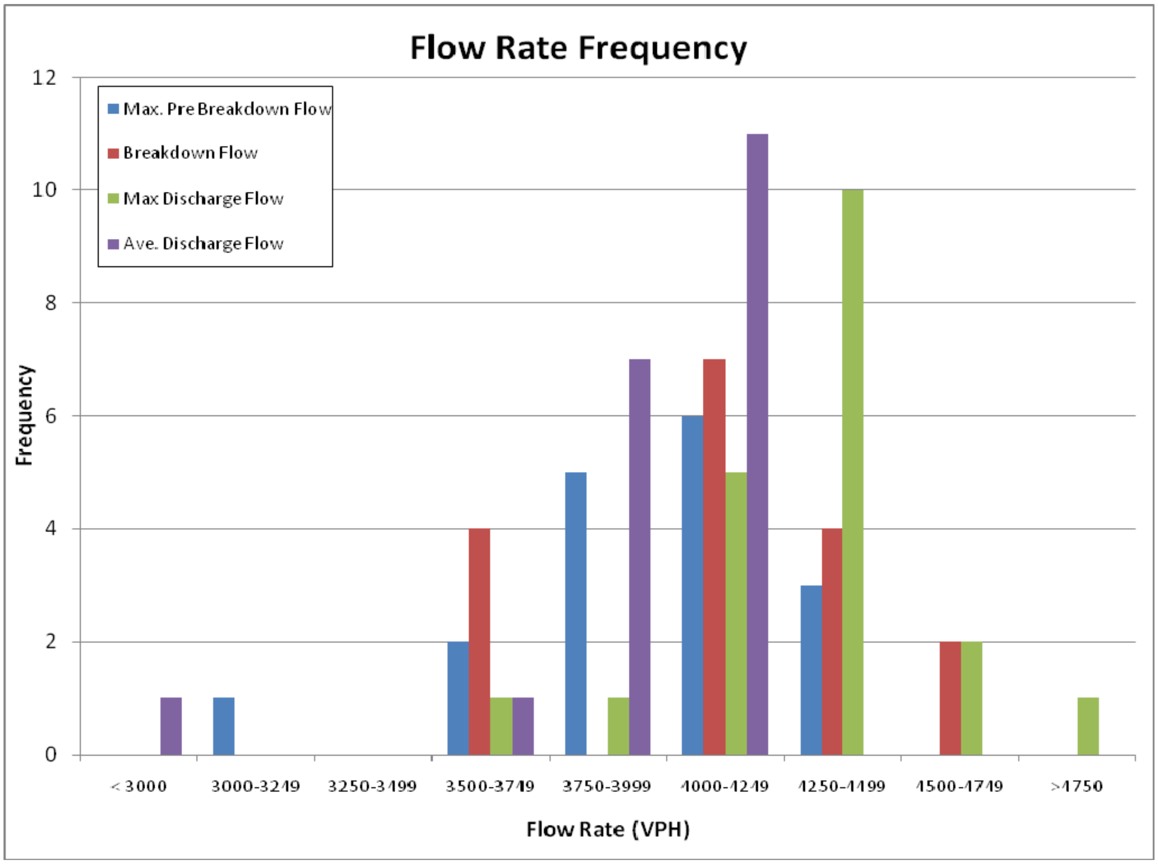

Figure 24: Histogram of Capacity Measures Observed for Both Work Zone Configurations

The following conclusions can be drawn from the data collection:

- An adequate sample size was collected to estimate four different capacity measures at a work zone in Jacksonville, FL;

- There was no significant difference in the capacity measures between the left and right lane closures;

- Rainy conditions significantly reduced three of the four capacity measures in the work zone:
    - Breakdown flow (from 12 to 17 percent for the moderate and heavy rain respectively)

    - Maximum Discharge Flow (from 9 to 17 percent for the moderate and heavy rain respectively)

    - Average Discharge Flow (from 10 to 29 percent for the moderate and heavy rain respectively)

- The average discharge flow had the smallest standard deviation of all the capacity measures. The other three measures showed higher variability.

4. SIMULATION OF THE I-95 SITE IN JACKSONVILLE, FLORIDA

The field site operations were next simulated using CORSIM to compare the field capacity measures to those obtained by CORSIM, which was the simulator used in FDOT Project BD-545-51. The main objective of this analysis was to evaluate the CORSIM simulator with respect to its ability to replicate work zone operations and assess its flexibility to evaluate the impacts of various factors that affect work zones (such as left vs. right-lane closures). This section first describes the replication of the study site in CORSIM, the simulation approach used, and summarizes the assumptions employed. Next, it discusses the results of the simulation. The last section compares the field capacity estimates to those provided by CORSIM.

