Work Zone Lane Closure Analysis Model

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The University of Alabama, The University of Alabama at Birmingham,
and The University of Alabama in Huntsville

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16. Abstract

At the Alabama Department of Transportation (ALDOT), the tool used by traffic engineers to predict whether a queue will form at a freeway work zone is the Excel-based “Lane Rental Model” developed at the Oklahoma Department of Transportation (OkDOT) and whose work zone capacity values are based on the 1994 *Highway Capacity Manual* (*HCM*, 1994). The scope of this project pertains only to the queue estimation worksheet of that spreadsheet tool, herein referred to as the OkDOT Baseline Version. This tool, based on input-output logic, is simple to understand and use. Preliminary testing of the OkDOT Baseline confirmed a tendency to overestimate queue length, and an opportunity to update the capacity estimation method while keeping the rest of the tool intact. Two other versions were created using the work zone lane capacity model of *HCM* 2000; the *HCM* 2000 Version uses work zone intensity effects of -160 to +160 passenger cars per hour per lane (pcphpl) as prescribed in *HCM* 2000. The second modified version uses work zone intensity penalties of -500 to 0 pcphpl, a modification based on recent literature, and is therefore called the *HCM* 2000 Hybrid Version.

continued on next page →

Although work zone capacity estimation has been widely researched over the past three decades, only a few studies measured actual queue start times, queue lengths (hence maximum queue length), along with the free flow traffic volume approaching the work zone and the capacity of the work zone (rate of traffic exiting the downstream end of the work zone). One in particular, (Sarasua, et al. 2006) collected extensive data on lane capacity and queue characteristics (if a queue formed) at 35 freeway work zones in South Carolina. We used 32 of these work zone descriptions as the "test data bank" for comparing predictions produced by three versions of the OkDOT spreadsheet tool with the actual maximum queue length (MQL) and queue start time (QST). Minimizing the prediction error in MQL is the main criterion for comparing the accuracy of the three OkDOT model versions, though QST was also considered.

Based on prediction error analysis, the strong conclusion is that the current tool should be replaced by the *HCM* 2000 Hybrid Version we have developed and tested. *HCM* Hybrid Version minimized error in predicting actual MQL at the 32 South Carolina work zones, and minimized the error of not predicting a queue, when one actually formed. Additional testing revealed a PCE = 2.1 minimized error in MQL among typical PCE values in the range (2.0, 2.5). This tool was validated using six work zone cases, three from Alabama and three from North Carolina. In addition to modification of the capacity estimation method in the OkDOT tool, we endeavored to make it more useful for mobility impact assessment by including a graphical depiction of the queue profile.

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Executive Summary

During mobility impact planning for short-term work zones projects, a traffic engineer will use one or more tools available to consider the location, timing, and character of the project, and predict whether a traffic back-up (queue) upstream of the work zone might form. ALDOT policy is to schedule lane closures so that traffic queue formation is minimized. If a queue is predicted to form, the two most important performance measures for the planner are queue start time and maximum length of queue. At ALDOT, the tool currently in use is the Excel-based "Lane Rental Model" developed at the Oklahoma DOT and whose work zone capacity values are based on the 1994 *Highway Capacity Manual* (*HCM*, 1994).

The scope of this project pertains only to the queue estimation worksheet of that spreadsheet tool, herein referred to as the OkDOT Baseline Version. This tool, based on input-output logic, is simple to understand and use. However, users at ALDOT have expressed concern about whether internal logic errors or outdated assumptions could be producing inaccurate predictions about work zone queues. Internal logic was checked, and minor errors found and corrected. Preliminary testing of the OkDOT Baseline confirmed a lack of accuracy, and an opportunity to update the capacity estimation method while keeping the rest of the tool intact. Two other versions were created using the work zone lane capacity model of *HCM* 2000 (*HCM*, 2000); the *HCM* 2000 Version uses work zone intensity effects of -160 to +160 pcphpl, as prescribed in *HCM* 2000. The second modified version uses work zone intensity penalties of -500 to 0 pcphpl, a modification based on recent literature, and is therefore called the *HCM* 2000 Hybrid Version.

Although work zone capacity estimation has been widely researched over the past three decades, only a few studies measured actual queue start times, queue lengths (hence maximum queue length), along with the free flow traffic volume approaching the work zone and the capacity of the work zone (rate of traffic exiting the downstream end of the work zone). One in particular, (Sarasua, et al. 2006) collected extensive data on lane capacity and queue characteristics (if a queue formed) at 35 freeway work zones in South Carolina (SC). We use 32 of these work zone descriptions in Chapter 4 as the "test data bank" for comparing predictions produced by three versions of the OkDOT spreadsheet tool with the actual maximum queue length (MQL) and queue start time (QST). Minimizing the prediction error in MQL is the main criterion for comparing the accuracy of the three OkDOT model versions, though QST was also considered.

Based on the analysis and evaluation in Chapter 4, the strong conclusion is that the current tool should be replaced by the *HCM* 2000 Hybrid Version we have developed and tested. *HCM* Hybrid Version minimized error in predicting actual MQL at the 32 SC work zones, and minimized the error of not predicting a queue, when one actually formed. Additional testing revealed a PCE = 2.1 minimized error in MQL among typical PCE values in the range (2.0, 2.5). This tool was validated using six work zone cases, three from Alabama (AL) and three from

North Carolina (NC). In addition to modification of the capacity estimation method in the OkDOT tool, we endeavored to make it more useful for mobility impact assessment by including a graphical depiction of the queue profile. Additional guidance is provided in Chapter 6 for cases of planning work zones whose conditions fall outside the normal conditions expected by the model. Specifically, adjustment factors are recommended for poor weather and darkness; PCE = 2.5 is recommended for long grades > 2 degrees; and use of a maximum queue length input is recommended for urban work zones of length > 0.25 miles.

Deliverables from this project are this report, and on a CD the following software:

- 123 Test Data Sets from real work zones (separate Excel spreadsheets)
  - 41 cases (South Carolina, Alabama, North Carolina, and Illinois)
  - Model runs for each of three OkDOT Versions

- OkDOT *HCM* 2000 Hybrid Version (Excel Spreadsheet with brief instructions) featuring
  - *HCM* 2000 Capacity Equation
  - Six-level Intensity Scale with multiple examples as guide
  - Graphical queue profile output box

- User's Guide for OkDOT *HCM* 2000 Hybrid Version (Word document), which may be printed, bound, and distributed

1.0 Assessment of OkDOT Model Strengths and Weaknesses

All the state DOTs schedule and conduct freeway projects that involve work zones along active roadways and bridges. Furthermore, the Federal Highway Administration's *Final Rule on Work Zone Safety and Mobility* (2005) requires the development of a Traffic Management Plan during the design phase of road construction and maintenance projects; both safety and mobility impacts of the planned work zone must be estimated. As a result, state DOTs perform work zone traffic analyses (along with cost analyses) to select alternative lane closure strategies to minimize impact on the traveling public. Lane closure durations/schedules are divided into four categories: (1) daytime off-peak, (2) nighttime, (3) weekend closures, and (4) continuous lane closure for the duration of one or more phases, or the entire project (Jeannotte and Chandra, 2005). Concerns about inconvenience to the traveling public are first addressed during planning, and are closely monitored during set-up and operation of the associated lane closures.

Many studies since 1970 have attempted to develop models which *predict the reduction in lane capacity* that occurs within a short-term freeway work zone, because this capacity is a dominant determining factor in whether a queue might form upstream and what length it might attain. Kermode and Myyra (1970) studied freeway work zones in California; Dudek and Richards (1981) studied freeway lane closures in Texas. These two studies resulted in the lane capacity value guidelines in the 1994 *Highway Capacity Manual* (*HCM*, 1994). Edara and Cottrell (2007) state "it is clear that the *HCM* 1994 capacity charts significantly under-predict the capacity values at short-term freeway work zones. However, it is possible to obtain realistic capacity values from *HCM* 2000." These same 1994 charts were used in *HCM* 1998, and important for this research, are embedded in the Oklahoma Department of Transportation (OkDOT) tool in use currently by ALDOT.

The Krammes and Lopez (1994) studies of urban interstates in Texas (Austin, Dallas, Houston, and San Antonio) became the basis for the work zone lane capacity estimation formulas found in the 2000 *Highway Capacity Manual*. They recommended a base capacity of 1600 passenger cars per lane per hour (pcplph) for all short-term freeway lane closure configurations, and proposed several adjustment factors for: intensity of the work activity; percentage of heavy vehicles; and presence of entrance ramps in the approach zone prior to the taper to close lanes. Long-term work zone capacities remained the same as in *HCM* 1994. The *HCM* 2000 capacity estimating method is widely accepted, is found in the popular QUEWZ tool used around the U.S., and is the starting point for modified versions of the OkDOT spreadsheet tool we ended up testing, as described in Chapter 4.

More recent work zone lane capacity studies have been reported in Dixon, et al. (1996) and Jiang (1999). Three of the cases detailed by Dixon, et al. (1996) became validation data for our recommended modification of the OkDOT spreadsheet tool in Chapter 4. More recently, Kim, et al. (2001) at the University of Maryland developed a multiple-regression equation to estimate lane capacity for freeway work zones. This equation has seven independent variables, but was based on only twelve observed work zones so its value is limited; hence, we did not consider it. Karim and Adeli (2003a) developed a neural network-based tool for the estimation of capacity and delay in work zones, but it has eleven independent variables. Finally, Sarasua, et al. (2006) collected extensive data on lane capacity and queue characteristics (if a queue formed) at 35 freeway work zones in South Carolina. We used 32 of these work zone descriptions in Chapter 4 as the "test data bank" for comparing predictions produced by three versions of the OkDOT spreadsheet tool with actual maximum queue length and queue start time.

Only a few studies, in particular those described in Chapter 4, actually measured queue start times, queue lengths (hence maximum queue length), along with the free flow traffic volume approaching the work zone and the capacity of the work zone (rate of traffic exiting the downstream end of the work zone). In most cases, other descriptors of the work zone were recorded such as milepost location and side of interstate affected, number of lanes closed, type of work, start and end time of the lane closure, etc. These additional data proved very useful in the course of the project.

The study reported here is unique in that we set out to test and calibrate an existing spreadsheet tool to *predict queue start time* (military time, to nearest minute) *and maximum length* (in feet) attained during the closure of one or more lanes of a freeway at a temporary work zone. That is, we are using actual cases where queue start time and maximum queue length were measured, and through those two metrics extensively testing the existing tool used by the Alabama Department of Transportation (ALDOT), and two alternative versions. Furthermore, at a more detailed level, inputs such as passenger car equivalent (PCE) for heavy vehicles and work intensity have been considered and the models calibrated to give reasonably accurate queue length predictions. Note that work zone capacity is calculated within the three spreadsheet versions compared, but those calculations are according to *Highway Capacity Manual* guidelines - *HCM* 1994 for the OkDOT Baseline Version and *HCM* 2000 for the other two versions. A clear winner among the three OkDOT model versions emerges in Chapter 4, and is recommended in Chapter 5 with confidence to ALDOT as its work zone queue analysis tool for the future. Chapter 5 provides validation runs for the recommended modification to the baseline version in use at ALDOT at the time of this study.

Motivation for and Scope of the Research

The Alabama roadway system is mature, and is daily coping with more vehicles, larger vehicles and heavier vehicles. Maintaining, rehabilitating, and expanding roads are becoming more difficult and more expensive, especially since much of this work must be undertaken while traffic continues to use the road. ALDOT anticipates that the portion of work done "under traffic" will continue to increase in the future. Decisions about lane closures, working only at night, and "allowable" levels of congestion in work zones will become even more difficult. These decisions impact stakeholder travel time, economic competitiveness, safety, and the expense of road work.

During mobility and safety impact planning for short-term work zones projects, a traffic engineer will use one or more tools available to consider the location, timing, and character of the project, and predict whether a traffic back-up (queue) upstream of the work zone might form. ALDOT policy is to schedule lane closures so that traffic queue formation is minimized. If a queue is predicted to form, the two most important performance measures for the planner are queue start time and maximum length of queue. At ALDOT, the tool currently in use is the Excel-based "ODOT Lane Rental Model" obtained from the Oklahoma DOT. (Note: Throughout this report, we are using the abbreviation OkDOT to avoid confusion between the Oklahoma and Ohio Departments of Transportation.)

The scope of this project pertains only to the queue estimation worksheet of that spreadsheet tool, which we shall refer to as the OkDOT Baseline Version. The tool, based on input-output logic, is simple to understand and use. However, users at ALDOT have expressed concern about whether internal logic errors or poor assumptions could be producing inaccurate information about queue formation, duration, and maximum length. Internal logic has been checked and minor errors found and corrected. Two other versions were created using the work zone lane capacity model of *HCM* 2000; the first uses work zone intensity affects of -160 to +160 passenger cars per hour per lane (pcphpl), just as prescribed in *HCM* 2000. The second modified version uses work zone intensity penalties of -500 to 0 pcphpl, a modification based on recent literature, and is therefore called the *HCM* 2000 Hybrid Version. In addition to modification of the capacity estimation method in the OkDOT tool, we endeavored to make it more useful for mobility impact assessment by including a graphical depiction of the queue profile (should one be predicted by the spreadsheet).

