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Evaluation of Work Zone Enhancement Software Programs

Prepared for the
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Organizational Results

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The opinions, findings, and conclusions expressed in this publication are those of the principal investigators and the Missouri Department of Transportation. They are not necessarily those of the U.S. Department of Transportation, Federal Highway Administration. This report does not constitute a standard or regulation.

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16. Abstract The Missouri Department of Transportation (MoDOT) is looking for software tools that can assist in developing effective plans to manage and communicate work zone activities. QuickZone, CA4PRS, VISSIM, and Spreadsheet models are the tools that MoDOT is particularly interested in. These tools quantify the travel delays and hence can be used to plan, design, and schedule the work activity so as to minimize those delays. In this report, the findings of a research project on evaluating the four identified work zone tools are presented. Based on the results of a literature review, state DOT survey, and case studies conducted in this project, recommendations were made for the most appropriate tool for different work zone configurations. The study recommendations are: 1) For rural interstates, divided roadways, and multilane undivided highways in Missouri the Spreadsheet model developed in this study should be used, 2) For work zones in urban areas where lane closures on a roadway may impact the traffic on neighboring roadways, the use of VISSIM is recommended. It is also suggested that the driver behavior parameters in VISSIM be selected from the calibration charts developed in this study to obtain field capacity values, 3) For a two way one lane work zone with flagger operation, Quick Zone and VISSIM are recommended.			
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EXECUTIVE SUMMARY

The Missouri Department of Transportation (MoDOT) is interested in improving their management of work zones. One of the efforts is to look for tools (software) that can assist in developing effective plans to manage and communicate work zone activities. QuickZone, CA4PRS, VISSIM, and Spreadsheet models are the tools that MoDOT is particularly interested in. This research effort is geared towards the goal of identifying appropriate analytical tools for different types of work zones. These tools quantify the travel delays and hence can be used to plan, design, and schedule the work activity so as to minimize those delays. This information can also be used to help the construction programming and planning staff evaluate and compare different alternatives that can reduce user delay, queue length, user costs, and improve work zone safety for the traveling public and the workers.

In this report, the findings of a research project on evaluating the four identified work zone tools are presented. Based on the results of a literature review, state DOT survey, and case studies conducted in this project, the following recommendations were made for the most appropriate tool for different work zone configurations. These recommendations take into account the accuracy of results, the ease-of-use, the input data requirements, output options and interpretation of results.

- For rural interstates (two lanes in each direction), divided roadways, and multilane undivided highways in Missouri the Spreadsheet model should be used to estimate the traffic impacts of work zone lane closures. The alternative tools that may be considered (in descending order of priority) are CA4PRS, VISSIM, and Quick Zone.
- For work zones in urban areas where lane closures on a roadway may impact the traffic on neighboring roadways in the urban network, the use of VISSIM simulation program is recommended. It is also recommended that the users modeling work zones in the VISSIM program select the driver behavior parameters from the calibration charts developed in this study for obtaining field observed capacity values.
- For a two-way one-lane work zone with flagger operation, Quick Zone should be evaluated as the first option. In situations with high input volumes and/or the unavailability of detour routes Quick Zone will not give results for MoDOT's capacity value of 600 vehicles per hour per lane. The use of VISSIM program is recommended in such situations.

TABLE OF CONTENTS

List of Figures	ii
List of Tables	ii
Introduction.....	1
Literature Review and Survey of State DOTs	1
Methodology	4
Customization	9
Case Studies	18
Results and Discussion (Evaluation)	22
Recommendations.....	24
References.....	25

LIST OF FIGURES

Figure 1. Screenshot of the developed custom spreadsheet.....	7
Figure 2. Layout of data collection points for 2 to 1 (top) and 3 to 2 (bottom) work zone lane configurations.....	10
Figure 3. Lane distribution at 1000 ft upstream of taper for 5% trucks in a 2 to 1 lane.	15
Figure 4. Lane distribution at 1000 ft upstream of taper for 15% trucks in a 2 to 1 lane.	15
Figure 5. Lane distribution at 1000 ft upstream of taper for 20% trucks in a 2 to 1 lane.	16
Figure 6. Lane distribution at 1000 ft upstream of taper for 5% trucks in a 3 to 2 lane.	16
Figure 7. Lane distribution at 1000 ft upstream of taper for 15% trucks in a 3 to 2 lane.	17
Figure 8. Lane distribution at 1000 ft upstream of taper for 20% trucks in a 3 to 2 lane.	17
Figure 9. Layout of the first case study on I-44.....	18
Figure 10. Hourly traffic volumes for the I-44 case study.....	19
Figure 11. Layout of the second case study on I-70	19
Figure 12. Hourly traffic volumes for the I-70 case study.....	20
Figure 13. Layout of the third case study on US-63	20
Figure 14. Hourly traffic volumes (Tuesday) for the US-63 case study.....	21

LIST OF TABLES

Table 1. Parameter Combinations for 2 to 1 Lane Configuration.....	11
Table 2. Parameter Combinations for 3 to 2 Lane Configuration.....	13
Table 3. Performance measure values for the first case study on I-44	23
Table 4. Performance measure values for the second case study on I-70.....	23
Table 5. Performance measure values for the third case study on US 63.....	23

INTRODUCTION

Road construction, rehabilitation, and maintenance activities necessitate lane closures for the duration of work activity. The reduced capacities resulting from lane closures often lead to travel delays, queues, and increased travel times. It is estimated that more than 3000 work zones are present on the US National Highway System (NHS) during the peak construction season every year. For every 100 miles driven on the NHS motorists are likely to experience one active work zone. Twenty four percent of the non-recurring delay on freeways is attributed to work zones (FHWA, 2008). State departments of transportation (DOTs) continuously strive to lower the impacts of work zones on motorists through improved planning, scheduling, and operating mechanisms.

The Missouri Department of Transportation (MoDOT) is interested in improving their management of work zones. One of the efforts is to look for tools (software) that can assist in developing effective plans to manage and communicate work zone activities. QuickZone, CA4PRS, VISSIM, and Spreadsheet models are the tools that MoDOT is particularly interested in. This research effort is geared towards the goal of identifying appropriate analytical tools for different types of work zones. These tools quantify the travel delay and user costs and hence can be used to plan, design, and schedule the work activity so as to minimize the user costs. This information can also be used to help the construction programming and planning staff evaluate and compare different alternatives that can reduce user delay, queue length, user costs, and improve work zone safety for the traveling public and the workers.

In this report, the findings of a research study on evaluating the four identified work zone tools are presented. The following tasks were conducted to accomplish the study purpose. First, a literature review of past studies that used one or more of these tools to quantify work zone traffic impacts was conducted followed by a state-of-practice survey of six state DOTs. The features of each tool such as the input data requirements, output options, performance measure computation methods, etc, were analyzed in the next step. Case studies of three facilities: I-44 (3 to 2 lane), I-70 (2 to 1 lane), and US-63 (2 way 2 lane), were then performed. A Spreadsheet model was developed and customized for Missouri traffic conditions. And, recommendations were made on the choice of tool for different lane closure configurations.

LITERATURE REVIEW AND SURVEY OF STATE DOTs

A literature search of the existing work zone software tools and the practices of five other state agencies was conducted. The current practices in Ohio, Illinois, Minnesota, Texas, and Florida DOTs were reviewed. In addition, the spreadsheet applications used by California, Virginia, and New Jersey DOTs were also obtained and analyzed. The search focused on identifying, 1) the software or programs used by the states for enhancing work zones, 2) the input data requirements of the software, 3) output capabilities of the software, and 4) the calibration/customization of software parameters needed to implement in Missouri. This task also investigated the level of success attained by the states in using the software to enhance work zone operations in terms of the reported, 1) accuracy of travel time predictions, 2) traffic delays and associated user cost predictions, 3) estimated queue lengths, 4) cost savings by state (due to the use of software), and 5) ease of analysis and deployment. This section presents the findings of this task.

Literature Review

Highway Capacity Software (HCS), Synchro, CORSIM, NetSim, QUEWZ 92, and the Ohio DOT custom spreadsheet were used to estimate the capacity and queue length at four work zones on multilane freeways in Ohio (Schnell et al, 2002). The results were also compared with the field data. The simulation models could not be calibrated for oversaturated conditions that existed at the work zones, and even after calibration, these models consistently underpredicted the queue lengths. QUEWZ 92 was the most accurate in estimating the work zone capacity. When this capacity estimate was used in the Ohio DOT custom spreadsheet, it produced the most realistic estimates of queue lengths as compared to the estimates from other tools.

Chitturi and Benekohal (2004) compared the performance of QUEWZ 92, FRESIM, and QuickZone with field data at 11 freeway work zone locations in Illinois. Some of these work zones did not have queues. The results of the study showed that none of these models gave an accurate representation of real field conditions. QUEWZ 92 overestimated the capacity and underestimated the queue lengths, mainly because of its use of an outdated speed-flow relationship. FRESIM consistently overestimated the speeds under queuing conditions, overestimated the queue lengths for half of the cases, and underestimated the queue lengths for the other half of the cases. QuickZone consistently underpredicted the queue length and delay as compared to the field data.

Kim et al. (2001) developed a multiple regression model to estimate the capacity at work zones as a function of several key independent variables such as number of closed lanes, percentage of heavy vehicles, grade, and work intensity. To develop this model they collected data at 12 work zone sites in Maryland. They found that their regression model produced better estimates as compared to the HCM model. This model was later incorporated into Maryland's customized QuickZone model.

State DOT Survey

Texas

Texas DOT uses FREQ, HCS, CORSIM, and PASSER software programs to evaluate the impacts of work zones. The choice of software depends on the work zone configuration. Spreadsheets are used for capacity addition projects on all roads except urban arterials and urban freeways. They are also used for new facilities, paving projects with no capacity increases, bridge replacements, and detour routing. PASSER program is used for urban arterial roadways with signalized intersections, diamond interchanges, etc. For high impact urban freeway construction or rehabilitation projects, that involve capacity reductions, FREQ, HCS, or CORSIM is their preferred software.

Research recommendations on the use of QuickZone and CA4PRS made in a recently completed Texas Transportation Institute (TTI) study (Ding et al., 2008) will be used in the future impact assessments of work zones. The study also recommended updated work zone capacities on urban freeway locations in Texas that are currently being used by some districts.