4.1 Modeling of the I-95 Field Site with CORSIM 5.1

The software package CORSIM was used to simulate the study site, since that was the simulator selected in FDOT Project BD-545-51. The software, originally developed by FHWA, has been widely used and validated in the past twenty years, and it is available to the University of Florida through McTrans, allowing for a high level of software support in understanding the software's algorithms. This section discusses how CORSIM was utilized to recreate the field site, the modeling assumptions employed, as well as the number of runs required per scenario.

There is no explicit simulation of a work zone in FRESIM (which is the freeway analysis component of CORSIM); instead, there are two alternative techniques that allow FRESIM to approximate a work zone lane closure. The first of these is identified as a lane drop. The options allow up to three lane additions or drops to occur within the same link. To simulate a right-lane closure, the rightmost lane would be dropped at a point specified at a distance from the upstream node, and then it would be added at another specified point designated again by its distance from the upstream node. The second technique that can be used to simulate a lane closure is identified as an incident. The user can create multiple incidents during different times of the simulation on the same link.

Each of these can occur simultaneously and on several lanes if desired. Neither technique can simulate the taper section prior to the lane closure.

The previous project evaluated the two simulation alternatives and concluded that the performance of the freeway segment was very similar. Because the two alternatives produce almost identical values, the one which provides the most flexibility in the simulation, namely incident analysis, was selected and used. The incident technique allows for the effects of "rubbernecking" to be simultaneously implemented with a lane closure, which relates to the worker/equipment activity present at the work zone. To maintain consistency with the previous project this method was used for the simulation of the I-95 work zone.

Figure 25 presents an aerial photograph of the I-95 work zone. The black lines are the links that were modeled in CORSIM, while the white circles represent the nodes.

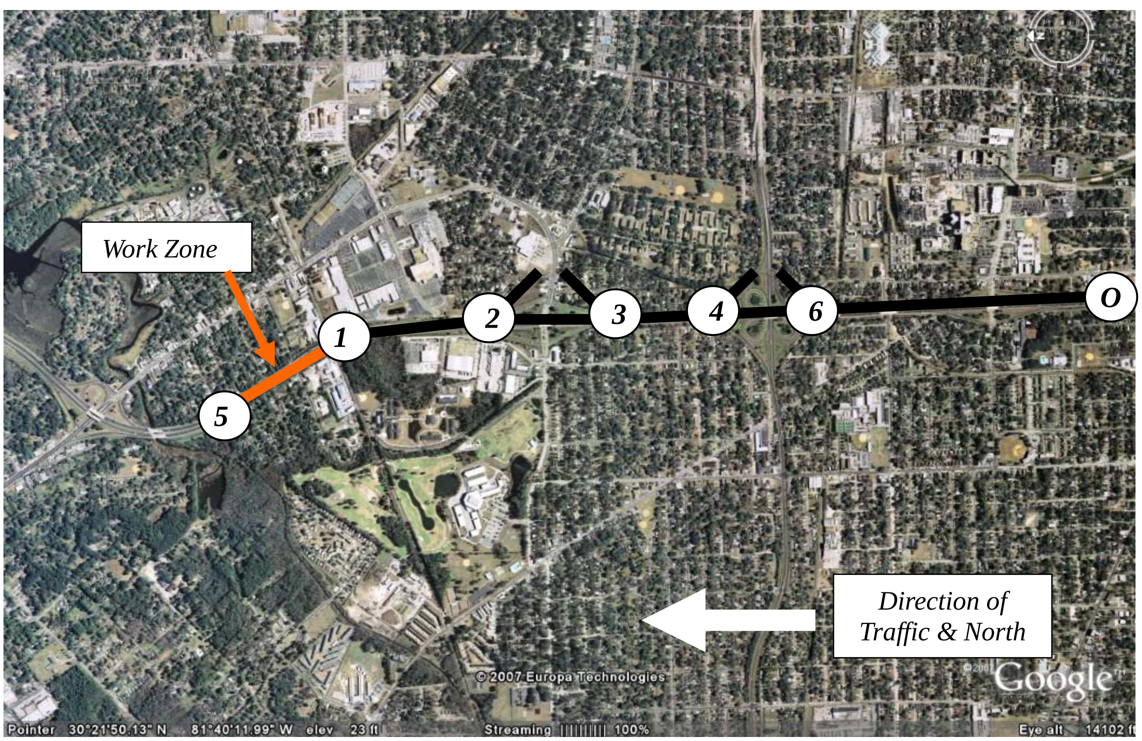

Figure 25: Aerial Photograph of Field Site with Overlay of the Simulated Freeway Network