Project Objectives

The University Transportation Center for Alabama (UTCA) at the University of Alabama (UA) conducted the research described in this report during the time frame June 1, 2008 to May 31, 2009 in order to meet ALDOT needs through accomplishment of the following objectives:

- Determine the state of practice of work zone lane closure analysis tools;
- Acquire Work Zone Lane Closure models that appear to be applicable and widely used;
- Acquire or develop a data bank for a wide variety of work zone scenarios, specifically including data about traffic flow, delays, and queue lengths;
- Calibrate the OkDOT tool to match actual work zone traffic results in a range of freeway situations, using Alabama work zones to the extent possible;
- If necessary, identify supplemental models to be tested and calibrated along with the OkDOT tool; and
- Deliver to ALDOT a modified tool (supplemented tool if needed) that can reasonably predict the effects of alternative lane closure situations, and the data sets acquired/collected in this project.

The OkDOT Model in Context

Current ALDOT Methodology

ALDOT has a goal of conducting its work so that there is no traffic back up (queue formation). This is a conservative philosophy that maintains maximum capacity and least impact on road users, but it is more expensive than other methods of working in active traffic. ALDOT policy also calls for work zone activity to be scheduled at times of the day when no traffic queues should form. Therefore, a key question for ALDOT traffic engineers is "What is the volume of traffic that will cause a traffic stoppage, not just moving slower?" ALDOT personnel use their current tool to ascertain this number, and in addition the time of day when a work zone could be set up and operated without queuing. However, given the high mobility of Alabamians, it is not always possible to reach this high level of service. And in the future it will become more difficult for ALDOT to maintain that philosophy.

ALDOT currently uses the Oklahoma Department of Transportation (OkDOT) Capacity Spreadsheet for its lane closure analyses, for at least three purposes:

1. To determine if a queue will form under forced-flow conditions at a work zone, at a given hour of the day.

2. To estimate the length of the queue in the startup hour and each subsequent hour until the queue dissipates; ultimately, how long might the queue grow?

3. To identify work periods (e.g., 9:00 a.m.-3:00 p.m., 9:00 p.m.-5:00 a.m.) when no queue should form, given the nature of the lane closures, the AADT, and other inputs.

The OkDOT tool is favored because it requires little data and is relatively simple to use. This allows quick analyses, both in the ALDOT headquarters and at field locations. The spreadsheet is based on an earlier (1994) version of the *Highway Capacity Manual*, not the current (2000) version. The OkDOT tool has, on occasion, produced over-estimates of queue length that did not match real ALDOT data from highway work zones. Of particular concern is the accuracy of the model for three-to-one lane closures for both rural and urban interstates. Such scenarios are included in the test data bank we use in Chapter 4. Other users have detected other inaccuracies during application of the model, as discussed below.

To use the Oklahoma spreadsheet, the user must input data like traffic demand (AADT, percent trucks, traffic hourly distribution, directional distribution) and work zone capacity by hours of lane closure, total number of lanes, free flow speed, and normal lane capacity (Lindly and Clark, 2004). Ideally, hourly traffic volume data is obtained and adjusted by heavy vehicles. Work zone capacity is estimated depending on work zone characteristics from charts specified in *HCM* 1994. When the volume exceeds the capacity, delay and congestion occur. A queue is formed and continues to grow until the traffic volumes are lower than the capacity. At that point the queue begins to dissipate. The OkDOT model can also compute the additional costs experienced by road users due to the lane closure. The two components considered in road user cost are delay cost and fuel cost (Lindly and Clark, 2004). However, the cost options within the OkDOT model were not investigated at all in the study reported herein.

In context, the *HCM* method of input-output queue analysis is considered the simplest of the work zone traffic analysis methods because the cost of maintenance is low, the training required is limited, and the input required of the planner is readily available. One of the inputs of the OkDOT Baseline, confidence level, turns out to be a measure of conservatism ranging from 0% (highest confidence in the programmed level of work zone lane capacity) to 100% (lowest confidence in the programmed level of work zone capacity). For example, in a two-to-one lane closure, a 0% input yields the highest possible capacity, 1465 vph; whereas a 50% input yields a capacity reduction to 1350 vph, and a 90% input yields a capacity reduction to 1259 vph. The absolute lowest level of capacity occurs with the extreme level of conservatism 100%, yielding a capacity of 1236 vph. Other models in the literature tend to use some measure or measures of work intensity to adjust the basic level of lane capacity.

Other Work Zone Traffic Prediction Models

A recent survey conducted by Edara and Cothell (2007) shows that *HCM*-based spreadsheets are the most popular tools used by state DOTs for estimating work zone delays and queues lengths. Other analysis models used by DOTs include QuickZone, QUEWZ, and microscopic simulation programs such as CORSIM, VISSIM and SimTraffic.

Spreadsheet Models (Including the OkDOT Model) Spreadsheets typically use a graphical procedure and analytical equations from the 1994 edition of the *Highway Capacity Manual* (*HCM*, 1994), with calculations carried out in Microsoft Excel. This includes the OkDOT capacity spreadsheet currently used by ALDOT.

There are other spreadsheet models. For example, the New Jersey DOT developed a “Road User Cost Spreadsheet” to help the designers make better decisions in regard to construction staging, allowable work hours, and alternative project delivery (NJDOT, 2001). The Oregon DOT (2007) uses the same process but adjusts traffic volumes for growth, construction season, and for weekdays vs. weekends. The Oregon DOT spreadsheet is flexible and allows a volume adjustment for special events like school athletic events. The Ohio DOT has added consideration of terrain and truck percentage in determining work zone capacity. The developed spreadsheet is also used to analyze route closure and acceptable queue length (Maze, et al. 2005).

Spreadsheet tools based on *HCM* 1994 offer two advantages: (1) low data input requirements and (2) ease of use; however, the capacity values are outdated and too small, leading to over-prediction of queue length in current applications. The capacity charts in *HCM* 1994 were constructed with data from studies actually conducted before 1982, and only in Texas urban areas. Based on the more recent data that have been incorporated in the *HCM* 2000, it is clear that the *HCM* 1994 capacity charts significantly under-predict the capacity values at short-term freeway work zones (Edara and Cottrell, 2007). This is one reason why we created the *HCM* 2000 Version of the OkDOT spreadsheet.

QUEWZ The Queue and User Cost Evaluation of Work Zones, QUEWZ, is a DOS-based work zone traffic analysis tool developed by the Texas Transportation Institute. QUEWZ-98 is the most recent version of the QUEWZ family of programs. QUEWZ-98 can identify hours of a day when a given number of lanes can be closed without causing excessive queuing, while allowing the user to define "excessive queuing." It is reported that the QUEWZ-98 model is applicable to work zones on freeways or multilane divided highways with up to six lanes in each direction and any number of lanes closed in one or both of the directions (Benekohal, et al. 2003).

The data required for QUEWZ-98 includes hourly traffic volumes, percentage of trucks, capacity values under normal conditions, lane closure hours, work zone configuration, etc. The model uses the capacity calculation equation shown in the 2000 edition of the *HCM* (*HCM*, 2000) to calculate the work zone capacity. The model has a diversion algorithm to adjust traffic demand based on estimates of the vehicles that may switch to alternate routes. However, this algorithm is based on observations in urban Texas sites where parallel frontage roads are typical; it may not be applicable to freeway designs in other states. For the calculation of queue length, it uses the same input-output procedure incorporated in *HCM* 1994. We obtained a copy of QUEWZ, and experiments with it during the early months of this project encouraged us to create an *HCM* 2000 Version of the OkDOT spreadsheet tool.

QuickZone QuickZone is another popular Excel-based tool for work zone traffic impact analysis. It was developed by Mitretek Systems for the FHWA to be an easy-to-use, easy–to-learn tool to quantify delay impacts in work zones. QuickZone can also identify delay impacts of alternative project phasing plans and provide data for a tradeoff analysis between construction costs and delay costs (Mitretek, 2001). There are four major modules including Input Data, Program Controls, Output Data and Open/Save. The data input requirements for QuickZone are greater than those for simple *HCM*-based spreadsheets discussed earlier. Users must have a complete description of the network, including node links with their attributes, and detour links, along with traffic volumes, project information and the work zone plan (Benekohal, et al. 2003). QuickZone computes delay and mainline queue growth by comparing travel demand against capacity for every link on an hour-by-hour basis for the life of the project. Due to the detailed description of the network at a work zone, QuickZone can provide a comprehensive and highly detailed analysis that incorporates various factors that have an impact on the delays occurring at work zones, e.g. route changes, peak-spreading, and mode shifts. The tradeoff in acquiring this level of output is the extra time and effort involved in data entry compared to simple spreadsheet models. QuickZone is an open-source software that may be customized by individual DOTs (e.g., Maryland DOT, 2006). However, due to its moderate level of complexity, it is not an appropriate alternative to the OkDOT tool now in use at ALDOT.

Microscopic Simulation and Adaptive Computational Models Microscopic simulation programs such as CORSIM, SimTraffic, etc., can also be used to estimate the traffic impacts at work zones. They are stochastic based models and the user must code the roadway network, input the traffic volumes, and run the traffic simulation. The simulation will generate the work zone capacity. Similarly, queue lengths and delays at desired time points can be obtained as outputs from the model. Because of high input data requirements and greater time required from the user, microscopic simulation programs are used only occasionally, primarily for complex projects (Schnell, et al. 2002).

Based on the study conducted by Dixon, et al. (1996), work zone capacity is affected significantly by work intensity, rural vs. urban location, and darkness. Several adaptive computational models have been developed using neural network techniques and case-based reasoning (Karim and Adeli, 2003a, 2003b) and (Adeli and Jiang, 2003). However, there has been a limited application of such advanced models.

The OkDOT Model

The original OkDOT spreadsheet tool was created by Karl Zimmerman, Oklahoma Department of Transportation, in 1997. The spreadsheet was modified by Richard Jurey, Federal Highway Administration, in June 2000 and again in January 2001. The January 2001 version is the one currently in use at ALDOT.

Changes made to the original spreadsheet included:

- The original spreadsheet was converted from Quattro Pro to Microsoft Excel 97.
- A maximum queue length value was defined. Users can use it to limit the queue length. If users don't want to limit queue length, then enter a large number (99 for example).
- Custom number formatting was used to make data easier to read.
- Input cells were color-coded.
- Non-input cells were protected to prevent accidental user modification or deletion.
- A more user-friendly interface was created.

OkDOT Model Worksheets

In the January 2001 version in use at ALDOT, the edition of Excel used by this model is Microsoft Excel 97-2003 Worksheet. There are four worksheets in the model: "Information & Instructions" sheet, "LR Input Sheet," "LR Table Sheet," and "LR Calculation Sheet."
The functions of each worksheet are (briefly) as follows:

- "Information & Instructions" worksheet provides users with information of the OkDOT model and gives instructions on how to run the model.
- "LR Input Sheet" allows users to input variables according to their needs and situations. This worksheet also provides outputs in hourly basis, as well as outputs based on peak hour divisions. Outputs include traffic volume, maximum number of cars in queue, maximum queue length, cost of delay, etc.

- "LR Table Sheet" does not directly appear to users. It converts user input information to provide indirect parameters to run the calculation. "LR Table Sheet" contains information on highway factor and direction factor, which allocate daily traffic volume to the traffic volumes for different hours and directions; it also contains highway capacity information from *HCM* 1994, which determines work zone capacity based on original number of lanes and number of lanes closed.

- "LR Calculation Sheet" does not directly appear to users. It uses user inputs and indirect parameters converted by "LR Table Sheet" to do the calculation, and provide output to "LR Input Sheet."

OkDOT Model User Instructions and Structure

The basic instruction for running the model is that all needed inputs are highlighted with yellow color. The users need to provide inputs into the yellow cells to run the model. The detailed structure of OkDOT Model is introduced as follows.

Model Input There are four parts of inputs: two of which are required; the other two parts are optional. (See Tables 1-1 and 1-2.)

Table 1-1. Part I: Required Model Input I

Analysis Code (use code from table):	IR
Direction (Inbound or Outbound):	Inbound
AADT (both directions)	40,000
Percent Trucks:	26.2%
Passenger cars / day:	50,480
Number of lanes (one direction):	2
Free flow speed (mph):	70
Basic lane capacity (pcphpl):	2400
Max. queue length limit (miles):	99
Confidence Level (%) - enter from 20-100	100
Delay ($/hour) passenger car:	$10.00
Fuel costs ($/gal):	$2.00
Average # people per vehicle:	1.2

Analysis Code (enter two-letter code above):					
IU	Interstate - Urban	AU	Arterial - Urban	UF	User Defined Factors
IR	Interstate - Rural	AR	Arterial - Rural	UV	User Defined Volumes

- Input 1 "Analysis Code": Choose Analysis Code from the Analysis Code table, depending on the highway type and work zone location. If the user chooses IU/IR/AU/AR, the model will provide highway factor and direction factor to allocate daily traffic volume. If the user has their own source of allocation factor, they can choose input UF here and input allocation factor in "LR Table Sheet." If the user has information on hourly traffic volume, they can input UV here and input their own hourly traffic volume in “LR Table Sheet.”