Maryland

The Maryland State Highway Administration (SHA) uses QuickZone as the main tool to estimate traffic impacts of work zones. The tool is customized to include analysis components specific to Maryland. A simpler version of the tool called the 'Lane Closure Analysis Program (LCAP)' is also used for simple work zone configurations. The choice of tool varies with the work zone configuration. Work zones on arterials or interstates that do not involve any signalized intersections are analyzed using QuickZone or LCAP. For two-lane roadways with flagging operations, the CORSIM simulation program with sufficient parameter calibration is used. The lane capacity value is customized in all tools.

The level of satisfaction of SHA staff was very high in terms of accuracy of travel times, traffic delays, and estimated queue lengths. Although, the user costs could not be accurately estimated through the tools, the basic data determined from these tools was reported to be satisfactory. The potential cost savings to the state were also acknowledged.

The software requirements in terms of input data was reported to depend on the facility and scenario being analyzed with more complex projects making it more challenging. Output capabilities and calibration of parameters were found to be relatively easy.

Florida

Florida DOT uses a customized spreadsheet program (Florida DOT, 2008) to evaluate work zone impacts for any work zone configuration. The amount of traffic diversion onto alternate routes, expressed as a percentage of the total traffic volume, is customized to match the observed field values. The level of satisfaction in terms of using the program was reported to be good. The program input requirements and output capabilities were deemed to be less challenging compared to the calibration and customization requirements.

Ohio

Ohio DOT reported the use of a customized excel spreadsheet with input capacity values determined by the QUEWZ program. The choice of software does not vary with the work zone configuration. The lane capacity value and amount of traffic diversion to alternate routes are customized to match field values observed in Ohio. The QUEWZ program has produced good estimates of queue lengths in the past, however, since the software is no longer maintained Ohio DOT is looking for alternatives for the future. A low level of satisfaction was reported for the accuracy of estimated traffic delays and associated user cost predictions. In terms of input data requirements, output capabilities, and calibration needs, the spreadsheet program was reported to be user friendly and easy to use.

Minnesota

A survey of different districts within Minnesota DOT was conducted. The survey revealed that the Metro district consisting of St. Paul and Minneapolis had the most experience with work zone impact assessment for high volume roadways. It was mentioned that a customized spreadsheet was occasionally used. Custom data analysis tools for reading and summarizing historic and real-time traffic data were developed and used by the Metro district. These tools were believed to produce better results than the other commercially available software by

providing a factual record of impacts of different traffic control plans used in the past. The traffic reports are obtained in real-time by the traffic management center to analyze the effects of lane closures.

In other districts, the assessment of work zone impacts was done primarily based on past experience and knowledge of the staff. Traffic volume data collected bi-annually or for specific projects is used along with predefined threshold capacity values while determining appropriate traffic control plans. One of the districts also mentioned using SYNCHRO software.

Illinois

Work zone analysis in Illinois DOT is conducted by district personnel and consultants leading to a variety of tools being used. These tools include, observation and prior experience with similar work zones, a customized excel spreadsheet that performs HCM analysis, QuickZone, and SYNCHRO. The choice of software does not vary by work zone configuration. The lane capacity value and amount of traffic diversion are customized by the staff for these tools. The estimated values were reported to be generally accurate for travel times, traffic delays, and queue lengths. However, it was mentioned that the analysts were generally dissatisfied with the 'ease of use' of these tools. In particular, QuickZone was found to be cumbersome in terms of data input, output, and calibration.

METHODOLOGY

In this section, three popular work zone traffic analysis programs are reviewed: 1) QuickZone (FHWA, 2005), CA4PRS (UC-Berkeley, 2006), and VISSIM (PTV, 2008). A new spreadsheet program that was developed in this project is also described. The input requirements, output options, and other features of each program are presented in detail.

QuickZone (Version 2.0)

QuickZone is a Microsoft Excel based software that is easy to use for users familiar with Excel and its applications. All the worksheets and code modules of QuickZone are password protected to make sure that the user does not alter any key system elements. The current version (Version 2.0) is an updated version of QuickZone in which program developers enhanced the software by introducing features such as network editor, modeling of two way one lane operation with flagging operations and more detailed analysis of user cost estimation. The introduction of network editor made it very easy to draw road networks and enter inputs into QuickZone. Building of networks, mainly composed of nodes and links, is further simplified with the option of drawing the network layouts on top of imported background images.

Network Editor

Road networks can be created by drawing nodes and links in the network editor. Road segments are represented by links and the ends of a link are represented by nodes. After creating the network, properties are assigned to each link. Link properties include information such as the number of lanes, free flow speed, link length, link orientation (inbound or outbound), link category, etc. The network created in the network editor can then be opened in QuickZone with all the link properties intact. The link properties are also accessible in QuickZone for the user to update any values.

QuickZone User Interface

The main interface of QuickZone consists of four menus: 1) Input data, 2) Program control, 3) Output data, and 4) Save/Open. A detailed discussion of each of the menus follows.

Input data

In order to estimate delay and user costs, the user has to enter data for input variables such as demand, value of time of users (both passenger cars and trucks), truck percentage, demand patterns, K-values, passenger car equivalent (PCE) values, and work zone capacity. This information is entered in the input data menu on the main screen. The input data menu is further divided into nine modules.

- a) Nodes module - The coordinates of all nodes are defined in this module. This data is usually read automatically from the network editor. However, there is an option to manually enter the coordinates or to make any changes to the network editor imported data.
- b) Links module - Similar to the nodes module, information describing link properties is automatically read from the network editor. Any changes to the properties can be made in the links module.
- c) Inbound demand patterns/Outbound demand patterns - The daily demand distribution factors (K values) are first entered based on the average daily traffic (ADT) values for different days of the week. The detailed procedure to compute K values is provided in the program manual. When such detailed data is not available, a value of 1 is entered for all days indicating a uniform distribution of demand over all days of the week. Next, the hourly demand pattern for each day of the week is entered in the demand module.
- d) Demand module - The desired inputs for the demand module would be the hourly demand patterns for both passenger cars and trucks. When such detailed data is not available, users can enter the AADT values for every link which will be converted into hourly patterns by QuickZone using the HCM procedure. Another key demand input is the passenger car equivalent (PCE) value for trucks which is used in the delay and user cost calculations.
- e) Seasonality demand - Seasonal variations in demand can be entered as monthly percentages. The default seasonal pattern is derived from the HCM and can be used when actual data is not available.
- f) Project information – All project related information is entered in this input module including the project duration, presence of a detour, percentage of traffic diversion, and yearly capacity reduction and demand increase.
- g) Construction phase data – Projects are usually divided into smaller construction phases. In QuickZone a phase represents construction activity during a time period (minimum one week).
- h) User and economic costs – Values of time of users and other economic costs are used by QuickZone to compute the user costs. The program provides an option to use default values when such data is not available to the user.

Program control

The program control menu allows the users to execute the QuickZone program. First, data and model checks are performed using the 'generate network' option. Any errors will be shown as warning messages. The 'calculate phase data' option estimates the delay and user costs using the in-built algorithm for baseline (without work zones) and after+baseline (with work zones).

Output data

Two main output formats are provided – 1) graphical and 2) summary tables. Delay graphs can be plotted by phase or by work zone. Queue length and travel times can also be plotted versus time. Summary tables provide data on maximum queue lengths, maximum delays, and total project user costs for both baseline (no work zone) and after conditions.

Construction Analysis for Pavement Rehabilitation Strategies (CA4PRS)

CA4PRS is a traffic analysis tool developed by University of California – Berkeley for California Department of Transportation for scheduling construction activity based on the estimated construction and traffic delay costs. The tool is primarily focused on costs of different construction strategies and the focus on traffic impact analysis (and costs) is very limited. Delays are estimated using the Highway Capacity Manual's (2000 edition) methodology of demand versus capacity analysis.

In this project, only the traffic impact analysis procedure in CA4PRS was evaluated. The user interface for the traffic impacts modules consists of the following five options.

- 1) Before construction: Geometric and traffic control characteristics of the actual roadway segment (without a work zone) such as the posted speed limit, number of lanes, and direction of traffic are entered in this module.
- 2) During construction: Information on reduced speed limits, length of the work zone segment, duration on lane closure, and number of lane closures by direction are entered in this module.
- 3) Traffic inputs: The hourly traffic counts in both directions are the main traffic inputs for delay estimation. If hourly traffic demand is not available, AADT values can be entered which will be converted into hourly counts using California's historical hourly patterns. Four different historical patterns are available to choose from: urban weekdays, urban weekends, rural weekdays, or rural weekends. Data on annual traffic growth rate, percentage traffic diversion to detour routes, and lane closure charts are also inputted.
- 4) Unit costs and capacity: Costs per vehicle-hour of delay for trucks and cars are necessary for calculating the total user costs for the duration of the work zone. Truck percentages are input in this module. Lane capacity values for before construction and during construction are also specified.
- 5) Outputs: The results of traffic impacts analysis are shown in an output window. The outputs include values for average queue length, maximum delay per vehicle, and user costs per closure by direction.

Spreadsheet

A custom spreadsheet program was developed by the investigators to estimate the traffic impacts of work zones. To do this, first, the spreadsheet programs developed and used by a few state DOTs were obtained and analyzed. The review included spreadsheets from the following DOTs: California, Virginia, New Jersey, Ohio, Florida, and Illinois. Several features including the input requirements, output options, impact assessment algorithm, cost estimation, etc were analyzed. Then, a new spreadsheet that reflects MoDOT's capacity values was developed.

The developed spreadsheet uses the delay calculation procedure based on the demand-capacity model of the Highway Capacity Manual. The main intent behind developing a new spreadsheet was to be able to easily customize it to Missouri conditions. One of the main objectives of this effort was to minimize the user input requirements to allow for a quick estimation of the impacts. The spreadsheet needs the following inputs: 1) the total number of lanes and the number of open lanes, 2) the hourly traffic volumes and truck percentages for each day of the week, 3) the start time and total duration of lane closure, 4) users value of time costs (optional), 5) the base capacity values for normal conditions (a default value of 1600 vphpl can be used when no data is available).