Figure 26 shows the simulated test segment and the network view in CORSIM. The following is a discussion of the function and characteristics of each of the freeway links:

Link (1, 5) – This link is the work zone link, with two through lanes that are open and one lane that is closed. The left and right lane closure configurations were modeled separately. The work zone was modeled as an incident as detailed previously. One of the inputs in the simulation of an incident is the distance to the first upstream warning sign. This was entered as 10,000 ft, to replicate the field operations. Detectors were placed on the link to collect speed and flow data and to replicate the data collection location in the field. The detectors were placed 250 ft from the downstream end of the link. The free flow speed on this link was set at 60 mph. The length of the link was 1,012 ft.

Link (2, 1) – This link has three through lanes and starts where the queue begins to form. There were no detectors placed on the link. The free flow speed on this link was set at 60 mph. The length of the link is 1,000 ft.

Link (3, 2) – This link has three through lanes and is located between the exit ramp and entrance ramps for the Golfair Blvd. interchange. There were no detectors placed on the link. The free flow speed on this link was set at 60 mph. The length of the link is 2,000 ft.

Link (4, 3) – This link has three through lanes and one auxiliary lane that connects the entrance and exit ramps for adjacent interchanges at MLK Parkway and Golfair Blvd. There were no detectors placed on the link. The free flow speed on this link was set at 60 mph. The length of the link is 1,000 ft.

Link (6, 4) – This is the first upstream link in advance of the work zone. Since the distance from the work zone to the first upstream work zone warning sign is 10,000 ft. (as indicated above), simulated vehicles entering this link have already had one warning of the work zone ahead. This link has three through lanes. The length of the link is 5,000 ft.

Link (8001, 1) – This is the feeder link for the network.

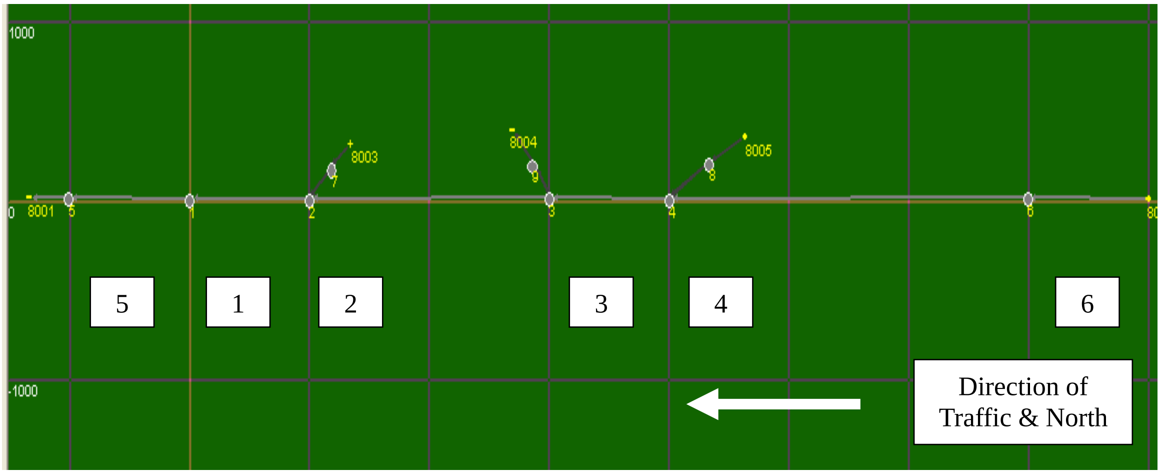

Figure 26: The Simulated Work Zone in CORSIM

The following inputs, based on field data, were entered into CORSIM:

- Presence of trucks (percentage) – 5 percent
- Rubbernecking factor (percentage) – 0 percent (There were no workers in the vicinity of the lane drop)
- Free flow speed – 60 mph

The following assumptions were also used in the simulation:

- Demand flow rate 1,800 vph at the beginning of the simulation, increasing by 600 vph every five minutes for an hour of simulated time. This technique was used so that all four capacity measures (pre-breakdown flow, breakdown flow, maximum discharge flow, and average discharge flow) could be obtained, as the network was loaded gradually to simulate the process of breakdown.