- Input 2 “Direction”: Direction input requires user to input either Inbound or Outbound, depending on the direction of traffic flow. If the traffic flow at the work zone location is toward a substantial city, the user should input Inbound; otherwise, the input should be Outbound.

- Input 3 “AADT”: AADT stands for Annual Average Daily Traffic. This input can be obtained from the state DOT or other historical sources.

- Input 4 “Percent Trucks”: Trucks here represent all types of heavy vehicles, which may be differentiated from passenger cars. The model will calculate passenger cars based on AADT input and Percent Trucks input, based on the assumption that one truck equals to two passenger cars on its effect on traffic flow, that is PCE = 2.0 in the OkDOT Baseline tool.

- Input 5 “Number of lanes”: Input original number of lanes in one direction before closure.

- Input 6 “Free flow speed”: Input flow speed when there is no work zone. This input affects highway capacity during hours which there is no lane closed. When there is lane closed, the confidence level (CL) input determines highway capacity.

- Input 7 “Max queue length limit”: If there is a ramp or interchange upstream from the work zone, or in any other cases where the queue length must be limited, input queue length limit here. If there is no queue length limitation, input a large number such as 99. The unit of this input is mile.

- Input 8 “Confidence Level”: Input a number between 20 and 100, based on conservatism of the user. The input 100 means that the user is quite conservative and gives the minimum work zone lane capacity, hence maximum queue length if a queue is predicted; the input 20 gives the minimum queue length prediction.

- Input 9 “Delay passenger car”: Input the delay cost of each passenger car.

- Input 10 “Fuel costs”: Input fuel costs for each gallon of gasoline.

- Input 11 “Average # people per vehicle”: Input average number of people in each vehicle.

- Input 12 “# of Lanes Closed”: Input the number of lanes closed during each hour in one direction.

- Input 13 “User Defined Volumes”: If user chooses to input their own hourly traffic volume, they need to input in the column “User Defined Volumes.”

- Input 14 “User Defined Factors”: If user chooses to input their own highway factor and direction factor, they need to input in the column of “Factor K” and “Factor D,” which allocate traffic volume to each hour and different direction, respectively. The user only needs to input inbound direction factor; the outbound direction factor will be calculated by the model.

Table 1-2: Parts II, III, and IV: Required Model Input

Part II

Hour	# of Lanes Closed
Midnight -1:00 a.m.	0
1:00 a.m.-2:00 a.m.	0
2:00 a.m.-3:00 a.m.	0
3:00 a.m.-4:00 a.m.	0
4:00 a.m.-5:00 a.m.	0
5:00 a.m.-6:00 a.m.	0
6:00 a.m.-7:00 a.m.	0
7:00 a.m.-8:00 a.m.	0
8:00 a.m.-9:00 a.m.	1
9:00 a.m.-10:00 a.m.	1
10:00 a.m.-11:00 a.m.	1
11:00 a.m.-Noon	0
Noon-1:00 p.m.	0
1:00 p.m.-2:00 p.m.	0
2:00 p.m.-3:00 p.m.	0
3:00 p.m.-4:00 p.m.	0
4:00 p.m.-5:00 p.m.	0
5:00 p.m.-6:00 p.m.	0
6:00 p.m.-7:00 p.m.	0
7:00 p.m.-8:00 p.m.	0
8:00 p.m.-9:00 p.m.	0
9:00 p.m.-10:00 p.m.	0
10:00 p.m.-11:00 p.m.	0
11:00 p.m.-Midnight	0

Parts III and IV

Hour	User Defined Volumes	User Defined Factors: (enter description)		
		K	D (inbound)	D (outbound)
Midnight-1:00 a.m.				
1:00 a.m.-2:00 a.m.				
2:00 a.m.-3:00 a.m.				
3:00 a.m.-4:00 a.m.				
4:00 a.m.-5:00 a.m.				
5:00 a.m.-6:00 a.m.				
6:00 a.m.-7:00 a.m.				
7:00 a.m.-8:00 a.m.				
8:00 a.m.-9:00 a.m.				
9:00 a.m.-10:00 a.m.				
10:00 a.m.-11:0 a.m.				
11:00 a.m.-Noon				
Noon-1:00 p.m.				
1:00 p.m.-2:00 p.m.				
2:00 p.m.-3:00 p.m.				
3:00 p.m.-4:00 p.m.				
4:00 p.m.-5:00 p.m.				
5:00 p.m.-6:00 p.m.				
6:00 p.m.-7:00 p.m.				
7:00 p.m.-8:00 p.m.				
8:00 p.m.-9:00 p.m.				
9:00 p.m.-10:00 p.m.				
10:00 p.m.-11:00 p.m.				
11:00p.m.-Midnight				

Model Output Model outputs have two parts: the output based on an hourly basis, and the output based on peak hour divisions, as illustrated in Tables 1-3 and 1-4.

Table 1-3. Part I: Hourly Output

Hour	Interstate – Rural									
	# of Lanes Closed	AADT Factor (K)	Direction Factor (D)	Volume	Limiting Capacity	Max Cars in Queue	Delay Cost	Fuel Cost	Total Costs	Max Queue Length (mi.)
Midnight-1:00a.m.	0	1.830	0.55	508	4,800	0	0	0	0	0.0
1:00 a.m.-2:00 a.m.	0	1.420	0.55	394	4,800	0	0	0	0	0.0
2:00 a.m.-3:00 a.m.	0	1.180	0.55	328	4,800	0	0	0	0	0.0
3:00 a.m.-4:00 a.m.	0	1.030	0.55	286	4,800	0	0	0	0	0.0
4:00 a.m.-5:00 a.m.	0	1.100	0.55	305	4,800	0	0	0	0	0.0
5:00 a.m.-6:00 a.m.	0	1.430	0.55	397	4,800	0	0	0	0	0.0
6:00 a.m.-7:00 a.m.	0	2.330	0.55	647	4,800	0	0	0	0	0.0
7:00 a.m.-8:00 a.m.	0	3.470	0.55	963	4,800	0	0	0	0	0.0
8:00 a.m.-9:00 a.m.	1	4.300	0.55	1,194	1,236	0	0	50	50	0.0
9:00 a.m.-10:00 a.m.	1	5.230	0.55	1,452	1,236	216	1,296	207	1,503	0.4
10:00 a.m.-11:00 a.m.	1	5.880	0.55	1,633	1,236	612	4,968	586	5,554	1.2
11:00 a.m.-Noon	0	6.170	0.55	1,713	4,800	98	808	43	851	0.2
Noon-1:00 p.m.	0	6.230	0.55	1,730	4,800	0	0	0	0	0.0
1:00 p.m.-2:00 p.m.	0	6.470	0.55	1,796	4,800	0	0	0	0	0.0
2:00 p.m.-3:00 p.m.	0	6.770	0.55	1,880	4,800	0	0	0	0	0.0
3:00 p.m.-4:00 p.m.	0	7.030	0.55	1,952	4,800	0	0	0	0	0.0
4:00 p.m.-5:00 p.m.	0	7.100	0.55	1,971	4,800	0	0	0	0	0.0
5:00 p.m.-6:00 p.m.	0	6.920	0.55	1,921	4,800	0	0	0	0	0.0
6:00 p.m.-7:00 p.m.	0	6.000	0.55	1,666	4,800	0	0	0	0	0.0
7:00 p.m.-8:00 p.m.	0	5.050	0.55	1,402	4,800	0	0	0	0	0.0
8:00 p.m.-9:00 p.m.	0	4.250	0.55	1,180	4,800	0	0	0	0	0.0
9:00 p.m.-10:00 p.m.	0	3.550	0.55	986	4,800	0	0	0	0	0.0
10:00 p.m.-11:00 p.m.	0	2.950	0.55	819	4,800	0	0	0	0	0.0
11:00 p.m.-Midnight	0	2.300	0.55	639	4,800	0	0	0	0	0.0

- Output Group 1 "AADT Factor (K)" and "Direction Factor (D)": These two are outputs from "LR Table Sheet."

- Output Group 2 "Volume": Volume output has two sources. One source is directly given by the user; the other one is from calculation with direct inputs of AADT, Percent Trucks, and parameters of Factor K and Factor D.

- Output Group 3 "Limiting Capacity": This output is from "LR Table Sheet" based on the original number of lanes and number of lanes closed. The relationship between capacity and number of lanes refers 1998 *Highway Capacity Manual*.

- Output Group 4 Queue and Costs: Queue and cost outputs include "Max Cars in Queue," "Max Queue Length," "Delay Cost," "Fuel Cost," and "Total Costs." These outputs are from "LR Calculation Sheet." Costs calculated are for one direction only.

Table 1-4. Part II: Output Based on Peak Hour Divisions

	Morning Peak 6:00 a.m.- 9:00 a.m.	Daytime Non-Peak 9:00 a.m.- 3:00 p.m.	Evening Peak 3:00 p.m.- 7:00 p.m.	Nighttime Non-Peak 7:00 p.m.- 6:00 a.m.	Daily (24 Hr.) Summary
Total Cost of Delay ($):	0	0	0	138	170
# of Hrs. Lanes Closed:	0	0	0	5	10
Ave Cost of Delay/Hr. ($):	0	0	0	13	7
Traffic Volume:	4,919	7,222	5,254	3,328	21,855
Max # of Cars in Queue:	0	0	0	0	0
Max Queue Length (mi.):	0.0	0.0	0.0	0.0	0.0

Model Reference and Calculation The model has two references: highway capacity reference and allocation factor reference. These two references are in "LR Table Sheet." Users do not need to visit "LR Table Sheet" unless they need to input user defined factors or volume. Model calculation is conducted in "LR Calculation Sheet." Users do not need to visit this sheet.

OkDOT Model Logic and Assumptions

Model Logic The OkDOT Model relies on a deterministic model of traffic flow calculated at ten-minute increments. The model takes the previous ten-minute queue slice, adds the additional inflow for the current ten-minute period, and then subtracts the work zone's processing capacity during the ten-minute period. (Look at "LR Calculation Sheet" for these calculations and values.) The model converts all traffic – commercial trucks, commuters, etc. – to an equivalent number of cars with a fixed conversion factor of two passenger cars per one truck. This conversion is done before allocating daily traffic volume to hourly traffic volume; therefore, the following calculation is based on passenger cars, and 20 feet is built in the model as the distance occupied by one passenger car in a queue.

Model Formulas The following information (Table 1-5) is provided to users who are interested in the underlying formulas for queue computation and relations between inputs and outputs.

Table 1-5. Queue Input/Output and Computational Formula in OkDOT Spreadsheet

	Category	Parameter	Note or Formula
Input Data	Basic work zone information	Analysis Code	Interstate/Arterial; Urban/Rural
		Direction	Inbound/Outbound
		Original # of Lanes	One direction
		# of Lanes Closed at each hour	One direction
	Available from historical source or observation	AADT	Both directions
		Percent of Trucks	Trucks mean heavy vehicles
		Free Flow Speed	Flow speed when there is no work zone
		Max Queue Length	If there is no limitation, set a large number
	Subjective determined	Confidence Level	Conservative level of the user
Process Data	Not visible to users	Queue at Slice End limited by Max Queue Length Limit	= (Max Queue Length Limit* Original # of Lanes)/ (20/5280)
Output Data	Process Output	Factor K	Allocate daily traffic volume to each hour
		Factor D	Allocate each hour traffic volume to different direction
		Passenger Cars per day*	= AADT*(1+ Percent of Trucks)
		Basic Lane Capability	• If Free Flow Speed is>=70, Basic Lane Capacity=2400; • Else if FFS>=65, BLC=2350; • Else if FFS>=60, BLC=2300; • Else BLC=2250.
		1 hour Capacity Limit	• If Original # of Lanes is 2 (3, 4), # of Lanes Closed is 0, Capacity= 2 (3, 4)* Passenger Cars per day; • If # of Lanes Closed is 1 (2), Capacity is calculated based on 1998 *Highway Capacity Manual*; • If # of Lanes Closed is 3, Capacity is copied from 3 lanes with 2 lanes closed
		10 minute Capacity Limit	= 1 hour Capacity Limit /6
		10 minute Volume	= (Passenger Cars per day* (Factor K/100)* Factor D) /6
	Final Output	Queue Length	= (Queue at Slice End/Original # of Lanes) * (20/5280)
		Queue at Slice End	= Minimum { Maximum{Queue at Slice End in the beginning of current interval+10 min Volume-10 min Capacity Limit, 0}, Queue at Slice End limited by Max Queue Length Limit}

* The deduction for passenger cars per day (the model assumes Passenger Car Equivalence = 2):
Passenger Cars per day
= AADT*(1-Percent of Trucks)*1+ AADT*Percent of Trucks* PCE
= AADT*(1-Percent of Trucks)*1+AADT*Percent of Trucks*2
=AADT*(1+Percent of Trucks)

Model Assumptions

The OkDOT model is based on the following assumptions:

- A fixed cyclical day

  The single-day information the model is given is calculated in a loop starting at the end of 3:50 a.m. (time point 4:00 a.m.), and assumes that the same information applies for the next day. A result of this assumption is that any queue which appears at the end of 3:50 a.m. is immediately dropped to zero. This assumption seems to be based on the hourly allocation factor (Factor K) observed by OkDOT.