It is not required for the user to enter the reduced work zone capacity values as input. An in-built function automatically calculates the capacity values based on MoDOT's work zone guidelines document (MoDOT, 2004). A screenshot of the spreadsheet is shown in Figure 1 below.

The maximum delay, average delay, and user costs are computed based on the user inputs. Graphical representations of delay versus time and queue length versus time are also obtained as outputs.

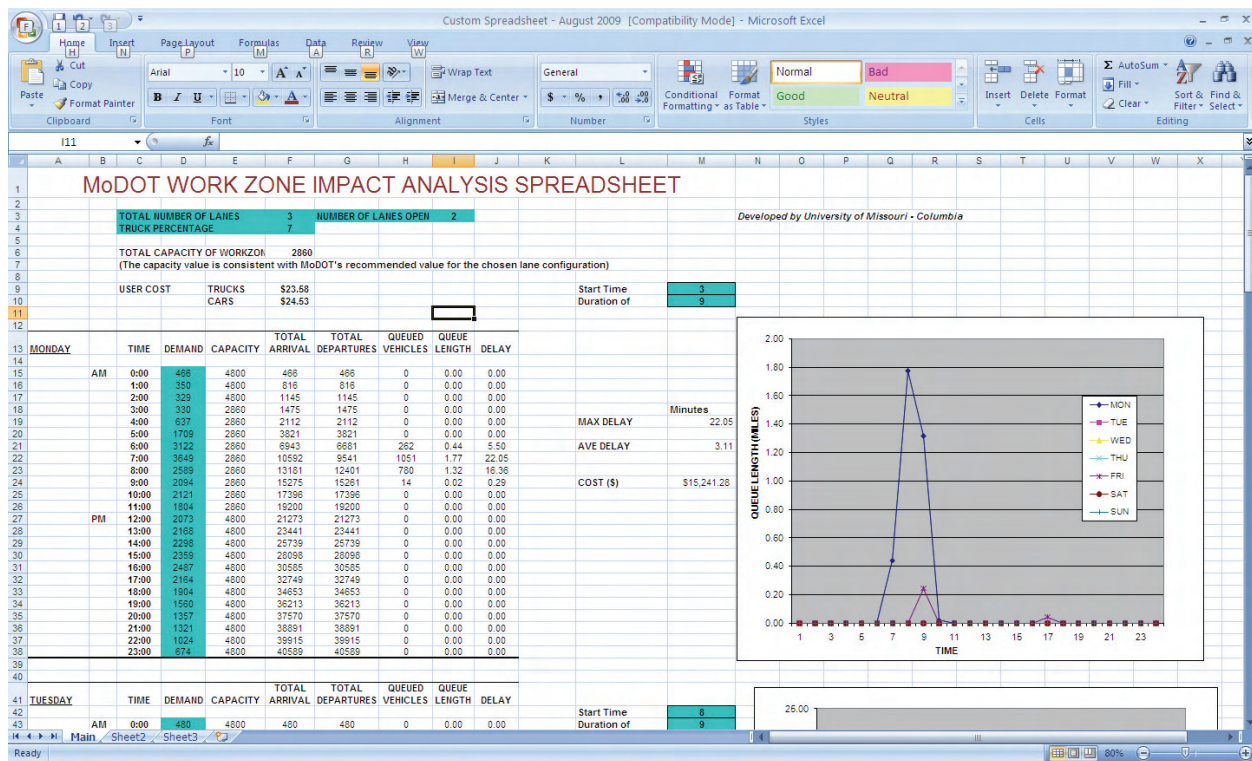


Figure 1. Screenshot of the developed custom spreadsheet

VISSIM Simulation Program

Traffic simulation tools are being increasingly adopted by DOTs for various traffic analysis studies, including assessing work zone traffic impacts. This is due, in part, to their ability to model individual vehicle and driver behavior at a highly detailed level to assess the traffic performance. In order to accurately use the simulation models for traffic analysis of work zones, it is necessary to calibrate the models to match the field conditions (such as lane capacity and queue lengths) by adjusting the driving behavior parameters. In this project the VISSIM microscopic simulation program is used.

VISSIM is a microscopic, stochastic, discrete time-step based simulation where individual vehicles represent the most basic elements of the simulation. It is based on the Wiedemann “psycho-physical” car-following model and lane changing model. The characteristics and behavior of individual vehicles (and drivers) affect performance measures such as speed, throughput, and queue length. One goal of the user of the simulation is to try to duplicate the field performance measures using simulation. The car-following model that represents freeway conditions, Wiedemann 99 car following model (W-99), has 10 user defined driving behavior parameters: $CC0$, $CC1$, $CC2$..., $CC8$, $CC9$ (PTV America, 2008). In the model, the driver can be in one of four driving modes: Free driving, Approaching, Following, and Braking. In W-99 a driver either accelerates or decelerates to change from one driving mode to other as soon as some threshold value expressed in terms of relative speed and distance is reached. Thus the whole car following process is based on repetitive acceleration or deceleration of individual vehicles with drivers having different perceptions of speed difference, desired speed, and the safety distance between two successive vehicles. Here is a brief description of the 10 driving behavior parameters used in W-99 car following model.

$CC0$ is the standstill distance which defines the desired distance between two consecutive vehicles at stopped condition. The default value is 4.94 ft.

$CC1$ is the desired time headway for the following vehicle. Based on these values the safety distance can be computed as $dx_{safe} = CC0 + CC1 * v$, where v is the speed of the vehicle (PTV, 2007). The default value is 0.9. Higher $CC1$ values characterize less aggressive drivers.

$CC2$ defines the threshold that restricts longitudinal oscillation beyond safety distance in a following process. The default value is approximately 13 ft.

$CC3$ characterizes the entry to the “following” mode of driving. It initiates the driver to decelerate upon recognizing a slower leading vehicle. It defines the time at which the driver starts to decelerate before reaching the safety distance.

$CC4$ and $CC5$ control the speed oscillations after the vehicle enters the “following” mode of driving. Smaller values represent a more sensitive reaction of the driver to the acceleration or deceleration of the leading vehicle. $CC4$ is used for negative speed difference and $CC5$ is used for positive speed difference. The default value of $CC4/CC5$ is -0.35/0.35.

$CC6$ represents dependency of speed oscillation on distance in the “following” state. Increased value of $CC6$ results in an increase of speed oscillation as the distance to the preceding vehicle increases. $CC7$, $CC8$, and $CC9$ parameters control the acceleration process.

The lane changing model in VISSIM is based on the driver response to the perception of the surrounding traffic. It uses gap acceptance criteria where driver changes lanes provided the available gap is greater than the critical gap. The decision to change lanes depends on the following hierarchical set of conditions: the desire to change lanes, favorable driving conditions in the neighboring lanes, and the possibility to change lanes (gap availability). Based on these conditions the lane changing phenomenon is broadly classified into two types: 1) discretionary lane change which includes drivers who want to change from slow moving lanes to fast moving lanes and, 2) necessary lane change in case of any lane closure due to work zones, incidents, etc. A detailed description of the lane changing algorithm is presented in Wiedemann and Reiter (1992).

Necessary lane changes depend on the aggressiveness of drivers in accepting/rejecting gaps in the adjacent lanes that is represented by parameters such as acceptable and threshold deceleration values of lane changing and trailing vehicles, and the safety distance reduction factor (called *SRF*). The safety reduction factor refers to the reduction in safety distance (dx_{safe}) to the trailing and leading vehicle on the desired lane and the safety distance to the leading vehicle in the current lane. The default value of *SRF* is 0.6 which means the safety distance during lane changing is reduced by 40%. A lower *SRF* value (say 0.4) would mean that the safety distance for lane changing is reduced by 60% meaning the drivers have become more aggressive in accepting shorter gaps.

CUSTOMIZATION

The input capacity values in the work zone analysis tools are highly critical to the accuracy of estimated performance measures. The capacity values can be obtained by measuring the actual traffic flows at work zones. In this project, field data was collected for Interstate 70 at four work zone sites in the city of Columbia during the summer of 2009. All work activity was conducted during night time (7:00 PM onwards) with one lane closed and one lane open to traffic. Capacity value, defined as the 15 minute sustained flow rate (vehicles per hour), was derived from the high resolution video data (that recorded time stamps of every vehicle). The capacity values expressed in vehicles per hour per lane were observed to be 1172, 1268, 1420, and 1252 at the four sites. These values compare favorably to the 1240 value listed in the MoDOT work zone policy guide. The unavailability of suitable sites for other lane closure configurations during the project timeline did not allow for collecting field data for those configurations. The values recommended by the policy guide may be used until field data becomes available in the future.

Analysis tools such as QuickZone, CA4PRS, and custom spreadsheet models, use a deterministic queuing model to compute the queue lengths (procedure documented in the HCM 2000.) The core input for the analytical tools is the value of lane capacity. On the other hand, traffic simulation tools arrive at the queue lengths based on car following and lane changing models. Unlike the analytical tools, capacity is not a direct input to the micro simulation models; it is a measure that is a result of driver behavior.

In traffic simulation capacity is not an input parameter; it is derivative of the driving behavior parameters. In order to obtain the driving behavior parameters that reproduce field capacity values, a thorough simulation customization exercise was conducted for VISSIM. The proportion of right lane traffic to the total through traffic, also called lane distribution, is obtained at four locations upstream of the taper (labeled as points 2, 3, 4, and 5 in Figure 2). A driving behavior

scenario is defined as a set of CC1, CC2, and SRF parameters. The capacity value for each driving behavior scenario was plotted against the proportion of right lane traffic at 1000 ft upstream of the beginning of taper (location 2).