- Entering and exiting traffic on each ramp upstream of the work zone- 100 vph. Field data were not available for those ramps; however their presence and respective demands do not affect the capacity of the work zone. Therefore, their demand was assumed to be 100 vph.

Another consideration in modeling work zones relates to the driving behavior of trucks. CORSIM provides three choices for truck behavior: not biased or restricted to any lanes, biased to a set of lanes, and restricted to a set of lanes. The lanes to which a truck is biased can be specified. For this project, trucks were modeled as not biased to any lanes as observed in the field. There were approximately 40 percent trucks observed in the left lane and 60 percent in the right lane. This is a different assumption then in the modeling effort from the previous FDOT project where trucks were assumed to be biased to traveling on the rightmost lane of the freeway.

Sample size calculations were conducted to determine the number of simulation runs necessary to obtain a level of confidence in the simulation to account for simulator variability. The sample size was estimated based on throughput using a 95 percent confidence interval with an acceptable deviation of 100 vehicles per hour. For each of the left lane and right lane closure scenarios, 20 runs were conducted which provided a confidence level well above the 95 percent confidence level with an acceptable error level less than the 100 vph that has been used on the project in estimating the required sample size. The results for each are reported in the next section.

4.2 Simulation Results

Two primary sets of output data were collected from the simulation experiments: a) discharge flows by lane in link (1,5), and b) speed-flow time series, similar to those obtained for the field data, and the respective capacity measures for each run. A summary of those results is provided in the remainder of this section.

To obtain discharge flows by lane in link (1, 5), the simulation model was run 20 times for each of the left and right lane closures. CORSIM's default output provides link flows, however the field data collected were flows measured using detectors at specific locations. To replicate the field data collection as much as possible, in the design of the CORSIM simulation detectors were placed on link (1, 5) and these data were compared to the link flows generated from the simulation to determine whether there was a significant difference between those two values. Table 11 presents the results of each of the runs as well as summary statistics for average discharge flows for the left- and right-lane closures. It was concluded that the two methods of obtaining flows do not provide significantly different results. Also, the differences in the mean discharge flows between the left and the right lane closure were found to not be significant at the 95 percent confidence level. As shown in Table 11, the variability in flows is slightly higher for the right-lane closure.

Table 11: Results of the I-95 CORSIM Simulation

	Left Lane Closure		Right Lane Closure	
Run	**Link Flow from CORSIM Output**	**Point Detector Flow**	**Link Flow from CORSIM Output**	**Point Detector Flow**
1	3716	3704	3916	3876
2	3820	3828	3860	3851
3	3788	3768	3860	3876
4	3792	3792	3876	3849
5	3824	3836	3812	3808
6	3780	3784	3972	3956
7	3908	3912	3868	3840
8	3804	3796	3680	3672
9	3748	3756	3828	3808
10	3852	3860	3720	3736
11	3808	3780	3856	3844
12	3804	3820	3784	3788
13	3860	3840	3756	3765
14	3748	3760	3840	3828
15	3824	3828	3780	3752
16	3748	3748	3800	3792
17	3780	3800	3828	3808
18	3724	3720	3764	3760
19	3732	3740	3936	3937
20	3840	3816	3772	3764
Mean	**3795**	**3794**	**3825**	**3816**
Std. Dev	49.89	50.19	71.87	67.51

Next, time series of speed-flow data were obtained to “observe” the process of breakdown in the simulator. To accomplish this, data were obtained using spot detectors from the left lane closure in CORSIM every two minutes for the duration of the simulation. Since the difference between a left and a right lane closure was statistically not significant, the experiments only focused on the left-side closure.

Figure 27 presents the data collected from the detectors for one of the 20 runs. The horizontal axis represents 2-min time intervals. The results of the 20 runs are fairly similar therefore, only one of them is presented here. As shown, the general shape of the speed and flow time series around the breakdown is similar to those observed in the field data (shown in Chapter 3 of this report).