- Queues in all lanes have the same length

  It is assumed that drivers will maneuver as they join queued traffic in a balanced manner. This assumption is the basis for the formula Queue Length = (Queue at Slice End/Original # of Lanes) * (20/5280). It has two sub-assumptions: the first one is that arriving drivers will choose the shorter lane in queue, keeping the length in each open lane essentially equal; the second one is that the taper will not affect the length of cars in queue, which is not the actual case, but seems an acceptable approximation.

- Passenger car equivalence (PCE) per truck is two.

- Average lane space used by queued passenger cars is 20 feet.

- Within an hour, the traffic volume of each ten minutes is equal.

OkDOT Model Strengths

The OkDOT model is easy to use. Its logic is clear and free from mistakes.

- Most inputs are clearly defined and easily to be determined.

- Model logic is clear and free from mistakes.

- Complex underlying relationship between parameters is hidden from customers.

- It is convenient for customers to observe the effect on outputs caused by changing inputs.

- The model handles the conversion of different types of vehicles into passenger cars skillfully.

OkDOT Model Errors and Weaknesses

Minor Errors

There are three minor errors we found in the OkDOT model.

The first error is in “LR Input Sheet”: The outputs for Nighttime Non-Peak hours (7:00 p.m.-6:00 a.m.) only use outputs from 7:00 p.m. to Midnight. It is corrected by using outputs from 7:00 p.m. to Midnight and outputs from Midnight to 6:00 a.m.

The second error is a unit error in “LR Table Sheet.” The unit for Roadway Capacities should be pcphpl (passenger cars per hour per lane) instead of vphpl (vehicles per hour per lane).

The third error is in “LR Calculation Sheet.” Number of Lanes Closed at 24:00 (Cell L161) has an invalid formula, which will always give the value of zero. It is corrected to be equal to Number of Lanes Closed during Midnight-1:00 a.m.

Model Weaknesses

<u>Presentation Output to User</u> Tables 1-6 and 1-7 present a comparison between the OkDOT regular tabular output and an overlaid graphical profile of predicted queue growth and decline.

- Regular tabular output as found in current tool (Table 1-6)

- Graphical profile of predicted queue easily created and linked to the tabular output (Table 1-7)

The added Max Queue Length Graph shows the queue length and its tendency more directly, and proved quite useful in our many runs of the Baseline OkDOT tool and the two additional versions we created based on *HCM* 2000.

Table 1-6. Regular Tabular Output of the OkDOT Spreadsheet

OkDOT Model
NC Site #1 I-95 NB

Analysis Code (use code from table):	IR
Direction (Inbound or Outbound):	Inbound
AADT (both directions)	40,000
Percent Trucks:	26.20%
Passenger cars / day:	50,480
Number of lanes (one direction):	2
Free flow speed (mph):	70
Basic lane capacity (pcphpl):	2400
Max. queue length limit (miles):	99
Confidence Level (%) - enter from 20-100	100
Delay ($/hour) passenger car:	$10.00
Fuel costs ($/gal):	$2.00
Average # people per vehicle:	1.2

	Morning Peak 6am-9am	Daytime Non-Peak 9am-3pm	Evening Peak 3pm-7pm	Nighttime Non-Peak 7pm-6am	Daily (24 Hr.) Summary
Total Cost of Delay ($):	50	7,908	0	0	7,957
# of Hrs. Lanes Closed:	1	2	0	0	3
Ave Cost of Delay/Hr. ($):	17	1,318	0	0	332
Traffic Volume:	2,804	10,203	7,510	7,244	27,761
Max # of Cars in Queue:	0	612	0	0	612
Max Queue Length (mi.):	0.0	1.2	0.0	0.0	1.2

Analysis Code (enter two-letter code above):					
IU	Interstate - Urban (ODOT)	**AU**	Arterial - Urban (ODOT)	**UF**	User Defined Factors - enter values on LR Table Sheet
IR	Interstate - Rural (ODOT)	**AR**	Arterial - Rural (ODOT)	**UV**	User Defined Volumes - enter values on LR Table Sheet

		Interstate – Rural								
Hour	# of Lanes Closed [1]	AADT Factor (K)	Direction Factor (D)	Volume [2]	Limiting Capacity	Max Cars in Queue	Delay Cost	Fuel Cost	Total Costs	Max Queue Length (mi.)
Mid.-1am	0	1.830	0.55	508	4,800	0	0	0	0	0.0
1am-2am	0	1.420	0.55	394	4,800	0	0	0	0	0.0
2am-3am	0	1.180	0.55	328	4,800	0	0	0	0	0.0
3am-4am	0	1.030	0.55	286	4,800	0	0	0	0	0.0
4am-5am	0	1.100	0.55	305	4,800	0	0	0	0	0.0
5am-6am	0	1.430	0.55	397	4,800	0	0	0	0	0.0
6am-7am	0	2.330	0.55	647	4,800	0	0	0	0	0.0
7am-8am	0	3.470	0.55	963	4,800	0	0	0	0	0.0
8am-9am	1	4.300	0.55	1,194	1,236	0	0	50	50	0.0
9am-10am	1	5.230	0.55	1,452	1,236	216	1,296	207	1,503	0.4
10am-11am	1	5.880	0.55	1,633	1,236	612	4,968	586	5,554	1.2
11am-Noon	0	6.170	0.55	1,713	4,800	98	808	43	851	0.2
Noon-1pm	0	6.230	0.55	1,730	4,800	0	0	0	0	0.0
1pm-2pm	0	6.470	0.55	1,796	4,800	0	0	0	0	0.0
2pm-3pm	0	6.770	0.55	1,880	4,800	0	0	0	0	0.0
3pm-4pm	0	7.030	0.55	1,952	4,800	0	0	0	0	0.0
4pm-5pm	0	7.100	0.55	1,971	4,800	0	0	0	0	0.0
5pm-6pm	0	6.920	0.55	1,921	4,800	0	0	0	0	0.0
6pm-7pm	0	6.000	0.55	1,666	4,800	0	0	0	0	0.0
7pm-8pm	0	5.050	0.55	1,402	4,800	0	0	0	0	0.0
8pm-9pm	0	4.250	0.55	1,180	4,800	0	0	0	0	0.0
9pm-10pm	0	3.550	0.55	986	4,800	0	0	0	0	0.0
10pm-11pm	0	2.950	0.55	819	4,800	0	0	0	0	0.0
11pm-Mid.	0	2.300	0.55	639	4,800	0	0	0	0	0.0

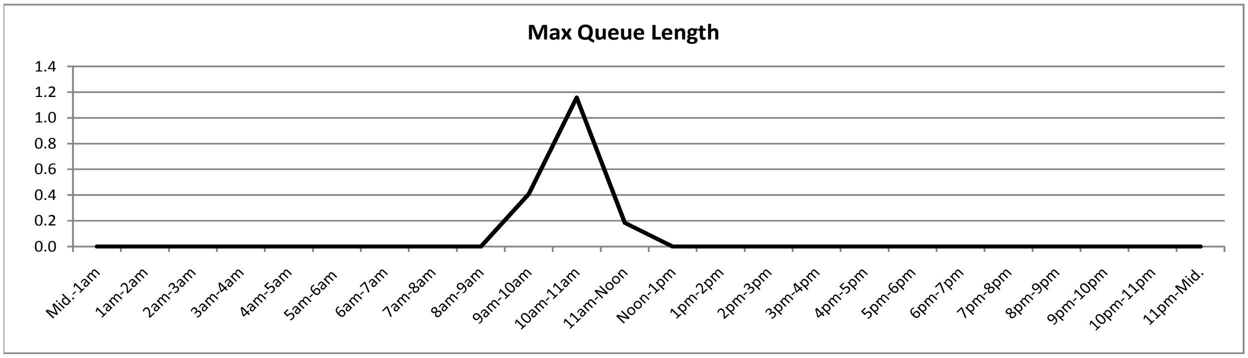
(1) One direction only.
(2) Passenger car volumes (adjusted for % of trucks) for one direction only

Table 1-7. Queue Layout Profile Added to Regular Tabular Output

OkDOT Model
NC Site #1 I-95 NB

Analysis Code (use code from table):	IR
Direction (Inbound or Outbound):	Inbound
AADT (both directions)	40,000
Percent Trucks:	26.20%
Passenger cars / day:	50,480
Number of lanes (one direction):	2
Free flow speed (mph):	70
Basic lane capacity (pcphpl):	2400
Max. queue length limit (miles):	99
Confidence Level (%) - enter from 20-100	100
Delay ($/hour) passenger car:	$10.00
Fuel costs ($/gal):	$2.00
Average # people per vehicle:	1.2

	Morning Peak 6am-9am	Daytime Non-Peak 9am-3pm	Evening Peak 3pm-7pm	Nighttime Non-Peak 7pm-6am	Daily (24 Hr.) Summary
Total Cost of Delay ($):	50	7,908	0	0	7,957
# of Hrs. Lanes Closed:	1	2	0	0	3
Ave Cost of Delay/Hr. ($):	17	1,318	0	0	332
Traffic Volume:	2,804	10,203	7,510	7,244	27,761
Max # of Cars in Queue:	0	612	0	0	612
Max Queue Length (mi.):	0.0	1.2	0.0	0.0	1.2



Analysis Code (enter two-letter code above):					
IU	Interstate - Urban (ODOT)	**AU**	Arterial - Urban (ODOT)	**UF**	User Defined Factors - enter values on LR Table Sheet
IR	Interstate - Rural (ODOT)	**AR**	Arterial - Rural (ODOT)	**UV**	User Defined Volumes - enter values on LR Table Sheet

		Interstate – Rural								
Hour	**# of Lanes Closed [(1)]**	**AADT Factor (K)**	**Direction Factor (D)**	**Volume [(2)]**	**Limiting Capacity**	**Max Cars in Queue**	**Delay Cost**	**Fuel Cost**	**Total Costs**	**Max Queue Length (mi.)**
Mid.-1am	0	1.830	0.55	508	4,800	0	0	0	0	0.0
1am-2am	0	1.420	0.55	394	4,800	0	0	0	0	0.0
2am-3am	0	1.180	0.55	328	4,800	0	0	0	0	0.0
3am-4am	0	1.030	0.55	286	4,800	0	0	0	0	0.0
4am-5am	0	1.100	0.55	305	4,800	0	0	0	0	0.0
5am-6am	0	1.430	0.55	397	4,800	0	0	0	0	0.0
6am-7am	0	2.330	0.55	647	4,800	0	0	0	0	0.0
7am-8am	0	3.470	0.55	963	4,800	0	0	0	0	0.0
8am-9am	1	4.300	0.55	1,194	1,236	0	0	50	50	0.0
9am-10am	1	5.230	0.55	1,452	1,236	216	1,296	207	1,503	0.4
10am-11am	1	5.880	0.55	1,633	1,236	612	4,968	586	5,554	1.2
11am-Noon	0	6.170	0.55	1,713	4,800	98	808	43	851	0.2
Noon-1pm	0	6.230	0.55	1,730	4,800	0	0	0	0	0.0
1pm-2pm	0	6.470	0.55	1,796	4,800	0	0	0	0	0.0
2pm-3pm	0	6.770	0.55	1,880	4,800	0	0	0	0	0.0
3pm-4pm	0	7.030	0.55	1,952	4,800	0	0	0	0	0.0
4pm-5pm	0	7.100	0.55	1,971	4,800	0	0	0	0	0.0
5pm-6pm	0	6.920	0.55	1,921	4,800	0	0	0	0	0.0
6pm-7pm	0	6.000	0.55	1,666	4,800	0	0	0	0	0.0
7pm-8pm	0	5.050	0.55	1,402	4,800	0	0	0	0	0.0
8pm-9pm	0	4.250	0.55	1,180	4,800	0	0	0	0	0.0
9pm-10pm	0	3.550	0.55	986	4,800	0	0	0	0	0.0
10pm-11pm	0	2.950	0.55	819	4,800	0	0	0	0	0.0
11pm-Mid.	0	2.300	0.55	639	4,800	0	0	0	0	0.0

[(1)] One direction only.
[(2)] Passenger car volumes (adjusted for % of trucks) for one direction only

Allows Illogical Inputs The model does not check the rationality of inputs. The calculation is made such that misleading answers may appear even given illogical input. For example, a two-lane road with two lanes closed will still generate compelling-looking data.