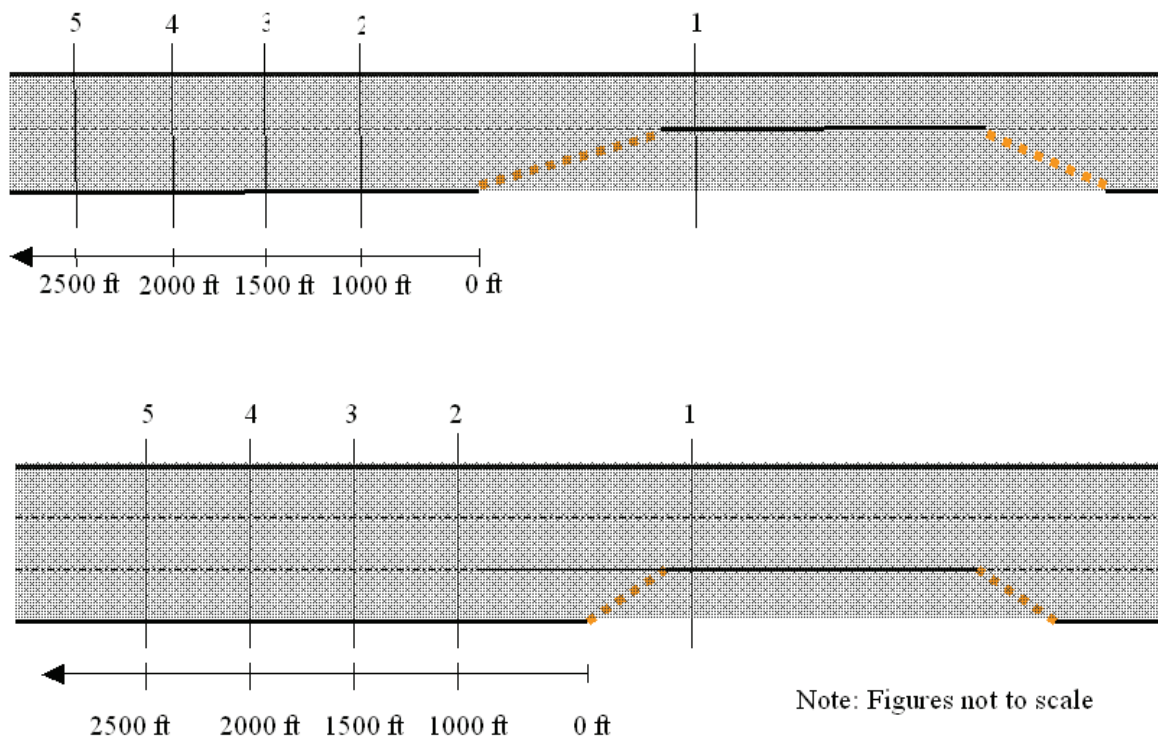


Figure 2. Layout of data collection points for 2 to 1 (top) and 3 to 2 (bottom) work zone lane configurations.

For the 2 to 1 lane configuration, these plots are shown in Figures 3, 4, and 5. The data labels in the figures correspond to parameter sets that are listed in Table 1. The respective plots for the 3 to 2 lane configuration are shown in Figures 6, 7, 8, and Table 2. An illustrative example of how to use these charts follows. Let us consider a 2 to 1 work zone site for which the lane distribution of 11% at 1000 ft from the taper and a capacity of 1550 vphpl were observed. The truck percentage was found to be approximately 5%. In Figure 3 the parameter set that corresponds to the data in this example is number 19. From Table 1, the parameter values can be read for this set number 19 as 1.4, 40, and 0.55 for *CC1*, *CC2*, *SRF* parameters respectively.

The application of this customization exercise can be best explained using a hypothetical example. Assume that some maintenance work is scheduled on I-70 between St. Louis and Kansas City that requires a lane closure from two lanes to one. Also assume that MoDOT has historical truck percentage values from count stations, an estimate of typical lane distribution from previous experience, and the expected capacity from the work zone policy guide or field data. Figures 3 through 5 and Table 1 then give the three parameter values for simulating the work zone section. Thus, MoDOT is able to simulate I-70 over various times of the day and various demand levels and determine potential queue lengths and delays. Decisions concerning the scheduling of the work zone (e.g. day vs. night, peak vs. off-peak) could be made based on the simulation results.

Table 1. Parameter Combinations for 2 to 1 Lane Configuration

Index	CCI	CC2	SRF	Index	CCI	CC2	SRF	Index	CCI	CC2	SRF
1	1.8	55	0.6	43	1	40	0.55	85	1.7	20	0.3
2	1.8	45	0.6	44	1.2	30	0.4	86	1.6	25	0.4
3	1.8	45	0.55	45	1.2	30	0.35	87	1.8	15	0.2
4	1.8	45	0.5	46	1.3	25	0.25	88	1	55	0.5
5	1.7	45	0.6	47	1.4	15	0.2	89	1	55	0.55
6	1.7	45	0.55	48	1.4	15	0.15	90	1.2	45	0.5
7	1.7	45	0.5	49	1.1	30	0.4	91	1.2	45	0.55
8	1.6	45	0.6	50	1	35	0.4	92	1.6	20	0.3
9	1.6	45	0.55	51	1	35	0.35	93	1.7	15	0.2
10	1.6	45	0.5	52	1	35	0.3	94	1	50	0.45
11	1.5	45	0.6	53	1.3	15	0.15	95	1	50	0.5
12	1.5	45	0.55	54	1	30	0.25	96	1.1	45	0.5
13	1.5	45	0.5	55	1	25	0.35	97	1.5	20	0.3
14	1.4	45	0.6	56	1	25	0.3	98	1	45	0.4
15	1.4	45	0.55	57	1	25	0.25	99	1	45	0.45
16	1.4	45	0.5	58	1	25	0.2	100	1	45	0.5
17	1.4	45	0.45	59	1	25	0.15	101	1.3	30	0.35
18	1.8	15	0.2	60	1.1	15	0.15	102	1.4	25	0.3
19	1.4	40	0.55	61	1	20	0.2	103	1.4	20	0.3
20	1.4	40	0.5	62	1	20	0.15	104	1.5	15	0.2
21	1.4	40	0.45	63	1.8	55	0.55	105	1	40	0.4
22	1.4	40	0.4	64	1.8	55	0.6	106	1	40	0.45
23	1.5	30	0.45	65	1.8	45	0.6	107	1.2	30	0.35
24	1.4	35	0.5	66	1.7	45	0.5	108	1	40	0.5
25	1.4	35	0.45	67	1.6	50	0.6	109	1.1	35	0.45
26	1.4	35	0.4	68	1.7	45	0.6	110	1.5	15	0.15
27	1.4	35	0.35	69	1.4	55	0.55	111	1.3	20	0.3
28	1.6	20	0.3	70	1.4	55	0.6	112	1.4	15	0.2
29	1.4	30	0.45	71	1.5	50	0.6	113	1	35	0.45
30	1.5	25	0.35	72	1.6	45	0.6	114	1.1	30	0.4
31	1.5	25	0.3	73	1.4	50	0.5	115	1.1	30	0.25
32	1	55	0.55	74	1.3	55	0.6	116	1.2	20	0.25
33	1.6	15	0.2	75	1.4	50	0.6	117	1	30	0.25
34	1.6	15	0.15	76	1.8	25	0.4	118	1.2	20	0.15
35	1	50	0.55	77	1.2	55	0.55	119	1	30	0.3
36	1	50	0.5	78	1.2	55	0.6	120	1.1	25	0.25
37	1	50	0.45	79	1.3	50	0.6	121	1.2	20	0.2
38	1.2	35	0.5	80	1.7	25	0.4	122	1	25	0.35
39	1	45	0.55	81	1.1	55	0.55	123	1.1	20	0.2
40	1	45	0.5	82	1.1	55	0.6	124	1	25	0.3
41	1	45	0.45	83	1.3	45	0.55	125	1	25	0.15
42	1	45	0.4	84	1.8	15	0.15	126	1.1	20	0.15

Table continued on next page.

Index	CCI	CC2	SRF	Index	CCI	CC2	SRF	Index	CCI	CC2	SRF
127	1	20	0.15	151	1.4	40	0.45	175	1	45	0.4
128	1.8	50	0.6	152	1.2	50	0.6	176	1	45	0.45
129	1.6	55	0.6	153	1.4	40	0.5	177	1	45	0.5
130	1.7	50	0.6	154	1.3	45	0.6	178	1.3	30	0.35
131	1.5	55	0.6	155	1.5	35	0.5	179	1.1	40	0.5
132	1.8	35	0.5	156	1.7	20	0.3	180	1.6	15	0.15
133	1.7	40	0.6	157	1.6	25	0.4	181	1.4	20	0.3
134	1.7	35	0.4	158	1	55	0.5	182	1	40	0.45
135	1.7	35	0.45	159	1	55	0.55	183	1	40	0.5
136	1.5	45	0.6	160	1	55	0.6	184	1.5	15	0.15
137	1.6	40	0.55	161	1.4	35	0.4	185	1.3	20	0.3
138	1.7	35	0.5	162	1.1	50	0.6	186	1	35	0.4
139	1.7	30	0.3	163	1.3	40	0.5	187	1.1	30	0.35
140	1.8	25	0.25	164	1.4	35	0.45	188	1.2	25	0.3
141	1.5	40	0.45	165	1.5	30	0.4	189	1.1	30	0.25
142	1.7	30	0.35	166	1.6	20	0.3	190	1.3	20	0.15
143	1.4	45	0.55	167	1	50	0.45	191	1	30	0.35
144	1.6	35	0.45	168	1	50	0.5	192	1	30	0.25
145	1.4	45	0.6	169	1	50	0.55	193	1.2	20	0.15
146	1.6	35	0.5	170	1	50	0.6	194	1.2	15	0.15
147	1.8	20	0.3	171	1.1	45	0.55	195	1	25	0.3
148	1.7	25	0.4	172	1.2	40	0.5	196	1	25	0.15
149	1.4	40	0.4	173	1.4	30	0.4	197	1	20	0.15
150	1.1	55	0.6	174	1.5	20	0.3				