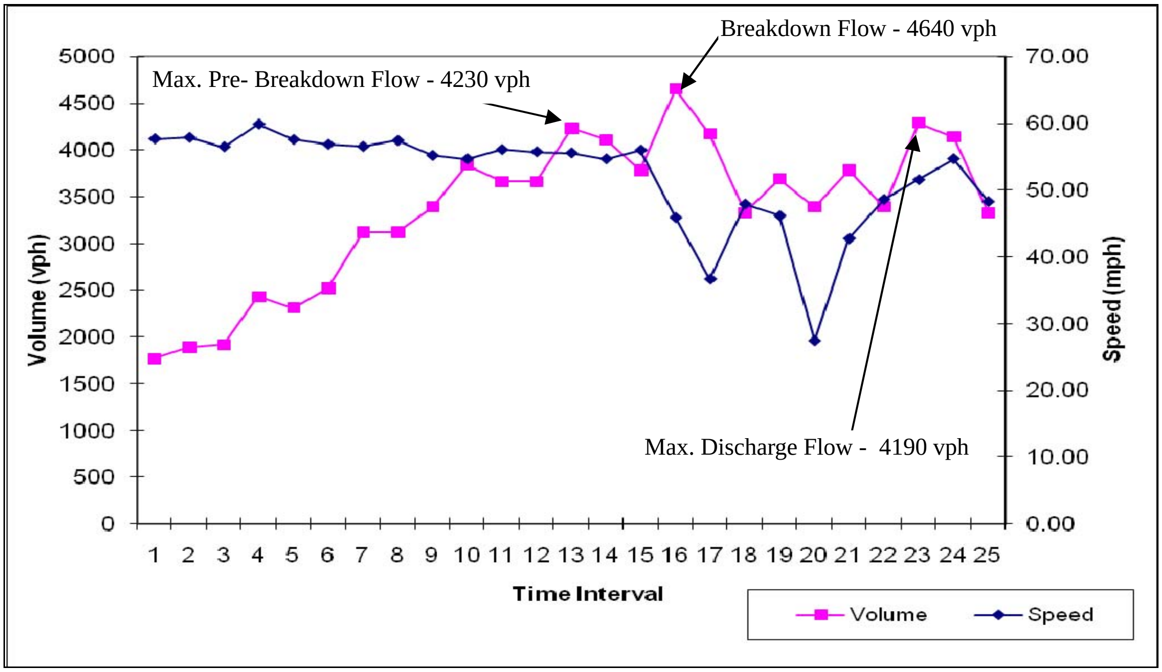

Figure 27: Time Series Diagram of Simulated Breakdown in CORSIM

Table 12 provides a summary of the four capacity measures obtained from CORSIM for each of the 20 runs. As shown, the pre-breakdown flow rates were the highest, with the average discharge flows the lowest. The maximum discharge flow values had the lowest standard deviation (i.e., small variability).

Table 12: Summary of the Capacity Measures Obtained From CORSIM (in VPH)

Run	Max Pre-Breakdown Flow	Breakdown Flow	Max Discharge Flow	Ave. Discharge Flow
1	4470	4440	4200	3777
2	4620	4200	4170	3917
3	4440	4240	3900	3827
4	4080	4200	4220	3873
5	4380	4020	4110	3957
6	4470	4590	4290	3870
7	4500	4240	4110	3998
8	4320	3780	4530	3960
9	4650	3990	4050	3847
10	4230	4650	4190	3837
11	4470	4440	4200	3932
12	4200	4590	4640	4037
13	4320	4350	4230	3948
14	4290	4260	4290	3980
15	4290	4260	4500	4035
16	3630	3830	4320	4031
17	4340	4380	4320	3922
18	4290	3990	4260	3968
19	4170	4650	4260	3968
20	4530	4230	4440	3948
Mean	4335	4267	4262	3932
Std. Dev.	222	255	171	73
Minimum	3630	3780	3900	3777
Maximum	4650	4650	4640	4037

4.3 Comparison of CORSIM to the Field Data

The field data were compared to the results obtained from CORSIM to determine whether CORSIM can adequately replicate the work zone operations observed in the field. The analysis compared a) the capacity measures obtained from CORSIM to those obtained in the field, and b) the lane distributions observed in the field upstream of the work zone to the respective ones from CORSIM.

Table 13 presents a summary of the capacity measures obtained from CORSIM and the field data. As shown, CORSIM predicts a higher maximum pre-breakdown flow on average, than that observed in the field. The other three capacity measures are comparable, with differences in the order of less than 100 vph. Generally the variability (i.e., standard deviation) is higher in the field than that predicted by CORSIM, and the standard deviation of the average discharge flow is the lowest both in the field, and in

CORSIM.