Interpretation and Use of Confidence Level Confidence level is an important parameter which directly affects work zone capacity. The problems concerning with this input are listed as follows:

- Very subjective

  Due to the lack of instruction provided to help users decide confidence level input, the choice is very subjective and depends on the user's experience and "best guess." In most cases, users are likely to choose a conservative level and thus overestimate queue formation. Instruction such as matching confidence level to several levels of work zone intensity, and describing the condition that corresponds to each level of intensity would greatly enhance the effectiveness of the model. In Chapter 4 testing, we actually use such an approach with six intensity levels to simulate the decision of a traffic planner using the OkDOT Baseline tool and having to make a judgment on which CL to use as input.

- Unclear in meaning and effect on model

  The meaning of confidence level and its effect on the model is unclear. The confidence level works in a way that the increase of confidence level leads to the decrease in capacity, which is illustrated in Table 1-8 below. This tendency shows that confidence level reflects the conservative level of the user. The more conservative the user is, the higher the confidence level which may be chosen.

Table 1-8. Confidence Level Impact on Lane Capacity Reduction in OkDOT Baseline Version

Confidence Level (CL)	Capacity
0%	1465
20%	1419
40%	1374
60%	1328
80%	1282
100%	1236

- Refers to an obsolete version of the *Highway Capacity Manual* (*HCM*,1994), whose capacity tables are known to under-predict actual lane capacity at highway work zones.

Fails to Consider Complex Factors The model makes no adjustments for the following factors: weather, work zone intensity, ramps, and the work zone's design (length of taper, speed zones, signage, etc.). Some of these factors can be manipulated into the model to some degree via other factors; for example, weather can be reflected by using a slower speed. Modeling days of traffic with irregular traffic patterns (major sporting events, Friday to Saturday traffic, Sunday to Monday traffic, etc.) is not practical; therefore, the model does not consider these events.

Fails to Account for Effects of Diversion The OkDOT method overestimates traffic impacts of work zones due to inability to account for effects of those drivers who divert to other routes. The issue of traffic diversion is not as important for rural roadways as it is for urban high-volume roads (Ullman and Dudek, 2003). For urban work zones, these authors state, and evidence supports that queues tend to grow but stabilize in length, even when input-output models predict they should keep growing.

Uses OkDOT Allocation Factor Unless the user inputs self-defined volume or allocation factors (K Factor, D Factor), the model will run the calculation based on built-in allocation factors derived from historical traffic patterns in the state of Oklahoma.

2.0 Data Collection Activity

In order to test the OkDOT model and any "versions" we might create, a set of real work zone "test cases" was needed. As stated in Chapter 1, many state DOTs have sponsored studies of work zone lane closures with the objective of quantifying the capacity of open lanes in the work zone. Almost always there would be an hour-by-hour description of the free-flow traffic volume approaching the site, and the flow (vph) exiting the work zone would be used to measure work zone lane capacity. Sometime approach and work zone speeds are recorded, and fewer times, queue start time, queue lengths, and queue end time were recorded. The date, time, location, and configuration of the work zone are always provided, along with a description of the work. Not knowing which researchers had actually measured queue start time and length, we decided to "cast a wide net" and contacted researchers in eight states asking them to share work zone data in electronic or paper formats. We also developed a data collection form for on-site observations at Alabama work zones, and a method we successfully used when on-site to record data using three "spotters."

Data Collection Sheets for Alabama

We were committed to on-site data collection at Alabama work zone for two reasons: (1) We could control the frequency, accuracy, and extent of data collected during a temporary work zone and (2) We could develop insights into the behavior and dynamics of freeway work zone, such as the behavior of drivers approaching the work zone, the effect of police presence on driver willingness to slow down and merge, the effect of entrance ramp traffic on open lane flow, how rapidly queues form and dissipate, and what happens when an equipment move closes down all lanes for a short period.

We developed the Data Collection Form shown in Figure 2-1. A faculty member would escort two or three students to the work zone site, and would record the data in Sections A, B, and D on site. The faculty member would take data at random times during the observation period to estimate the percentage of heavy vehicles in Section C. The sheets on the second and third page of Figure 2-1 were used by the students to make observations in ten-minute increments. The students carried watches that were pre-set to read out identical times, hence were synchronized. One student was positioned in the approach zone and using a mechanical counter, would record traffic counts "in" using ten-minute increments. Another student was positioned at the end of the work zone and would count vehicles "out" using the same ten-minute increments. Finally, the third student would observe the traffic slowing to accommodate the taper and entering the work zone. He/she would record the length of the queue (if one formed) to the nearest 100 feet using a series of 53 "marker poles" we would position at 100-foot increments upstream from the work zone, using a measurement wheel. At the end of observation, the professor would retrieve the poles and collect the data sheets from each student observer. The professor would rotate from position-to-position to bring snacks and permit breaks for the students.

Alabama Work Zone Descriptions

For the first observation, Dr. Turner escorted two students to an evening (6:30 p.m.-3:00 a.m.) temporary work zone on I-65 NB, at MP 176, on the evening of Tuesday, July 29, 2008. This "interstate urban, outbound" work was in-house maintenance by ALDOT, repair of spalling concrete on a bridge deck. The outside and middle lanes of three were closed, but the time of day was well-chosen to avoid queue formation. Observations stopped at 9:00 p.m. The percent of heavy vehicles was estimated at 20%, and work intensity at level 2.

Work Zone Lane Closure Analysis Model Data Collection Form

Date: ____________________ City or County: __________________

Location of lane closure: ____________________

Observation starts and ends times: ____________________

Lane closure starts and ends times: Temporary ☐ Extended ☐

Type of activity: Construction ☐ Maintenance ☐

Observers: 1. ______________ 2. ______________ 3. ______________ 4. ______________

A. Climatic Environment	
Please enter or circle the right choice.	*Comments*
Light condition (Day/ Night)	
Road condition (Wet/ Icy/ Dry/ Snowing)	
Weather (Clear/ Raining/ Snowing)	
Pavement edge/center lines (clear/ faint/None)	

B. Highway Information	
Please enter or circle the right choice.	*Comments*
Highway Name	
Type of area (Rural/Urban)	
Classification (Freeway/ Arterial/ Collector/ Local)	
Number of lanes of each direction (One/ Two/ Three/ Four)	
Width of each lane (feet)	
Location of lanes closed (Center lane/ Shoulder lane)	
Length of lane closed (feet)	
Shoulder (Exist/ Missing/Damaged)	
On-ramp present immediately upstream from WZ (yes/ no)	

C. Vehicles
Percentage of trucks (estimate several times if possible):

D. Traffic Control			
Speed limit (miles/hr)			
Average speed (miles/hr) Inbound: Outbound:			
Traffic volume (vehicles/hr)			
Type of merge barrier? Concrete / Barrels / Cones / Nothing			
Advanced warning	Flagger control	Flasher Device	Signs
	Highly visible? Yes/ No Positioned correctly? Yes/ No Need additional signing? Yes/ No		
Comments			

Figure 2-1. Work zone lane closure analysis model data collection form.

Queue Start Times: 1. 2. 3. End Times: 1. 2. 3. Durations: 1. 2. 3.																									
Observation		Hour 1 Start time:						Hour 2 Start time:						Hour 3 Start time:						Hour 4 Start time:					
		1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Queue Length (200 foot units, to nearest 0.5 unit)	Lane 1																								
	Lane 2																								
	Lane 3																								
Incoming traffic volume (vehicles/10 min.)																									
Departing the WZ traffic volume (vehicles/ 10 min.)																									
Average Incoming traffic volume (vehicles/hr)																									
Maximum of queue length (miles)																									
Maximum number of vehicles in queues (vehs)																									

Figure 2-1. Work zone lane closure analysis model data collection form (continued).

Queue Start Times: End Times: Durations:																									
Observation		Hour 5 Start time:						Hour 6 Start time:						Hour 7 Start time:						Hour 8 Start time:					
		1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Queue Length (200 foot units, to nearest 0.5 unit)	Lane 1																								
	Lane 2																								
	Lane 3																								
Incoming traffic volume (vehicles/10 min.)																									
Departing the WZ traffic volume (vehicles/ 10 min.)																									
Average Incoming traffic volume (vehicles/hr)																									
Maximum of queue length (miles)																									
Maximum number of vehicles in queue (vehs)																									

Figure 2-1. Work zone lane closure analysis model data collection form (continued).

This was an initial visit by the UA team to get an idea of how to access a site, what data could reasonably be collected, where to stand, what equipment (safety and data collection) would be needed, etc. An observation that shaped how we would conduct future data collection efforts was: "It would have been better to arrive on-site earlier to find the best vantage points for data collection, and to measure out standard length to help in estimating queue lengths." Also, "It would be good to carry three data collection people." No queues were observed at this site.

In fall 2008, a data collection opportunity was accepted in Morgan County, specifically, on I-65 NB at MP 317-320 (a dual bridge with asphalt paving at interface of bridges with roadway, both ends). Dr. Batson escorted three students to the site, with observation taken from 8:50 a.m. to 12:30 p.m. There was an entrance ramp 2700' upstream from the work zone, and a trooper present throughout the day. The percentage of trucks was estimated at 21%, and the speed limit was stepped down to 50 mph approaching the work zone. The average hourly traffic volume during our 3 hour 50 minute observation period was 822 vph, and this explains why no queue formed even though one lane was closed. The only queues observed were during equipment moves that would block the open lane for five-ten minutes at a time. The longest duration blockage (about 20 minutes) resulted in a queue of length 3400 feet = 0.644 miles. Three other "total blockage" queues were observed with length proportional to the duration of 10-20 minutes. The nature of the work we observed, including narrow shoulders on the two bridges and a lot of equipment on-site, led us to classify the work intensity here as a level 3. Two safety observations were:

- When the approach involves horizontal curves, the cones or barrels need to be set closer together.

- A stop sign instead of a yield at entrance to interstate single open lane is very confusing to drivers – some would slam on brakes, while others would ignore the stop sign and speed up to merge into the single lane of traffic.

Another opportunity arose in spring 2009 on January 7, 2009 in Chilton county on I-65 SB, MP 209 (bridge pavement repair, intensity level 2). The bridge itself was only 200 feet long. Again two lanes were reduced to one, with the total lane closure of approximately 4200 feet. Three students accompanied Dr. Batson again; a trooper was present the entire day. The speed limit was stepped down to 45 mph well in advance of the work zone, using fixed signs. A message board was positioned at the start of the taper. Still, vehicles we observed moving 60-70 mph at the start of taper and averaged around 50 mph passing the trooper, who was using arm motions out an open window to signal drivers to reduce speed. Outbound speed from the work zone was slower, perhaps 40 mph. The average in-flow was 900 vph during the observation period 10:00 a.m.-3:50 p.m., too low to predict a queue would form with the relatively low intensity work. During the final hour of observation, the in-flow reached 950 vph and we did observed two short queues, one of 200 feet and the other of 400 feet. These quickly dissipated, however.

The Alabama work zone data collection activity was less than we had hoped for. But, the reality is that most work on rural Alabama interstates (with one of two lanes open) will not create a queue – the traffic volume is just not large enough. Furthermore, temporary work zones on urban interstates (such as Alabama Case #1 above) are typically set on days of the week and at hours of the day when traffic volume are such that a queue should not form. When we obtained the extensive and diverse South Carolina data set (35 freeway sites), described later in this chapter and in more detail in Chapter 4, our efforts become focused on testing and calibration. The three Alabama sites were used in validating the version of the OkDOT model we recommend in Chapter 4.

Data Request Sheets for Other States

Through literature search, the researchers found references to data collection activities at freeway work zones in eight other states: Ohio, North Carolina, South Carolina, Maryland, Indiana, Wisconsin, Iowa, and Texas. We already had data from Illinois (Benekohal, et al. 2003) on three freeway work zones, which we used in preliminary work in fall 2008. During December 2008, we contacted a senior researcher in each state (most were at a state university) via e-mail with a professional cover letter and the Data Request Sheet in Figure 2-2. This sheet was developed to explain what sorts of records we were seeking. We did not expect other researchers to send us data organized along these lines. Four responded that they either did not measure queues, or if they did, the data had been lost over the years. Together with Illinois, a total of five researchers did cooperate by sending us reports they had prepared that contained at least some queue documentation.