Table 2. Parameter Combinations for 3 to 2 Lane Configuration

Index	CCI	CC2	SRF	Index	CCI	CC2	SRF	Index	CCI	CC2	SRF
1	1.8	55	0.55	43	1.3	35	0.4	85	1.5	55	0.45
2	1.8	55	0.6	44	1.3	35	0.45	86	1.5	55	0.5
3	1.8	50	0.5	45	1.3	35	0.5	87	1.5	55	0.55
4	1.8	50	0.55	46	1.3	35	0.55	88	1.8	35	0.45
5	1.8	50	0.6	47	1.2	40	0.6	89	1.8	35	0.5
6	1.6	55	0.5	48	1.3	30	0.3	90	1.8	35	0.55
7	1.8	40	0.5	49	1.4	25	0.3	91	1.4	55	0.4
8	1.6	55	0.6	50	1.4	25	0.35	92	1.4	55	0.45
9	1.8	35	0.4	51	1.4	20	0.2	93	1.7	35	0.4
10	1.8	35	0.45	52	1.4	20	0.25	94	1.4	55	0.55
11	1.7	40	0.5	53	1	45	0.45	95	1.6	40	0.5
12	1.8	35	0.5	54	1	45	0.5	96	1.8	30	0.45
13	1.8	35	0.55	55	1	45	0.55	97	1.5	45	0.6
14	1.8	35	0.6	56	1	45	0.6	98	1.6	40	0.6
15	1.7	35	0.4	57	1.2	30	0.25	99	1.6	35	0.3
16	1.8	30	0.4	58	1.2	30	0.3	100	1.3	55	0.45
17	1.8	30	0.45	59	1.1	35	0.35	101	1.6	35	0.4
18	1.7	35	0.55	60	1.2	30	0.35	102	1.3	55	0.6
19	1.7	35	0.6	61	1.1	35	0.4	103	1.4	45	0.6
20	1.6	35	0.4	62	1.1	35	0.45	104	1.5	40	0.6
21	1.7	30	0.4	63	1.1	35	0.5	105	1.6	30	0.25
22	1.7	30	0.45	64	1	40	0.55	106	1.2	55	0.4
23	1.6	35	0.55	65	1.3	20	0.25	107	1.2	55	0.45
24	1.7	30	0.5	66	1	35	0.25	108	1.2	55	0.5
25	1.6	30	0.35	67	1	35	0.35	109	1.2	55	0.55
26	1.7	25	0.35	68	1.1	25	0.2	110	1.5	35	0.45
27	1.3	50	0.55	69	1.1	25	0.25	111	1.4	40	0.55
28	1.5	35	0.5	70	1	30	0.2	112	1.4	40	0.6
29	1.3	45	0.4	71	1	30	0.25	113	1.2	50	0.35
30	1.3	45	0.45	72	1	30	0.3	114	1.1	55	0.4
31	1.6	25	0.35	73	1	25	0.15	115	1.1	55	0.45
32	1.7	20	0.3	74	1	25	0.2	116	1.1	55	0.5
33	1.3	45	0.55	75	1.1	20	0.2	117	1.1	55	0.55
34	1.3	45	0.6	76	1	20	0.15	118	1.1	55	0.6
35	1.5	30	0.5	77	1.8	50	0.45	119	1.4	35	0.5
36	1.7	15	0.15	78	1.8	50	0.5	120	1.3	40	0.6
37	1.6	20	0.25	79	1.7	55	0.55	121	1.1	50	0.35
38	1.3	40	0.45	80	1.8	50	0.55	122	1	55	0.4
39	1.3	40	0.5	81	1.8	50	0.6	123	1	55	0.45
40	1.3	40	0.55	82	1.6	55	0.5	124	1	55	0.5
41	1.3	40	0.6	83	1.6	55	0.55	125	1	55	0.55
42	1.3	35	0.35	84	1.6	55	0.6	126	1	55	0.6

Table continued on next page.

Index	CCI	CC2	SRF	Index	CCI	CC2	SRF	Index	CCI	CC2	SRF
127	1.3	35	0.5	167	1.7	45	0.45	207	1.3	40	0.6
128	1.2	40	0.6	168	1.8	40	0.45	208	1.3	40	0.3
129	1	50	0.35	169	1.7	45	0.5	209	1.1	50	0.4
130	1.1	45	0.4	170	1.6	50	0.55	210	1.1	50	0.45
131	1.1	45	0.45	171	1.6	50	0.6	211	1.1	50	0.5
132	1	50	0.55	172	1.8	40	0.55	212	1.1	50	0.55
133	1	50	0.6	173	1.8	35	0.6	213	1.1	50	0.6
134	1.1	40	0.25	174	1.5	50	0.4	214	1.4	30	0.45
135	1.1	40	0.25	175	1.5	50	0.45	215	1.2	40	0.6
136	1	45	0.3	176	1.5	50	0.5	216	1.2	40	0.3
137	1	45	0.35	177	1.6	45	0.5	217	1.1	45	0.35
138	1.1	40	0.4	178	1.4	55	0.6	218	1.1	45	0.4
139	1	45	0.4	179	1.5	50	0.6	219	1.2	40	0.4
140	1	45	0.45	180	1.6	45	0.6	220	1.1	45	0.45
141	1	45	0.5	181	1.8	30	0.5	221	1.1	45	0.5
142	1.2	30	0.2	182	1.7	35	0.6	222	1	50	0.6
143	1.2	30	0.25	183	1.3	55	0.4	223	1.2	35	0.25
144	1.2	30	0.3	184	1.4	50	0.45	224	1.2	35	0.3
145	1.1	35	0.4	185	1.4	50	0.5	225	1.2	35	0.35
146	1	40	0.45	186	1.3	55	0.55	226	1	45	0.5
147	1	40	0.5	187	1.3	55	0.6	227	1	45	0.55
148	1.4	15	0.15	188	1.4	50	0.6	228	1.3	25	0.15
149	1.2	25	0.3	189	1.8	25	0.4	229	1.4	20	0.15
150	1	35	0.45	190	1.6	35	0.55	230	1.3	25	0.25
151	1	35	0.5	191	1.7	30	0.5	231	1.5	15	0.15
152	1	35	0.2	192	1.3	50	0.35	232	1.1	35	0.4
153	1	35	0.25	193	1.2	55	0.45	233	1	40	0.5
154	1.1	25	0.15	194	1.4	45	0.45	234	1	40	0.55
155	1.1	25	0.2	195	1.2	55	0.55	235	1.2	25	0.3
156	1	30	0.25	196	1.2	55	0.6	236	1	35	0.45
157	1	30	0.3	197	1.3	50	0.6	237	1	35	0.2
158	1	30	0.35	198	1.8	20	0.3	238	1	35	0.25
159	1	25	0.15	199	1.7	25	0.4	239	1.1	30	0.25
160	1	25	0.2	200	1.2	50	0.35	240	1	35	0.3
161	1	20	0.15	201	1.3	45	0.4	241	1	30	0.4
162	1.8	55	0.5	202	1.2	50	0.45	242	1.1	25	0.2
163	1.8	55	0.55	203	1.2	50	0.5	243	1	30	0.3
164	1.8	55	0.6	204	1.1	55	0.6	244	1	25	0.25
165	1.7	55	0.5	205	1.2	50	0.6	245	1	25	0.15
166	1.8	45	0.6	206	1.7	20	0.3	246	1	20	0.15

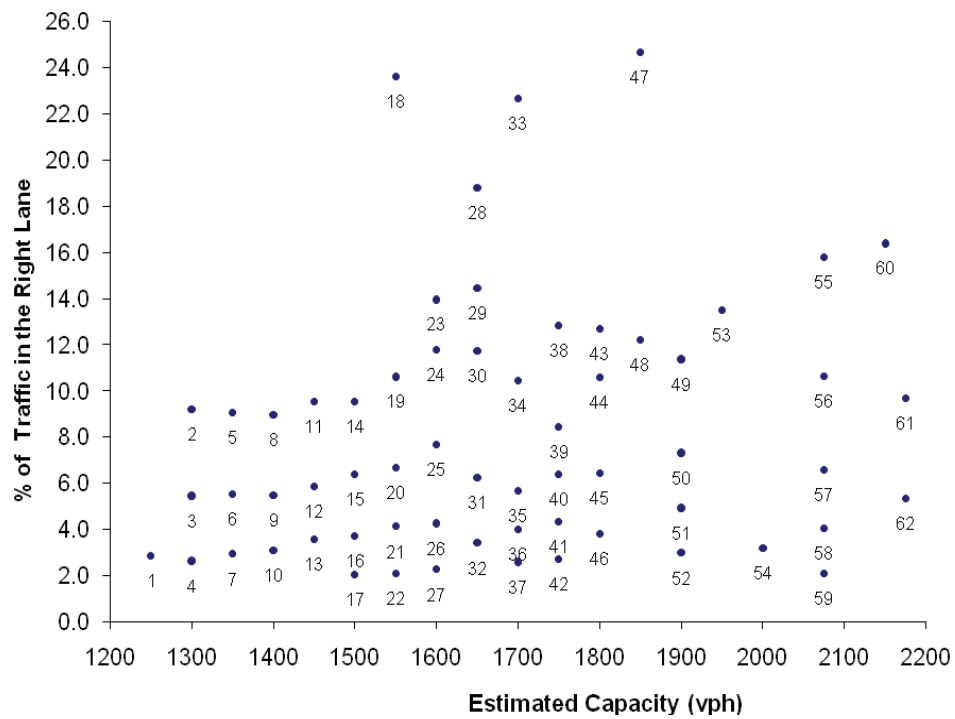


Figure 3. Lane distribution at 1000 ft upstream of taper for 5% trucks in a 2 to 1 lane.