Statistical testing was conducted using the t-test for means comparing each of the four capacity measures to the respective field data. The tests showed that the maximum pre-breakdown and average discharge flows were statistically different at the 95 percent confidence level, while the breakdown and maximum discharge flows were determined not to be significantly different at the 95 percent confidence level. Note that for the average discharge flow, the statistical test fails despite the fact that the difference between the field and the CORSIM value is only 81 vph. This occurs because the standard deviation for this measure is very low.

Table 13: Comparison of Capacity Measures in CORSIM to Field Data (in VPH)

CORSIM	**Max Pre-Breakdown Flow**	**Breakdown Flow**	**Max Discharge Flow**	**Ave. Discharge Flow**
# of Runs	20	20	20	20
Minimum	3630	3780	3900	3777
Maximum	4650	4650	4640	4037
Mean	4335	4267	4262	3932
Std. Dev.	222	255	171	73
Field Data (Excluding Rain Events)	**Max Pre-Breakdown Flow**	**Breakdown Flow**	**Max Discharge Flow**	**Ave. Discharge Flow**
# of Observations	15	15	18	18
Min Value	3078	3636	4044	3830
Max Value	4320	4500	4944	4228
Mean	4000	4179	4347	4013
Std. Dev.	325	283	202	102

Next, the lane utilization data obtained from data collection points 2 and 3 were compared to the respective ones from CORSIM. Table 14 presents the field-observed lane utilization and the lane utilizations produced by CORSIM (with a left lane closure through the work zone for both cases). As shown, in the field, the lane utilization of the center lane is higher than that of the other lanes, as well as that predicted by CORSIM.

Table 14: Lane Utilization in the Field and in CORSIM

	Left Lane	**Center Lane**	**Right Lane**
Field (3-27-07)	21%	45%	34%
Field (4-5-07)	19%	45%	36%
CORSIM	28%	28%	44%

In summary, the comparisons reported above show that there are some similarities and some differences between the field data and the simulator. CORSIM can replicate some aspects of work zone breakdown, and the general shape of the speed and flow time series relationship is similar to that in the field. Also, it can reasonably predict the breakdown and maximum discharge flows. However, the pre-breakdown and average discharge flows are not statistically equal, despite the fact that the numerical differences for the average discharge flows were relatively low (below 100 vph).

Generally, CORSIM appears to over-predict the pre-breakdown flow, while the differences for the remaining three capacity measures are relatively low. With respect to lane utilization, CORSIM does not predict very accurately the percent of traffic on each lane, and it does not have the flexibility to allow the user to enter these as inputs into the simulation for a particular site.

5. COMPARISONS OF FIELD-OBSERVED CAPACITIES TO OTHER TECHNIQUES

This chapter first presents a comparison of the field capacity measures to those estimated by the analytical models previously developed in FDOT BD 545-51. The next section presents a comparison of capacities obtained by CORSIM, the HCM 2000, and the existing FDOT lane closure methodology.

5.1 Comparison of Field Data to FDOT BD 545-51 Models

This section presents a comparison of the field estimated capacities to the models developed in the FDOT BD 545-51 project. Two sets of models were developed in that project: one for planning and one for traffic operations applications. Each of these was applied to estimate the capacity of the I-95 study site. Of the four capacity measures obtained in the field, the average discharge flow was selected to be compared to these models because the FDOT BD 545-51 project defined capacity as the average discharge flow, based on the CORSIM output.

Based on the field data the following inputs were used (items in bold were used for both the planning and the operations models, while the remaining ones were required only for the operations model):

1) Lane Width, LW = 12 ft

2) Lateral Clearance, LC = 6 ft
3) **Rubbernecking factor = 0**
4) **Passenger Car Equivalency Value for Trucks= 2.4**
5) **Heavy Vehicle Percentage = 5 percent**
6) Sign Distance = 2.0 mi
7) Speed in Lane 1 (unadjusted) = 45 mi/h
8) Lane Distribution in to-be-closed lane = 0.35
9) Lane Distribution in open lane = 0.25
10) Rain Conditions = 0.95 for moderate rain and 0.90 for heavy rain.