University of Alabama project (2008-09) with Alabama Dept. of Transportation (ALDOT) to Calibrate and/or Modify a Spreadsheet Model (originated with OkDOT) Used to Predict Queue Formation Timing and Length in Freeway Work Zones with Lane Closures

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Data being sought in January 2009:

We are seeking interstate work zone data from other states which would include at a minimum time-indexed traffic in-flow, queue length (either in linear distance or number of vehicles), and traffic out-flow exiting the work zone. The time index could be hourly, every ten minutes, or even minute-by-minute. Data does not have to be in a specific format, though spreadsheet data with time of day down the rows, and various observed data in the columns would be preferred. We would use whatever cases you send us as part of a database to calibrate the model in use by ALDOT.

Data Elements that would be desirable with each data set, if available:

- Date of observation
- Start and end times of observations
- Weather conditions, if known
- Highway, direction, and milepost(s)
- ADT, if known
- Type of interstate (rural, suburban, urban)*
- Work zone activity that caused the lane closure, and any other indications of work zone intensity
- Any entrance ramps in advance warning area of the work zone (yes, no)?
- Ordinary number of lanes in direction affected by work zone*
- Number of lanes closed (or open)*
- Which lanes were closed, if known
- Traffic volume in (vehicles/time unit)—in free flow approach to advance warning area*
- Speed limits in free flow approach, advance warning, transition, and work activity areas
- Queue lengths (with unit of measure indicated) observed*
- Traffic volume departing work zone (vehicles/unit time)
- P = Percentage of heavy vehicles in traffic during the observation*
- Conversion factors used (if known): passenger car length assumed; E = passenger car equivalent factor for heavy vehicles.

The six data items with * are the minimal set needed.

Direct questions or comments to Dr. Batson at the above e-mail address or telephone number.

Thanks So Much if you can assist us in this research endeavor! Bob Batson

Figure 2-2. Data request sheet.

Data Obtained from Other States

Work zone data with queue characteristics recorded was received in the form of reports from *five* states: Illinois (IL), Ohio (OH), South Carolina (SC), North Carolina (NC), and Wisconsin (WI). In addition, the Illinois lead researcher sent us electronic files on three work zones where queues formed. We will describe each of these work zone data sets *generally* in subsections below. *Detailed* descriptions of the work zones used in our testing appear in the tables in Chapter 3. It turned out that the South Carolina data became our test data bank (32 of 35 sites data were useable); the Ohio data turned out to be simulated (not real), but helped us verify the logic in our *HCM* 2000 version of the OkDOT tool; and the three North Carolina work zones with queue information became (along with the three Alabama work zones) the validation data for the recommended modification to the OkDOT tool now in use at ALDOT. The Illinois data, once we had analyzed it and tried to predict it using the OkDOT tool, was limited to such short durations as to be unusable in our testing. The Wisconsin data was from permanent urban interstate work zones of several miles in length, with multiple entrance/exit ramps, and did not behave in a predictable manner; hence, we could not use it.

Illinois Data

Upon contacting the lead author of (Benekohal, et al. 2003), he sent us Excel files for three Illinois work zone sites where queues arose:

- I-74 EB MP 5
- I-55 NB MP 55-56
- I-55 SB MP 55-56.

with data correspondences as identified in Table 2-1:

Table 2-1. Data Correspondences Between Illinois and Oklahoma

Illinois Data	OkDOT Model
demand	volume
departing volume	limiting capacity
# of vehicles in queue	cars in queue
queue length	queue length

The following formulas were found to apply in the calculation of Illinois data:

- Calculation is based on three-minute moving average.
- Calculation formulas:
  1 hour Volume = (average demand in every min)*60
  1 hour Capacity = (average departing volume in every min)*60

1 hour Max # of Vehicles in Queue = max (# of vehicles in queue at the end of every min)
1 hour Max Queue Length = max (queue length at the end of every min)

- Data recorded at k time point represents information between k and (k+1) time period.

Tables 2-2 – 2-4 provide the basic parameters of the three work zone sites. Note the observation period is two hours in the first set, and *slightly less than one hour* for Illinois data sets 2 and 3.

Table 2-2. Data for I-74 EB MP 5

	Period Observed	1 hour			
		Volume	Limiting Capacity	Cars in Queue	Max. Queue (mi.)
4:00 p.m.-5:00 p.m.	4:15-4:59	1649	1315	264	1.33
5:00 p.m.-6:00 p.m.	5:00-5:59	1204	1298	358	1.8
6:00 p.m.-7:00 p.m.	6:00-6:15	951	1351	94	0.47

Table 2-3. Data for I-55 NB MP 55 and 56

	Period Observed	1 hour			
		Volume	Limiting Capacity	Cars in Queue	Max. Queue (mi.)
5:00 p.m.-6:00 p.m.	5:10-5:59	1435	1008	402	2.3
6:00 p.m.-7:00 p.m.	6:00-6:03	923	1010	361	2.07

Table 2-4. Data for I-55 SB MP 56 and 55

	Period Observed	1 hour			
		Volume	Limiting Capacity	Cars in Queue	Max. Queue (mi.)
1:00 p.m.-2:00 p.m.	1:15-1:59	1349	988	357	2.18
2:00 p.m.-3:00 p.m.	2:00-2:14	1264	992	326	1.99

We used the input data in Table 2-5 in early trials using the OkDOT baseline tool to predict queue start time and maximum queue length for these three real situations.

Table 2-5. Simulation Input

	I-74 EB MP5	I-55 NB MP55&56	I-55 SB MP56&55
Analysis Code	IU	IU	IU
Direction	Inbound	Outbound	Inbound
AADT	43,200	25,100	25,100
Percent Trucks	3.90%	13.06%	18.08%
Number of lanes	2	2	2
# of lanes closed	1	1	1
Free flow speed	49.03	55	45
Max. queue length limit	99	99	99
Confidence Level	20%, 50%, 100%	20%, 50%, 100%	20%, 50%, 100%

The results of running these scenarios through the OkDOT baseline tool are shown in Table 2-6 (queue start time) and Table 2-7 (queue length estimates). In both cases, the OkDOT model could not match the data provided by Illinois researchers – results were poor. Note that we did not receive information on the start-up of the queue, and at the end of each Illinois data set, the queue still existed. This incomplete queue formation/dissipation data, and data from such short observation period, simply could not be used in our calibration testing. The Illinois data also used different assumptions about passenger car length, and the conversion of truck percentage into average vehicle length, than the OkDOT model. Bottom line, these data provided good early exercises for the learning about the ALDOT model, its data requirements, and what we were looking for in future test cases from other states.

Table 2-6. Queue Start Time Results

	Illinois	OkDOT		
	I-74 EB MP5	CL=20%	CL=50%	CL=100%
Starting Time	4:18 p.m.	3:00 p.m.	3:00 p.m.	12:00 a.m.
Ending Time	6:08 p.m.	22:20	11:00 p.m.	0:20 a.m. next day

	Illinois	OkDOT		
	I-55 NB MP55 and 56	CL=20%	CL=50%	CL=100%
Starting Time	5:10 p.m.	4:00 p.m.	4:00 p.m.	4:00 p.m.
Ending Time	N/A	5:50 p.m.	6:20 p.m.	7:00 p.m.

	Illinois	OkDOT		
	I-55 SB MP56 and 55	CL=20%	CL=50%	CL=100%
Starting Time	1:19 p.m.	7:00 a.m.	7:00 a.m.	7:00 a.m.
Ending Time	N/A	8:00 a.m.	8:10 a.m.	9:00 a.m.

Table 2-7. Queue Length Prediction Results

	Volume	Limiting Capacity	Max # of Cars in Queue	Queue Length
I-74 EB MP5	overestimated	acceptable	overestimated	overestimated
I-55 NB MP55 and 56	good	overestimated	acceptable	underestimated
I-55 SB MP56 and 55	underestimated	overestimated	underestimated	underestimated

Ohio Data

A paper by Adeli and Jiang (2003) alerted us to a total of 168 data sets on work zone capacity. Some provided as few as four variables (number of lanes, number of lanes closed, work zone intensity, and work zone duration) or as many as 14 (the four just mentioned, along with percentage of heavy trucks, grade of pavement, work zone speed, proximity of ramps to work zone, work zone location, length of the lane closure, work times, work day of week, weather conditions, and driver composition). Of these 168 sets, only three from North Carolina and four from Ohio contained queue information, hence were usable in our research.

The four Ohio cases are described in Jiang and Adeli (2003), and are labeled Examples 1A, 1B, 2A, and 2B. These four cases were used to test "a new freeway work zone traffic delay model" which depended on only two variables: (1) the length of the work zone segment and (2) the starting time of the work zone. Average hourly traffic data was the main input. We discovered that the four cases used in their model testing were “simulated” 24-hour work zone traffic volume and queued vehicle results, not real data. But, because the model they used to generate the Examples 1A, 1B, 2A, and 2B was based on *HCM* 2000, their tables and graphs provided an excellent way to verify the correctness of our reprogramming of the OkDOT tool to use *HCM* 2000 work zone lane capacity equations and input factors.

Table 2 in Jiang and Adeli (2003) describes Example 1A as ADT = 1000 vph with a maximum traffic flow of 2430 at 16:00; Example 1B has ADT = 2000 vph with a maximum traffic flow of 4840 at 16:00. The work zone configuration is two lanes reduced to one open lane. The maximum queued vehicles in 1A is 1220 at 16:00, with a queue existing for seven hours, 12:00-18:00. The maximum queued vehicles in 1B is 3640 at 16:00, with a queue existing from 5:00 until 20:00. In Chapter 4, Figure 4-2, the reader can see the queue profile for Ohio 1B and how our OkDOT *HCM* 2000 versions were able to track along with the profile, and for one set of input, match it exactly. Examples 2A and 2B are similar, but with a three lane freeway with one or two lanes closed, respectively.

South Carolina Data

Dr. Wayne Sarasua at Clemson and Dr. William Davis at The Citadel led a four-year study (2001-05) of freeway highway capacity for short-term work zone lane closures in South Carolina (Sarasua, et al. 2006). Phase I of this SCDOT-sponsored research was completed in May 2003, and focused on “threshold volumes” for two-to-one lane closure work zone configurations. A total of 23 work zones were observed, and besides capacities also noted were queue start times and maximum queue lengths. Phase 2 expanded to 12 other work zones, including three-to-two and three-to-one lane closures, and was completed in May 2005.

A threshold volume is the number of vehicles per lane per hour that can pass through a short-term interstate work zone lane closure with minimum or acceptable levels of delay as defined by the state DOT. The South Carolina researchers observed that threshold limits are a function of traffic stream characteristics, highway geometry, work zone location, type of construction activities, and work zone configuration. Therefore, these researchers developed an alternative to the standard *HCM* 2000 work zone lane capacity equation as follows:

$$C = (1460 + I) * f_{HV} * N$$

where I = adjustment factor for type, intensity, length, and location
f_{HV} = heavy vehicle adjustment factor
N = number of lanes open through the work zone.

One of their findings was that an 800 vehicles per hour per lane threshold, previously used by SCDOT, was too low. The authors stated that based on their Phase I, SCDOT increased their threshold volume to 1,000 vehicles per hour per lane. Another interesting finding by this research team was that passenger car equivalents (PCEs) differed for various speed ranges, specifically:

- Less than 15 mph, PCE for trucks = 2.47
- 15-30 mph, PCE for trucks = 2.22
- 30-45 mph, PCE for trucks = 1.90
- 45-60 mph, PCE for trucks = 1.90.

Sarasua, et al. (2006) states "observed differences in PCE values are primarily due to acceleration and deceleration characteristics of trucks, and are further explained by understanding that for speeds less than 30 mph, vehicles are likely traveling in a forced flow state where acceleration and deceleration are cyclically surging within the traffic stream." Of course, *HCM* 2000 does not account for such variable PCE values; our Chapter 4 recommendation that ALDOT use PCE = 2.1 seems a good compromise between the 1.9 the observed for speeds greater than 30 mph, and the 2.22 for speeds in the range of 15-30 mph. Speeds less than 15 mph are unusual once vehicles leave the queue and are in the work zone.

A full accounting of the 35 South Carolina work zones will be presented in a table in Chapter 3. It turned out that three of the sites were "rained out," hence 32 of these sites were usable as our test data. The diversity of the sites was outstanding, as illustrated in these various descriptors and counts of the 32 sites in Table 2-8.

Table 2-8. Descriptors and Counts for South Carolina Work Zones

Descriptors	Counts
Lane Closure:	
2 to 1	14
3 to 2	4
3 to 1	12
4 to 2	1
4 to 1	1
Inbound	14
Outbound	18
Intensity Level	
1	2
2	7
3	5
4	8
5	8
6	2
Interstate Urban (IU)	27
Interstate Rural (IR)	5

North Carolina Data

Dixon and Hummer (1996) collected capacity and delay field data at 23 North Carolina sites in the early 1990s. They found that North Carolina work zone capacities were higher than the *HCM* 1994 capacities by at least 10%, confirming observations of others. We contacted Dr. Hummer, and he provided us with the NC State report referenced above. Traffic demand exceeded work zone capacity at ten sites during the observation periods; however, the report only details the queuing results for three of these ten sites. We use these three sites in the validation phase of our research on a modified version of the OkDOT tool, in Chapter 4.