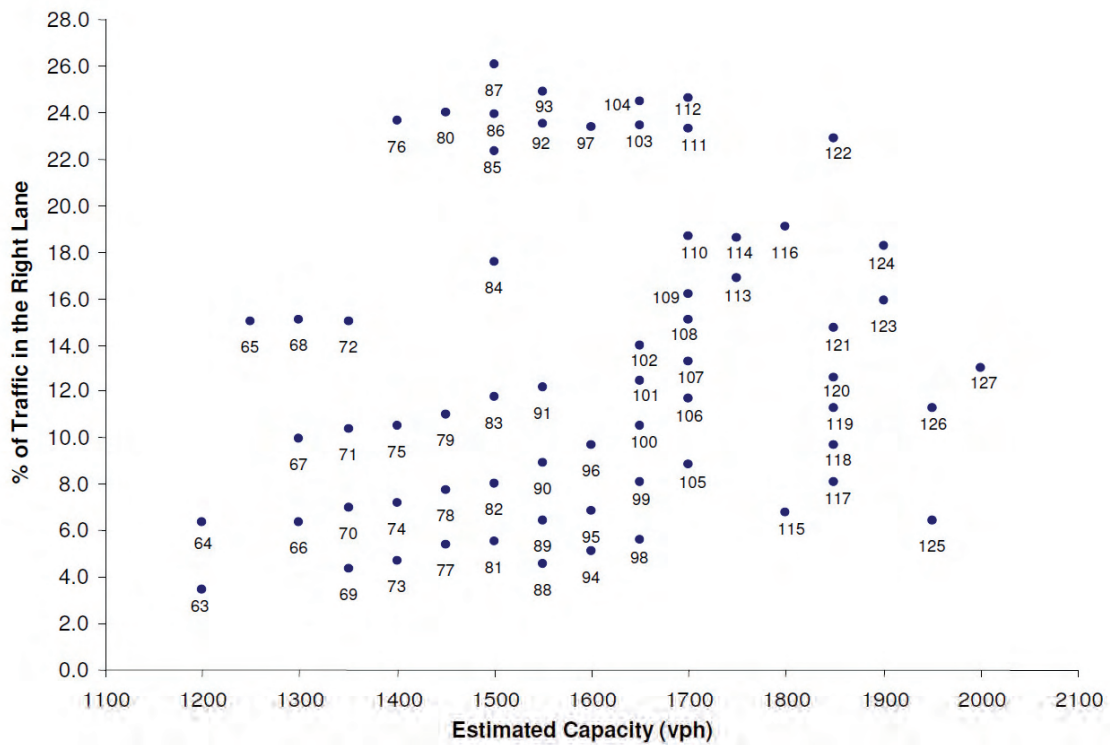


Figure 4. Lane distribution at 1000 ft upstream of taper for 15% trucks in a 2 to 1 lane.

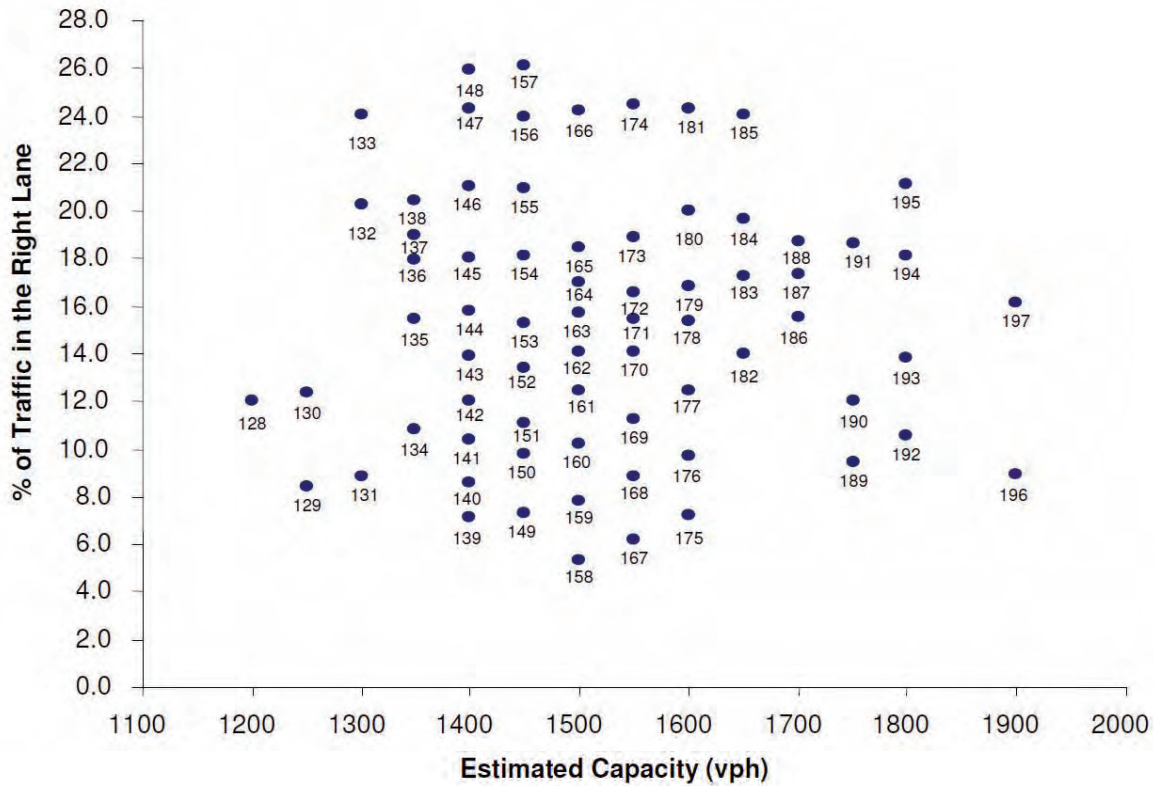


Figure 5. Lane distribution at 1000 ft upstream of taper for 20% trucks in a 2 to 1 lane.

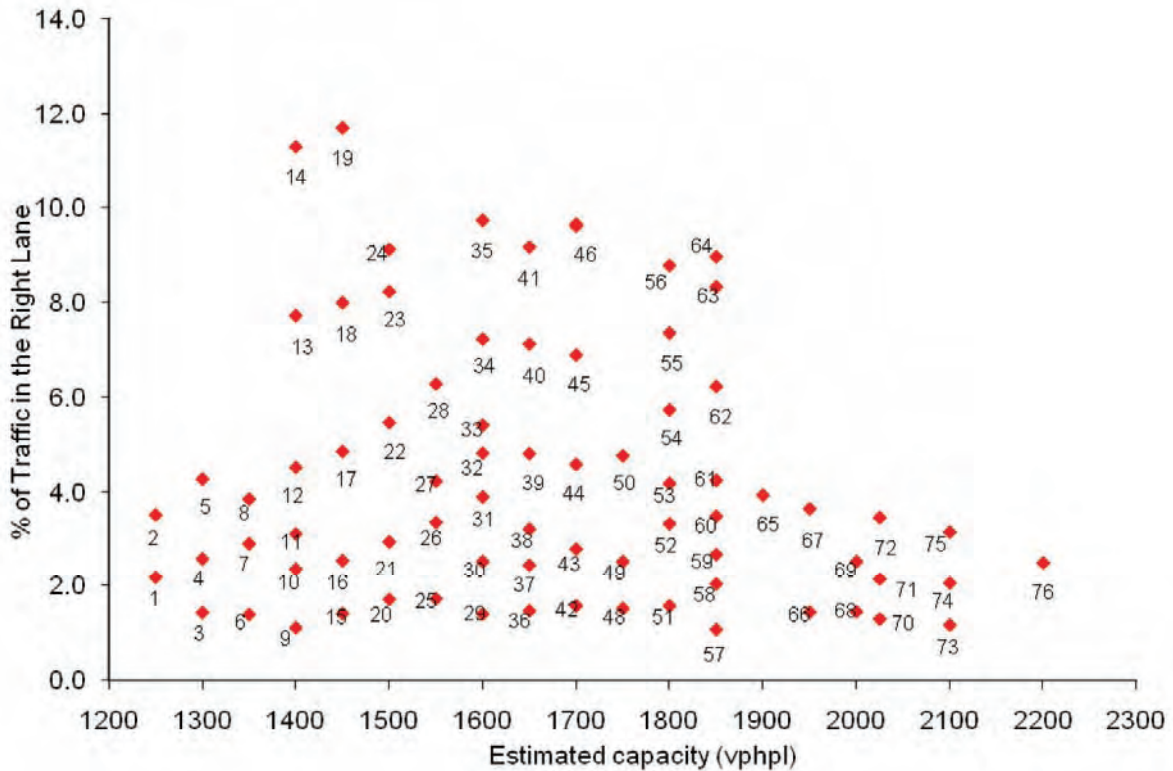


Figure 6. Lane distribution at 1000 ft upstream of taper for 5% trucks in a 3 to 2 lane.

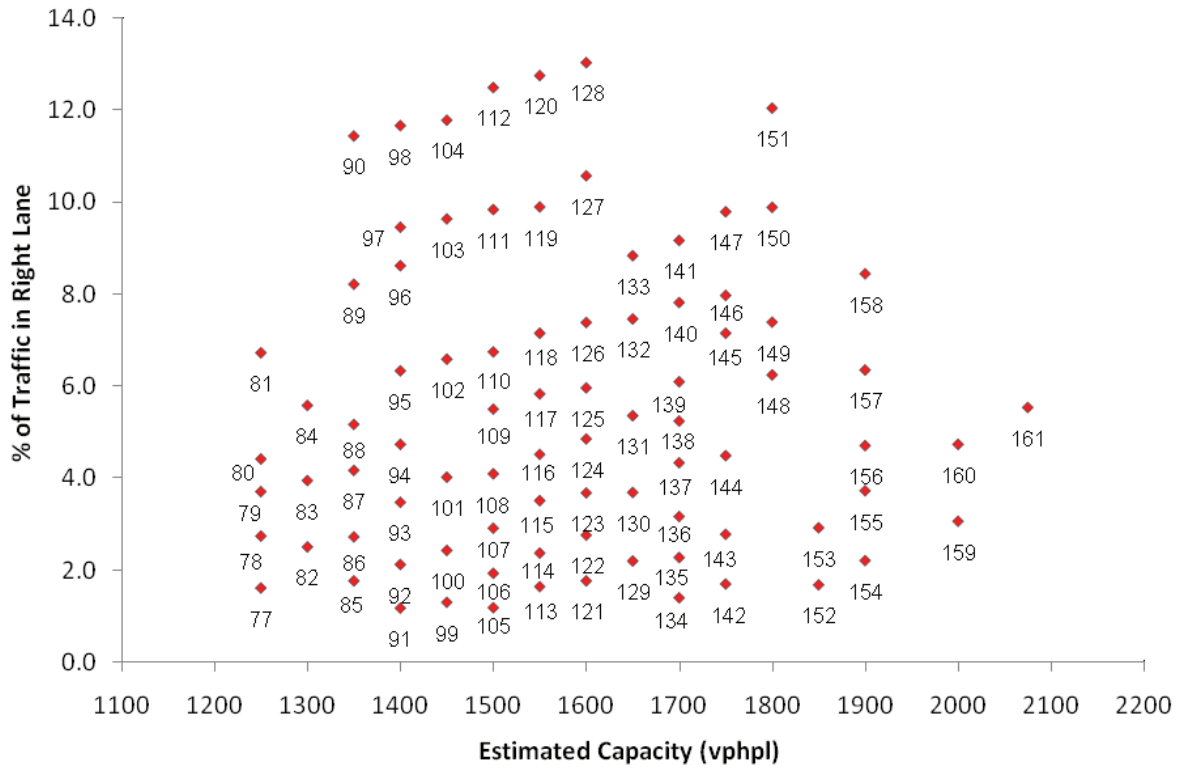


Figure 7. Lane distribution at 1000 ft upstream of taper for 15% trucks in a 3 to 2 lane.