In addition, the following were assumed:

1) No adjustments for driver population, **light conditions** and **presence of ramps** are necessary

Table 15 presents the results of the comparison of the models to the field data. The operations model yielded a value of 4046 vph, or 2023 vehicles per hour per lane (vphpl), for the no-rain days, while the respective field observations ranged between 3830 and 4228 vph. The predicted value is nearly in the middle of the field observations, with a very small average difference between the two (33.06 vph). A statistical t-test was conducted to compare the field data to the operations model estimates (for no rain events only), and it was concluded that there was no significant difference at the 95 percent confidence interval. However, the planning model produced a value of 3660 vph (1830 vphpl) for the no-rain days, which was lower than any of the values in the field data. Note that the models were built with an acceptable level of error of 100 vph.

For observations 12 and 19 the rain factors were applied for moderate and heavy rain respectively. In both cases the rain had a more detrimental effect on capacity than that predicted by the operations model. The difference was particularly high for the heavy rain event (777 vph). Even the planning model, which underestimated the capacity for all days, overestimated the predicted capacity during the heavy rain event.

Table 15: Comparison of Field Data to FDOT BD 545-51 Models (in VPH)

Observation	Field Data - Average Discharge Flow	Operations Model Predicted Capacity	Difference (vph)	Planning Model Predicted Capacity	Difference (vph)
1	4040	4046	6	3660	-380
2	3910	4046	136	3660	-250
3	4004	4046	42	3660	-344
4	3950	4046	96	3660	-290
5	3939	4046	107	3660	-279
6	4079	4046	-33	3660	-419
7	4068	4046	-22	3660	-408
8	4180	4046	-134	3660	-520
9	4228	4046	-182	3660	-568
10	4035	4046	11	3660	-375
11	3830	4046	216	3660	-170
12	*3584*	*3842*	*258*	*3476*	*-108*
13	4036	4046	10	3660	-376
14	3899	4046	147	3660	-239
15	3904	4046	142	3660	-244
16	4099	4046	-53	3660	-439
17	4074	4046	-28	3660	-414
18	3944	4046	102	3660	-284
19	*2863*	*3640*	*777*	*3294*	*431*
20	4014	4046	32	3660	-354
Average Difference without Rain Observations (vph)			33.06		-301.5
Average Difference for the Rain Observations (vph)			-517.5		161.5

Note: Rain events shown in italics

Table 16 summarizes the average discharge flows by level of flow difference. As shown, 50 percent of the observations are within 100 vph from the estimated capacity, while 90 percent are within 200 vph.

Table 16: Differences Between Operations Model and Field Data

Summary of Differences in Average Discharge Flow		
Flow Difference (vph)	Number of Observations	Percent of Observations
0-100	10	50%
101-200	8	40%
201-300	1	5%
301-400	0	0%
401-500	0	0%
501-600	0	0%
601-700	1	5%

In summary, it can be concluded that the operations model can reasonably predict the capacity of this freeway work zone, while the planning model (which requires fewer inputs) under-predicts it. The effect of rain is not captured very well by either of these models. Additional research should be conducted to determine the effects of rain for various levels of rainfall, and for various sites.

5.2 Comparisons to CORSIM, HCM 2000, and the Existing FDOT Lane Closure Methodology

This section presents a comprehensive comparison of the field data to several other available methods for estimating capacity including a) the FDOT BD 545-51 project models, b) the CORSIM results, c) the HCM 2000, and d) the existing FDOT lane closure method. The first two methods were discussed in previous sections of the report along with the respective results. The methods and results for the last two methods are presented below, followed by a summary and comparison of the results from all methods.

The HCM 2000 method is presented in Chapter 22 of the Highway Capacity Manual (TRB 2000). The following equation is used to estimate the capacity of a freeway work zone:

$$c_a = (1{,}600 + I - R) * f_{HV} * N$$

where

c_a = adjusted mainline capacity (vph)

f_{HV} = adjustment for heavy vehicles; based on the field data (there are 5 percent trucks) this factor was estimated to be 0.975

I = adjustment factor for type intensity and location of the work activity (ranges from -160 to +160 pc/h/ln); there is no specific guidance in the HCM 2000 regarding this factor; since there was no work activity during the data collection, this factor is assumed to be +160 pc/h/ln or +320 pc/h.

R = adjustment for presence of ramps; there are none within the study area, therefore this factor is zero.

Using the HCM 2000 method, the capacity is estimated to be 3,440 vph.