Dixon, et al. (1996) confirmed from their study that intensity of work activity and the type of site (rural vs. urban) strongly affected work zone capacity. They found an interesting phenomenon comparing urban to rural two-to-one work zones. For moderate intensity work, they found that urban sites had about 30% higher capacity than rural; for heavy intensity work, urban sites had about 20 % higher capacity than rural sites. The explanation was that rural drivers are often encountering the work zone for the first time, whereas urban drivers are predominately commuters from home to work or school, hence become familiar with temporary work zones that may be in effect over multiple days. We will develop recommendations for ALDOT on adjustments to make when estimating queue potential (dependent on capacity) for urban work zones, based on the findings of these North Carolina researchers and those in Wisconsin, reported next.

Wisconsin Data

Researchers Lee and Noyce (2007) at the University of Wisconsin were sponsored by the Wisconsin Department of Transportation (WisDOT) to develop and calibrate a spreadsheet-based tool called Work Zone Capacity Analysis Tool (WZCAT). WZCAT was developed by WisDOT as a tool to predict delays and queues for short-term (daily) work zone lane closures. WZCAT bases its queue length predictions on a simple input/output model, similar to the OkDOT tool, with the capacity of the work zone controlling the throughput. Apparently, WZCAT has a fixed capacity of 1500 vphpl for work zones, so is much simpler than the models used by ALDOT and SCDOT.

Queue length data were observed for 12 short-term work zones on urban freeways in metropolitan Milwaukee, WI. These were extremely long work zones (average length 0.9 miles, three over 1.2 miles). It is at this point that their calibration study ran into significant problems. First, the model WZCAT grossly overestimated the maximum queue length. Because these were urban freeway work zones of approximately one mile in length, with multiple traffic count detectors embedded in the roadway, the researchers had a choice of which approach volume to use. But even using the lowest hourly flows from among the applicable counters, the maximum queue length was overestimated by a factor of five or more. Secondly, at all these work zone sites, the queue length would grow at first and then stabilize, never growing any longer though traffic volumes continued to exceed predicted capacity of the open lanes. An explanation may be based on three arguments that may be useful for ALDOT as well:

1. In urban traffic flow, the driver may well be able to see a queue forming miles ahead of him, at least at certain points in his drive;

2. Even if he cannot see the queue ahead, he may receive advance warning from electronic message boards, the radio, or even cell phone communications from friends or family;

3. There are numerous exits and entrances on urban interstates, with many alternative "surface street" routes that can be taken by those experienced with the roadway system, or even by those simply "passing through" who have a navigation system in their vehicle.

Edara and Cottrell (2007) made a similar observation: "Urban areas have closely spaced freeway interchanges, and significant proportions of drivers take the ramp or use alternate routes to avoid the work zone queues (they are aware exist or may form). In addition, the demand at entrance ramps upstream of the bottleneck will not be the same as the demand under normal conditions; it will be lower. The results of these traffic diversions are that the queue length does not continuously increase with time; instead they stabilize after some time."

In summary, the 12 data sets reported in Lee and Noyce (2007) could not be used in our calibration analysis because their characteristics defy the input-output logic and queue growth phenomena inherent in the OkDOT model and its modified versions. Some other tool or set of rules will be needed by ALDOT for urban interstate work zones of significant length (one or more miles of work zone). Our calibration study and recommended spreadsheet tool accommodates urban work zones of shorter length; in fact, 27 of the 32 South Carolina work zones in the calibration data are urban.

3.0 Electronic Data Bank of Work Zone Queue Formation Cases

One of the deliverables mentioned in Chapter 1 was electronic descriptions of the freeway work zone cases we collected and used in our research on the OkDOT spreadsheet tool. In Chapter 3 we provide tabular descriptions, in standard format, of the work zone cases from Illinois, South Carolina, Alabama, and North Carolina – a total of 41 cases. In Chapter 3 we also describe electronic files we prepared for each of these 41 cases as they were input to the OkDOT Baseline Version, and two modified versions we named OkDOT *HCM* 2000 and OkDOT *HCM* 2000 Hybrid. The output of running each version with the given input file is provided as well, in the same file. A total of 123 Excel spreadsheet files are provided to ALDOT on a CD accompanying this report.

Work Zone Descriptions

Table 3-1 describes the three Illinois data sets we received from the University of Illinois. These were useful for learning early in this project, but proved unusable in our testing because: (1) we did not receive information on the start-up of the queue, and at the end of each Illinois data set, the queue was still existing and (2) the Illinois data from such short observation periods (1-2 hours); and finally, (3) the Illinois data used different assumptions about passenger car length, and the conversion of truck percentage into average vehicle length, than the OkDOT model versions. Hence, they are not used in Chapter 4.

Table 3-1. Illinois Work Zone Data Sets

Site #	Date	Start Time	End Time	Location	Code	Direction	AADT	T%	Original # of lanes	# of lanes Closed	Closure Geometry	Type of Work	WZ Intensity	Ramp	Queue?	Max QL
IL #1	7/25/2002	15:50	17:50	I-74 EB 5	IU	Outbound	43,200	3.9	2	1	Inside	Pavement Repair	5	Y	Y	1.8 mi
IL #2	8/2/2002	16:40	20:10	I-55 NB 55	IU	Outbound	25,100	13.06	2	1	Inside	Pavement Repair	5	N	Y	2.3 mi
IL #3	8/2/2002	10:30	14:30	I-55 SB 55	IU	Inbound	25,100	18.08	2	1	Outside	Pavement Repair	5	N	Y	2.18mi

Table 3-2 describes the six "validation data sets," three from Alabama and three from North Carolina.

Table 3-2. Alabama and North Carolina Work Zone Data Sets

Site #	Date	Start Time	End Time	Location	Code	Direction	AADT	T%	Original # of lanes	# of lanes Closed	Closure Geometry	Type of Work	WZ Intensity	Ramp	Queue?	Max QL
AL #1	7/28/2008	18:30	21:00	I-65 NB 176	IU	Outbound	76,170 (1)	20	3	1	Outside	Bridge deck patching	2	Y	N	0
AL #2	10/27/2008	8:50	12:30	I-65 NB 317	IR	Outbound	35,930 (2)	20	2	1	Outside	Paving asphalt-bridge interface	3	Y	N	0
AL #3	1/7/2009	10:00	15:50	I-65 SB 209	IR	Outbound	36,210 (3)	16.6	2	1	Outside	Bridge deck patching	2	N	Y	400'
NC #1	Spring 1995	8:30	11:00	I-95 NB*	IR	Inbound	40,000	26.2	2	1	Inside	Heavy with 2' clearance	6	Y	Y	1.55 mi
NC #2	Spring 1995	8:00	11:00	I-95 NB*	IR	Inbound	40,000	24.6	2	1	Outside	Heavy with 2' clearance	6	Y	Y	1.4 mi
NC #3	Spring 1995	8:30	11:00	I-95 NB*	IR	Inbound	40,000	18.8	2	1	Outside	Heavy with 2' clearance	6	N	Y	2.9 mi

* Johnston County, NC, but no MP given

(1) AADT 2007 for site I-65 at mile marker 172.295 in Montgomery county.

(2) AADT 2007 for site I-65 at mile marker 308.275 in Cullman county is 37,360; for site I-65 at mile marker 326.23 in Morgan county is 34,490. Mile marker 317 is between 308 and 326, use average AADT.

(3) AADT 2007 for site I-65 at mile marker 210.115 in Chilton county.

Table 3-3 describes the 35 South Carolina data sets we extracted from the research reports of Sarasua, et al. (2006) prepared at Clemson University. 32 of these cases became the "test data bank" employed in comparing the three versions of the OkDOT tool, the results of which are documented in Chapter 4. As described in Chapter 2, these 32 cases were remarkably diverse in work zone configuration, work intensity, and inbound vs. outbound direction of flow.