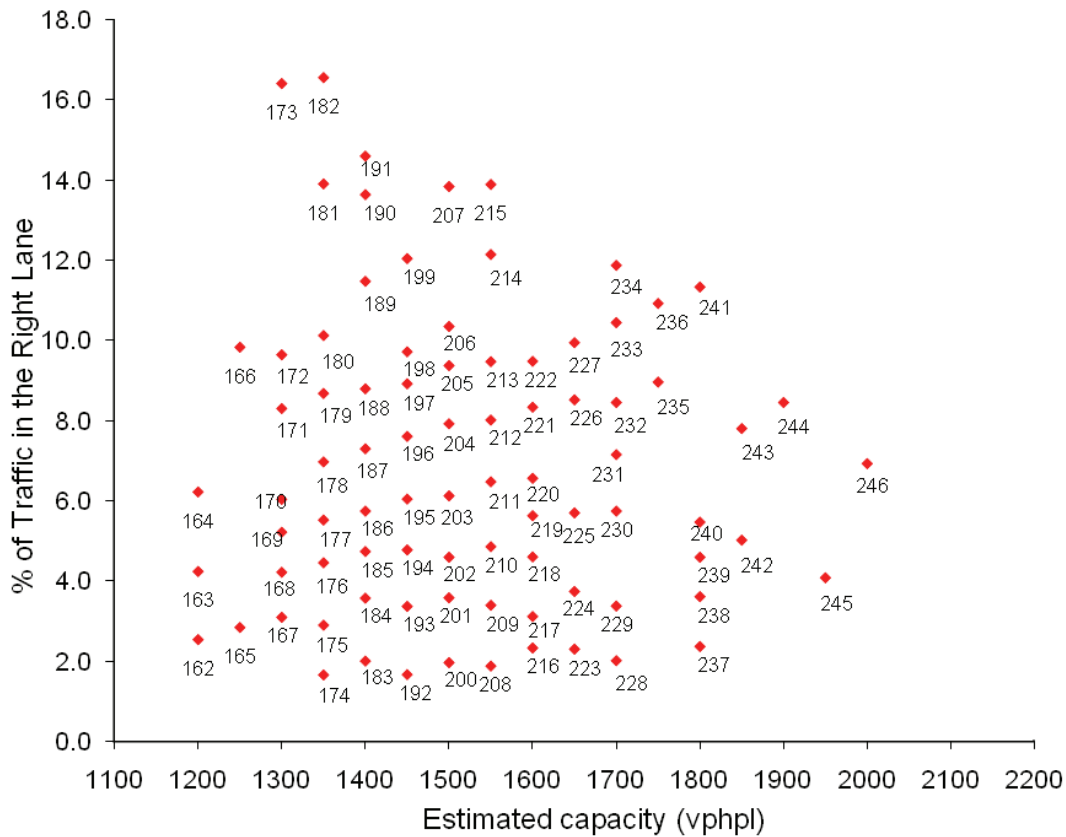


Figure 8. Lane distribution at 1000 ft upstream of taper for 20% trucks in a 3 to 2 lane.

CASE STUDIES

In order to evaluate the chosen work zone software, case studies of different work zone configurations were studied. The objective of this task was to compare the results produced by the software programs and to recommend the program choice for each work zone configuration.

Description of Case Studies

Case study 1: A 3 to 2 lane work zone on an eastbound segment of I-44 near St. Louis with a lane closure of one mile was evaluated. A screenshot of the study site is shown in Figure 9. The hourly vehicle counts for every day of the week were provided by MoDOT. A plot of the total hourly volumes (passenger cars plus trucks) is shown in Figure 10. The truck percentage was 7% for every hourly interval. A capacity value of 1430 vehicles per hour per lane was obtained from the MoDOT's work zone guidelines document (MoDOT, 2004). From Figure 10 it can be seen that the hourly volumes are the highest for Friday. In order to compare the queue lengths and delays estimated by the different software, it was essential to have queuing conditions. Therefore, the work zone duration was set from 6:00 am to 2:00 pm (8 hour shift) for this case study to generate queuing conditions.



Figure 9. Layout of the first case study on I-44

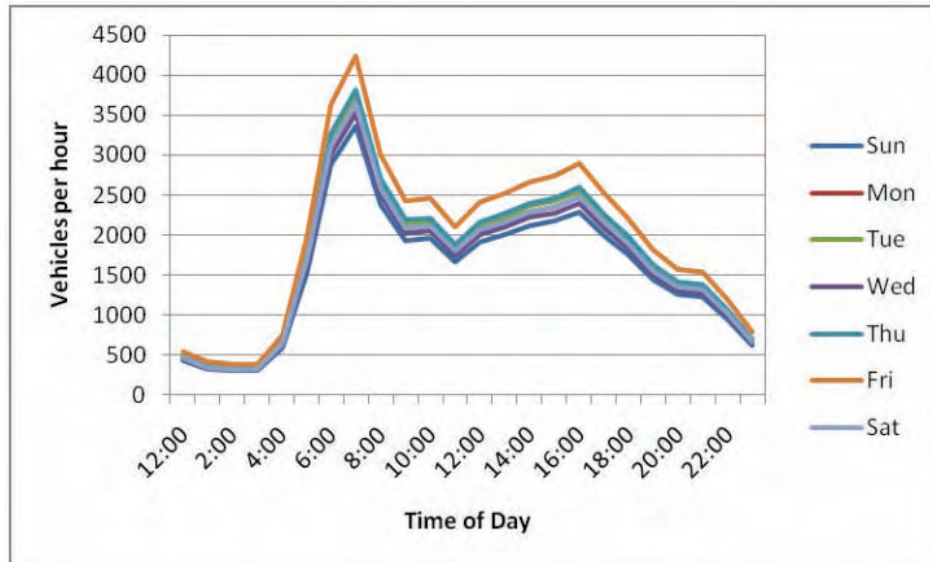


Figure 10. Hourly traffic volumes for the I-44 case study

Case study 2: A 2 to 1 lane work zone on an eastbound segment of I-70 (near exit 49) with a lane closure of a half mile was studied. The study site is shown in Figure 11. The hourly vehicle counts for every day of the week were provided by MoDOT. A plot of the total hourly volumes (passenger cars plus trucks) is shown in Figure 12. A capacity value of 1240 vehicles per hour per lane was obtained from MoDOT's work zone guidelines document (MoDOT, 2004). From Figure 12 it can be seen that the hourly volumes are the highest for Friday. In order to compare the queue lengths and delays estimated by the different software the work zone duration was set from 5:00 pm to 11:00 pm (6 hour shift) for this case study.



Figure 11. Layout of the second case study on I-70

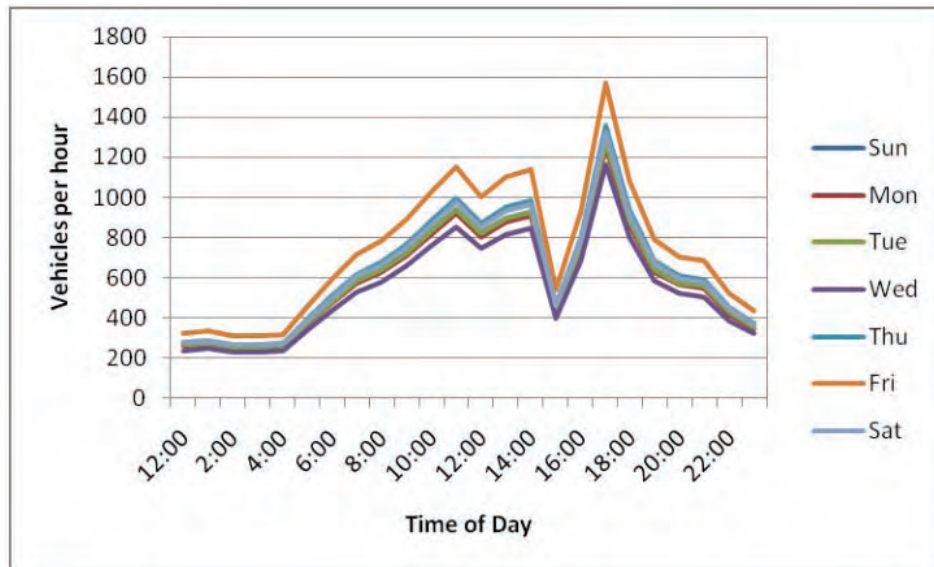


Figure 12. Hourly traffic volumes for the I-70 case study

Case study 3: A two way one lane (TWOL) work zone operation on US 63 (near Vienna) with the southbound lane closed and operating under flagger control was studied. The study site of the complete project length is shown in Figure 13. The lane closure length was assumed to be equal to 500 ft on all days. The hourly vehicle counts for every day of the week were provided by MoDOT. It was found that the cumulative hourly volumes (both southbound and northbound combined) were the greatest on Tuesday. A plot of the hourly volumes (passenger cars plus trucks) for Tuesday in each direction is shown in Figure 14. A capacity value of 600 vehicles per hour per lane was obtained from MoDOT's work zone guidelines document (MoDOT, 2004). The work zone duration was set from 6:00 pm to 12:00 am (6 hour shift) for this case study.