The existing FDOT lane closure methodology estimates the capacity of the work zone as follows:

Capacity = 3600 * OF

where

3600 = Base capacity for a 3 to 2 freeway lane closure

OF = Obstruction factor, which reduces the capacity of the remaining travel lanes to account for lane width less than 12 ft, and lateral clearance less than 6 ft; in this case, this factor is 1.00

Using the existing FDOT lane closure methodology the capacity of the work zone is estimated to be 3,600 vph.

Table 17 summarizes the field capacity estimates along with the results from each of the five alternate models. The field capacity measure used in the comparison is the average discharge flow for all days of data collection (both left- and right-lane closures) excluding the rain events. As shown, the field data were best approximated by the FDOT BD 545-51 operations model. CORSIM's results were also fairly close to the field values (within 2% of the field observations). It should be noted that the FDOT BD 545-51 models were developed based on CORSIM, but the scenarios simulated assumed all passenger cars in the traffic stream; the method then adjusted the capacity when trucks were present using Passenger Car Equivalency (PCE) values developed specifically for trucks on work zones (FDOT BD 545-51 Final Report). Thus the small discrepancy between the two models is probably due to the differences in handling truck presence through the work zone.

Table 17: Differences Between Field Data, CORSIM, HCM 2000, and the Existing FDOT Lane Closure Methodology

	Capacity	**Difference**	**% Difference**
Field	4013	-	-
FDOT BD 545-51 Operations	4046	33	0.8%
FDOT BD 545-51 Planning	3660	-353	-8.8%
CORSIM	3932	-81	-2.0%
HCM 2000	3440	-573	-14.3%
FDOT	3600	-413	-10.3%

6. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A previous FDOT project (FDOT BD 545-51), titled "Impact of Trucks on Arterial LOS and Freeway Work Zone Capacity," developed analytical models for estimating the capacity of freeway work zones based entirely on simulated data. Simulation was used because there were no freeway work zone field data available at the time. The models developed estimate the capacity of various freeway work zone configurations as a function of prevailing traffic, design, environmental, and work zone characteristics. As that project was nearing completion, it was determined that field data could be obtained from a recently installed freeway work zone along I-95 in Jacksonville, Florida, using the Jacksonville Traffic Management Center (TMC) cameras. Therefore this project was initiated to collect field data and based on these re-calibrate the models formulated using simulation.

The following were concluded from the research:

- The average discharge flow had the smallest standard deviation of all the capacity parameters. The other three parameters showed higher variability.

- The average per lane discharge flow (i.e., capacity during congested conditions) at the study site under good weather conditions was found to be 4013 vph, or 2,007 vphpl.
- Rainy conditions reduced the average discharge flow in the work zone by 10-29 percent; heavy rain had a much greater impact on capacity than moderate rain.
- There was no significant difference in the work zone capacity between a left- and a right-lane closure.
- CORSIM appears to over-predict the pre-breakdown flow, while the differences for the remaining three capacity measures are relatively low. With respect to lane utilization, CORSIM does not predict very accurately the percent of traffic on each lane, and it does not have the flexibility to allow the user to enter these as inputs into the simulation for a particular site.
- An operations and a planning model were developed under FDOT BD 545-51. That project defined capacity as the average discharge flow based on the CORSIM output. Therefore, that capacity measure from the field data was compared to the results provided by the two models. It was concluded that the operations model can reasonably predict the capacity of the work zone, while the planning model under-predicts it. The effect of rain is not captured well by either of these models. The existing FDOT lane analysis method underestimated the discharge flow for that site by approximately 10 percent.

The following are recommended:

- The operations model from FDOT BD 545-51 provided good estimates of the discharge flow for this site over several days of observation. Since the data were collected only at one site, the model should be evaluated in future freeway construction sites, and adjusted if necessary based on additional field data, before it is officially adopted.
- The planning model from FDOT BD 545-51 may also be further tested in future construction sites; however it does not seem to provide results as close as those of the operations model.

- As additional data are gathered, it may be possible to develop and apply a "Rain Factor" in traffic operations applications around work zones.

The following recommendations are provided regarding possible improvements to CORSIM with respect to freeway work zone simulation:

- The software should consider developing algorithms specifically applying to work zones, and replicating the use of taper sections.
- Guidance should be provided regarding the use of the "rubbernecking" factor and its relationship to worker and equipment presence in the work zone.
- Various geometric elements (such as lane width and shoulder width) are currently not considered within CORSIM. Its algorithms should be modified to consider such factors generally, as well as with respect to work zones.

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