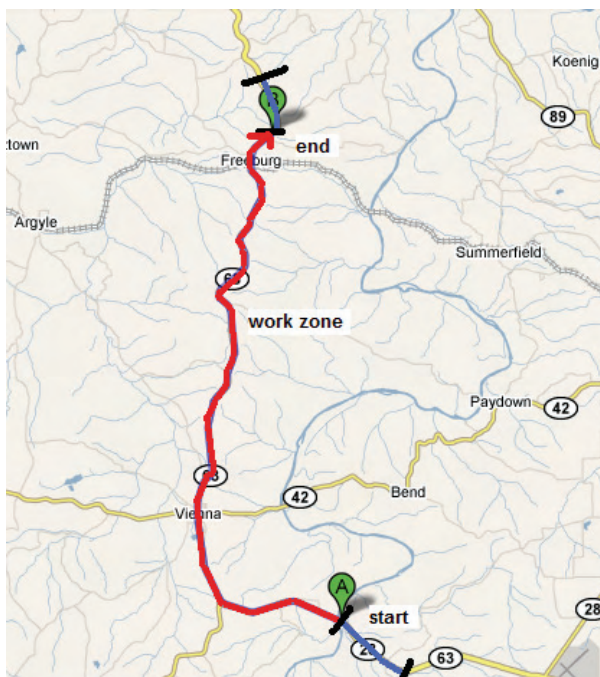


Figure 13. Layout of the third case study on US-63

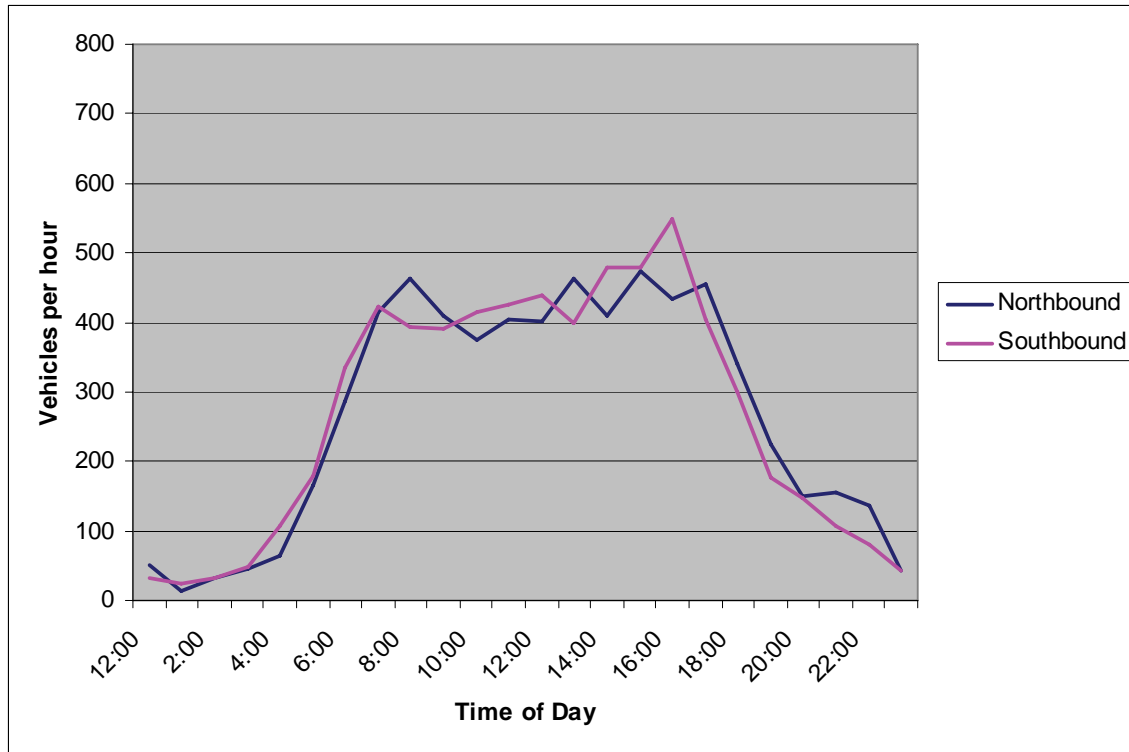


Figure 14. Hourly traffic volumes (Tuesday) for the US-63 case study.

Quick Zone Models for Case Studies

The road network for all case studies in this project were developed using the network editor. At first the location of each work zone was found on an online mapping site (e.g., Google maps). The availability of any detour routes near the work zone was also noted. A screenshot of the online map was captured and saved as a bit map image which is then imported as a background for plotting the network layout. All case study networks were composed of four links and five nodes, with the work zone link being in between the second and third mainline links. The input work zone capacity values were consistent with the values established by MoDOT for different lane configurations. The jam density value was kept same as the program default value. It is to be noted that all link property values need to be entered for *free flow conditions*, even for the work zone links. The work zone specific values will be computed by Quick Zone using values entered at a later stage in the program. In this research project, hourly traffic counts mode of vehicle input was used for all three case studies. Truck percentages for each hour of the day were also specified for both inbound and outbound links.

There is an option to perform two-way one lane operation in Quick Zone. However, for the case study traffic demands, an error message about the demands being too high and prompting to increase capacity or increase detour percentage was displayed. Since capacity value was predetermined from MoDOT guidelines it was decided not to change the capacity value for the analysis. In addition, there was no feasible detour route to which the traffic could be diverted making it unreasonable to increase the detour percentage in the model.

CA4PRS Models for Case Studies

The geometric characteristics, input demands, and user costs for trucks and passenger cars were the same as the values in Quick Zone so as to be able to compare the final results. The CA4PRS program has the capability to compute reduced lane capacities using percentage of trucks and other input variables. However, in this study, as mentioned earlier, the reduced lane capacities used by MoDOT were used in all case studies. The normal lane capacity (without a work zone) was assumed to be equal to 1600 vphpl for highway facilities. The CA4PRS program does not have an option to perform two-way one lane analysis studied in the third case study.

VISSIM models for Case Studies

The bit map image used in developing the network layout in Quick Zone was used as a background image in VISSIM. The normal and work zone links were drawn on top of the image. Reduced speed limits, traffic compositions (percentage splits for passenger cars and trucks), routing decisions, and input demands were entered. In order to obtain the capacity values used by MoDOT (1240 vphpl for 2 to 1, 1430 vphpl for 3 to 2) the driver behavior parameters were derived from the tables and charts presented earlier (Tables 1, 2 and Figures 3 to 8).

The two-way one lane flagger operation was modeled using a traffic signal in VISSIM. The key requirement was to have the common link (shared by both northbound and southbound traffic) clear before allowing the opposing movement to enter. This was accomplished by providing sufficient all-red clearance time determined iteratively. In the third case study, for a 500 ft long lane closure a clearance time of 10 seconds and green time of 5 seconds resulting in a cycle length of 30 seconds produced the MoDOT defined capacity of 600 vphpl.

Spreadsheet models for Case Studies

The input requirements of the spreadsheet, as discussed earlier, are very straightforward for the first two case studies. The two-way one lane operation could not be modeled in the spreadsheet due to the nature of the flagger operation. To model a two-way one lane operation the average amount of time a flagger allows each movement to pass through the work zone is required as an input. Unfortunately, the amount of time is the flagger's discretion based on their perception of queue lengths and delays in each direction.

RESULTS OF CASE STUDIES

In this section, the results produced by each of the software programs and the custom spreadsheet are presented for all case studies. For the purposes of comparison, two key operational performance measures were identified – Delay and Queue Length. Based on the program output options, the average and maximum values of these measures are reported. All programs (except VISSIM) compute user costs due to lane closures using different approaches. Due to the difference in approaches, significant variations were observed in the estimated costs and therefore were not compared. The results of the case studies are shown in Tables 3, 4, and 5 for case studies 1, 2, and 3, respectively.

Table 3. Performance measure values for the first case study on I-44

Tool	Maximum Delay (minutes)	Queue Length (miles)	
		Maximum	Average
CA4PRS	48.0	NA*	5.0
QUICK ZONE	47.9	4.0	NA
SPREADSHEET	47.9	3.8	NA
VISSIM	24.2	3.9	4.0

*NA indicates that the program does not output that performance measure

Table 4. Performance measure values for the second case study on I-70

Tool	Maximum Delay (minutes)	Queue Length (miles)	
		Maximum	Average
CA4PRS	16.0	NA*	1.0
QUICK ZONE	16.1	0.9	NA
SPREADSHEET	16.1	0.8	NA
VISSIM	10.9	1.3	1.1

*NA indicates that the program does not output that performance measure

Table 5. Performance measure values for the third case study on US 63

Tool	Maximum Delay (minutes)		Queue Length (miles)			
	SB	NB	Maximum		Average	
			SB	NB	SB	NB
VISSIM	11.6	24.6	0.3	0.8	0.3	0.7

From Tables 3 and 4, it is evident that the delay and queue length computed by the Quick Zone, CA4PRS, and Spreadsheet tools are almost equal. This was expected due to the fact that all three programs have the same underlying demand-capacity model recommended by the HCM. These results show that the decision to choose among the three tools can be based on the ease-of-use and input requirements given that the results are consistent across the tools. Of the three tools, the Spreadsheet program has the least input data requirements and has also been customized for Missouri DOT's capacity values. The delay values obtained in VISSIM were found to be lower than the other programs but the queue lengths were similar. This can be attributed to the difference in delay computations in the simulation model versus the analytical model. As noted earlier, the third case study could only be evaluated in VISSIM. The results shown in Table 5 indicate that the maximum delay occurred in the northbound direction of US 63. Although, the green times for the northbound and southbound approaches were the same the delays in each direction are different due to the differences in the travel demand values.

RECOMMENDATIONS

Based on the results of literature review, state DOT surveys, and case studies conducted in this project, the following recommendations are made for the most appropriate tool for different work zone configurations. These recommendations take into account the accuracy of results, the ease-of-use, the input data requirements, output options and interpretation of results.

- For rural interstates (two lanes in each direction), divided roadways, and multilane undivided highways in Missouri the Spreadsheet model should be used to estimate the traffic impacts of work zone lane closures. The alternative tools that may be considered (in descending order of priority) are CA4PRS, VISSIM, and Quick Zone.
- For work zones in urban areas where lane closures on a roadway may impact the traffic on neighboring roadways in the urban network, the use of VISSIM simulation program is recommended. It is also recommended that the users modeling work zones in the VISSIM program select the driver behavior parameters from the calibration charts developed in this study for obtaining field observed capacity values.
- For a two way one lane work zone with flagger operation, Quick Zone should be evaluated as the first option. In situations with high input volumes and/or the unavailability of detour routes Quick Zone will not give results for MoDOT's capacity value of 600 vehicles per hour per lane. The use of VISSIM program is recommended in such situations.

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