Table 3-3. South Carolina Work Zone Data Sets

Site #	Date	Start Time	End Time	Location	Code	Direction	T%	Closure Geometry	Type of Work	Equip. Activity	WZ Intensity	Ramp	Taper Length	WZ Length	Weather Conditions	5min hourly max	5min hourly min	Hourly max	Hourly min	AADT(1)	5min hourly max	5min hourly min	Hourly max	Hourly min	PCE(2)	Queue?	Max QL
1	9/12/2001	19:15	21:15	I-85 N MPM 32	IU	Inbnd	35.67%	Inside lane of 2 closed	Median Cable Guardrail	light	Level 2	Y	863	short	Warm, Clear	1056	648	-		50,000	1560	1044	-		2.53	none	-
2	9/13/2001	19:45	20:45	I-26 W MPM 54	IU	Outbnd	28.95%	Inside lane of 2 closed	Median Cable Guardrail	light	Level 2	Y	795	short	Warm, Clear	648	324	497	445	25,000	882	492	702	640	2.47	none	-
3	9/16/2001	19:40	21:15	I-85 S MPM 8.5	IU	Outbnd	12.75%	Inside lane of 2 closed	Median Cable Guardrail	light	Level 2	Y	600	short	Warm, Clear	1572	636	1221	767	55,000	1824	726	1414	918	2.39	few	3200
4	9/30/2001	19:05	22:30	I-85 N MPM 0	IR	Inbnd	17.37%	Inside lane of 2 closed	Median Cable Guardrail	light	Level 2	Y	665	short	Warm, Clear	1440	324	1320	995	50,000	1728	534	1540	1243	2.20	continuous	>1 mile
5	10/1/2001	9:00	18:00	I-77 N MPM 80	IU	Outbnd	15.44%	Inside 2 lanes of 4 closed	Paving (OGFC)	heavy	Level 4	Y	675, 1475, 850	long	Warm, Clear	1140	636	930	802	25,000	1389	765	1112	954	2.25	none	-
6	10/3/2001	17:00	22:30	I-385 N MPM 40	IU	Outbnd	3.17%	Outside lane of 2 closed	Paving (surface)	heavy	Level 4	Y	446	long	Warm, Clear	744	60	553	458	20,000	768	60	572	479	2.27	none	-
7	11/5/2001	20:00	22:00	I-26 W MPM 208	IU	Outbnd	12.38%	Outside 2 lanes of 3 closed	Final striping	heavy	Level 5	Y	668, 1544, 684	short	Cold, Clear	1308	576	1124	735	60,000	1506	666	1310	871	2.42	none	-
8	1/31/2002	15:30	16:00	I-26 E MPM 178	IU	Inbnd	15.55%	Outside lane of 2 closed	Conc Pvmt Repair	heavy	Level 3	Y	800	medium	Cool, Clear	1128	720	927	871	32,000	1416	864	1107	1059	2.32	none	-
9	3/11/2002	16:00	18:10	I-385 N MPM 2	IU	Inbnd	15.51%	Inside lane of 2 closed	Median Cable Guardrail	light	Level 2	Y	950	long	Cool, Clear	696	276	565	509	20,000	918	312	689	608	2.33	none	-
10	4/3/2002	8:30	10:30	I-26 E MPM 104	IU	Inbnd	11.32%	Inside lane 2 of 3 closed (3)	Median Cleanup	light	Level 1	Y	-	short	Warm, Clear	2016	1266	1041	1041	40,000	2262	1446	1178	1178	2.16	continuous	>4500
11	4/8/2002	8:42	11:10	I-26 E MPM 107	IU	Inbnd	8.94%	Inside lane of 4 closed	Median Cleanup	light	Level 1	Y	575	short	Warm, Clear	1480	1044	1308	1152	40,000	1620	1152	1437	1284	2.19	none	-
12	6/3/2002	19:00	21:15	I-85 S MPM 28	IU	Outbnd	31.39%	inside lane 1 of 3 closed	Paving	light	Level 3	Y	800		clear	1284	636	1090	820	60,000	1758	1056	1518	1217	2.40	none	-
13	6/4/2002	19:00	20:30	I-85 S MPM 28	IU	Outbnd	27.32%	Inside lane 2 of 3 closed (3)	Rumble Strips	light	Level 3	Y	-		clear	1668	756	1251	976	60,000	2232	960	1640	1428	2.42	Discontinuous	500
14	6/6/2002	19:00	19:00	I-85 S MPM 28	IU	Outbnd	26.31%	Inside lane 2 of 3 closed		light	Level 3	Y	800		clear	1524	1008	1357	1141	60,000	2202	1428	1836	1574	2.39	Discontinuous	800 (3)
15	6/7/2002			I-85 S				RAINED OUT							Rain												
16	6/13/2002	19:00	21:00	I-85 S MPM 28	IU	Outbnd	26.58%	Inside 2 lanes of 3 closed (3)		heavy	Level 5	Y			Warm, Clear	1500	936	1341	1047	60,000	2100	1296	1844	1441	2.41	Discontinuous	>1 mile
17	6/14/2002	19:00	21:20	I-85 S MPM 28	IU	Outbnd	17.21%	Outside lane of 2 closed	Concrete Paving	heavy	Level 5	Y	-	long	Warm, Clear	1680	660	1504	1240	60,000	2070	768	1793	1564	2.32	continuous	>1 mile
18	6/20/2002	20:00	22:00	I-85 S MPM 28	IU	Outbnd	30.33%	Outside lane of 2 closed	Concrete Paving	heavy	Level 5	Y	800	long	Warm, Clear	1452	732	1110	916	60,000	1998	1056	1552	1331	2.40	continuous	3000
19	7/9/2002	19:15	20:15	I-85 S MPM 02	IR	Outbnd	33.07%	Outside lane of 2 closed	Bridge Maintenance	light	Level 6	Y		long	Warm, Clear	1236	636	672	672	35,000	1674	930	995	995	2.45	none	-
20	7/21/2002	19:03	21:08	I-85 N MPM 179	IR	Inbnd	14.04%	Outside lane of 2 closed	Bridge Maintenance	light	Level 6	Y		long	Warm, Clear	1032	648	903	799	40,000	1500	978	1332	1198	4.47	continuous	>1mile
21	7/22/2002	18:56	20:30	I-85 N MPM 179	IR	Inbnd	34.43%	Outside lane of 2 closed	Bridge Deck Maintenance (3)	light	Level 2	Y		long	clear	1548	384	1339	867	40,000	1830	558	1536	1065	1.55	none	-
22	8/23/2002	21:00	22:00	I-26 W	IU	Outbnd	9.60%	Outside 2 lanes of 3 closed	Concrete Paving	light	Level 4	Y	800	long	clear	1104	948	920	131	70,000	1338	1110	1038	149	2.38	Discontinuous	250 (3)
23	8/14/2002	19:17	21:00	I-95 N MPM165	IR	Outbnd	30.65%	Inside 1 lane of 2 closed	Barrier Wall Erection	light	Level 2	Y	800	long	clear	1032	648	907	815	40,000	1500	924	1276	1179	2.39	Discontinuous	5000
24	10/14/2003	21:00	23:35	I-85 S MPM 54	IU	Inbnd	36.39%	Inside 2 lanes of 3 closed	Milling	heavy	Level 4	Y		long	Clear	1068	540	916	712	70,000	1650	870	1407	1131	2.55	continuous	3300
25	3/12/2004	20:15		I-85 S MPM 54	IU	Inbnd	31.70%	Inside 2 lanes of 3 closed	Paving	heavy	Level 4	Y	800, 1200, 800	long	Clear	1176	540	899	838	70,000	1564	752	1347	1201	2.47	continuous	4100
26	3/17/2004	21:35	0:11	I-85 N MPM 54	IU	Outbnd	40.69%	Inside 2 lanes of 3 closed	Milling	heavy	Level 4	Y		long	Clear	1188	504	860	639	70,000	1734	714	1224	1092	2.39	continuous	5033
27	5/13/2004	20:40	22:35	I-77 N	IU	Outbnd	14.59%	Outside 1 lane of 3 closed	Bridge Widening	light	Level 5	Y	800	medium	Warm, Clear	1734	726	1600	1083	90,000	1945	943	1816	1324	2.23	none	-
28	5/13/2004	16:15	18:15	I-77 S	IU	Inbnd	17.42%	Outside lane 1 of 3 closed	Bridge Widening	light	Level 5	Y	750	medium	Warm, Clear	1596	936	1380	1221	50,000	2002	1165	1712	1475	2.29	continuous	5000
29	5/14/2004	16:10	18:25	I-77 S	IU	Inbnd	14.08%	Outside lane 1 of 3 closed	Bridge Widening	light	Level 5	Y	750	medium	Warm, Clear	1824	1224	1533	1356	50,000	2124	1423	1795	1594	2.23	continuous	4000
30	5/14/2004	6:52	8:25	I-77 N	IU	Outbnd	22.06%	Outside 1 lane of 3 closed	Bridge Widening	light	Level 5	Y	800	medium	Warm, Clear	1572	852	1394	1237	60,000	1912	1099	1786	1575	2.26	continuous	4167
31	6/24/2004	19:00	19:00	I-20 W				RAINED OUT	Paving						Rain												
32	7/9/2004	21:25	22:10	I-20 W	IU	Outbnd	14.03%	Outside 2 lanes of 3 closed	Paving	heavy	Level 4	Y		long	Clear	1836	1224	1609	1343	100,000	2141	1423	1905	1578	2.28	continuous	3800
33	10/12/2004	7:15	9:00	I-26 E MPM 76	IU	Inbnd	14.89%	Outside lane of 2 closed	Milling	light	Level 3	Y	800	short	Warm, Clear	1464	660	1068	858	25,000	1644	846	1268	1047	2.37	discontinuous	3500
34	10/20/2004	20:50	23:30	I-85 S MPM 54	IU	Inbnd	14.03%	Inside 2 lanes of 3 closed	Paving	heavy	Level 4	Y	800	long	Warm, Clear	1836	1224	1609	1343	70,000	2130	1428	1902	1587	2.30	continuous	4000
35	12/13/2004			I-20 MPM 70				Inside 2 lanes of 3 closed	Paving	heavy	Level 4		800	medium	Clear												

(1) AADT is estimated from hourly vehicle volume with the exception of site one, whose AADT is estimated from 5min hourly vehicle volume.

(2) PCE is calculated from hourly vehicle volume and hourly pc volume with the exception of site one, whose PCE is calculated from 5min hourly volume.

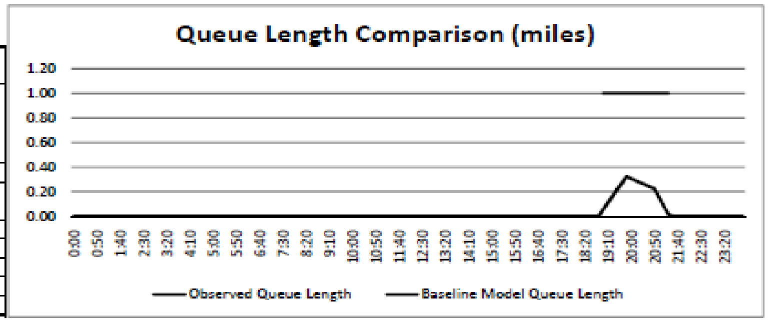
(3) Change is made from original data.

Electronic Records on CD

For each of the 38 work zone data sets described in Tables 3-1, 3-2, and 3-3, we have organized input-output results for each work zone into three files on the CD that accompanies this report. Note that three of the 35 work zones identified in Table 3-3 were unusable. We shall use South Carolina (SC) Site #17 as an example. The first file for SC #17 is the OkDOT Baseline model input and output, as seen in Figure 3-1; the second file for SC #17 is the OkDOT *HCM* 2000 model input and output, as seen in Figure 3-2; the third file for SC #17 is the OkDOT *HCM* 2000 Hybrid model input and output, as seen in Figure 3-3. Note that the AADT and hourly traffic volumes are the same for each file. In fact, the only difference in input to note is the Confidence Level (CL) declared at 80 % for the level 5 work intensity in the OkDOT Baseline, versus the I value of -120 in the OkDOT *HCM* 2000 version, and I value of -400 in the OkDOT *HCM* 2000 Hybrid version. Each model of course generates a different queue profile as output, which can be seen in the column labeled “Maximum Cars in Queue” or in the simple graphic display we have added as part of our efforts to improve the usability to ALDOT. These graphs contain an additional “bar” to indicate the level of maximum queue length attained during the lane closure.

OkDOT Model
SC 17

Analysis Code (use code from table):	IU
Direction (Inbound or Outbound):	Outbound
AADT:	60,000
Percent Trucks:	17.21%
Passenger car equivalent for heavy vehicles:	2.00
Passenger cars / day:	70,326
Number of lanes (one direction):	2
Free flow speed (mph):	
Basic lane capacity (pcphpl):	2250
Max. queue length limit (miles):	99
Confidence Level (%) - enter from 20-100	80
Delay ($/hour) passenger car:	
Fuel costs ($/gal):	
Average # people per vehicle:	



Analysis Code (enter two-letter code above):					
IU	Interstate - Urban (ODOT)	AU	Arterial - Urban (ODOT)	UF	User Defined Factors - enter values on LR Table Sheet
IR	Interstate - Rural (ODOT)	AR	Arterial - Rural (ODOT)	UV	User Defined Volumes - enter values on LR Table Sheet

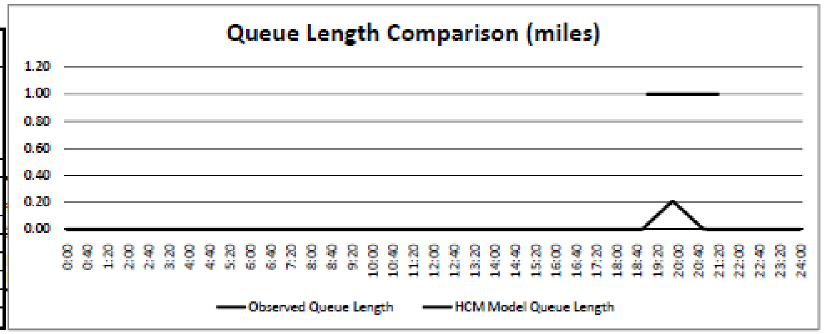
		Interstate – Urban								
Hour	# of Lanes Closed [(1)]	AADT Factor (K)	Direction Factor (D)	Volume [(2)]	Limiting Capacity	Max Cars in Queue	Delay Cost	Fuel Cost	Total Costs	Max Queue Length (mi.)
Mid.-1am	0	1.325	0.50	466	4,500	0	0	0	0	0.00
1am-2am	0	0.725	0.50	255	4,500	0	0	0	0	0.00
2am-3am	0	0.575	0.50	202	4,500	0	0	0	0	0.00
3am-4am	0	0.475	0.50	167	4,500	0	0	0	0	0.00
4am-5am	0	0.575	0.50	202	4,500	0	0	0	0	0.00
5am-6am	0	1.475	0.50	519	4,500	0	0	0	0	0.00
6am-7am	0	3.825	0.35	941	4,500	0	0	0	0	0.00
7am-8am	0	7.675	0.35	1,889	4,500	0	0	0	0	0.00
8am-9am	0	5.700	0.35	1,403	4,500	0	0	0	0	0.00
9am-10am	0	4.850	0.50	1,705	4,500	0	0	0	0	0.00
10am-11am	0	5.000	0.50	1,758	4,500	0	0	0	0	0.00
11am-Noon	0	5.500	0.50	1,934	4,500	0	0	0	0	0.00
Noon-1pm	0	5.775	0.50	2,031	4,500	0	0	0	0	0.00
1pm-2pm	0	5.725	0.50	2,013	4,500	0	0	0	0	0.00
2pm-3pm	0	5.975	0.50	2,101	4,500	0	0	0	0	0.00
3pm-4pm	0	7.050	0.60	2,975	4,500	0	0	0	0	0.00
4pm-5pm	0	8.425	0.60	3,555	4,500	0	0	0	0	0.00
5pm-6pm	0	8.675	0.60	3,660	4,500	0	0	0	0	0.00
6pm-7pm	0	5.700	0.60	2,405	4,500	0	0	0	0	0.00
7pm-8pm	1	4.125	0.50	1,450	1,282	170	0	0	0	0.32
8pm-9pm	1	3.500	0.50	1,231	1,282	162	0	0	0	0.31
9pm-10pm	1	3.025	0.50	1,064	1,282	82	0	0	0	0.15
10pm-11pm	0	2.575	0.50	905	4,500	0	0	0	0	0.00
11pm-Mid.	0	1.900	0.50	668	4,500	0	0	0	0	0.00

[(1)] One direction only.
[(2)] Passenger car volumes (adjusted for % of trucks) for one direction only

Figure 3-1. OkDOT Model input/output for Site #17.

HCM 2000 Model
SC 17

Analysis Code (use code from table):	IU
Direction (Inbound or Outbound):	Outbound
AADT:	60,000
Percent Trucks:	17.21%
Passenger car equivalent for heavy vehicles:	2.00
Heavy vehicle adj:	0.853
Passenger cars / day:	70,326
Number of lanes (one direction):	2
Free flow speed (mph):	
Basic lane capacity (pcphpl):	2250
Max. queue length limit (miles):	99
Intensity (-160 - 160 pcphpl):	-100
Ramp adj (0-160 pcphpl):	160
Delay ($/hour) passenger car:	
Fuel costs ($/gal):	
Average # people per vehicle:	



Analysis Code (enter two-letter code above):					
IU	Interstate - Urban (ODOT)	AU	Arterial - Urban (ODOT)	UF	User Defined Factors - enter values on LR Table Sheet
IR	Interstate - Rural (ODOT)	AR	Arterial - Rural (ODOT)	UV	User Defined Volumes - enter values on LR Table Sheet

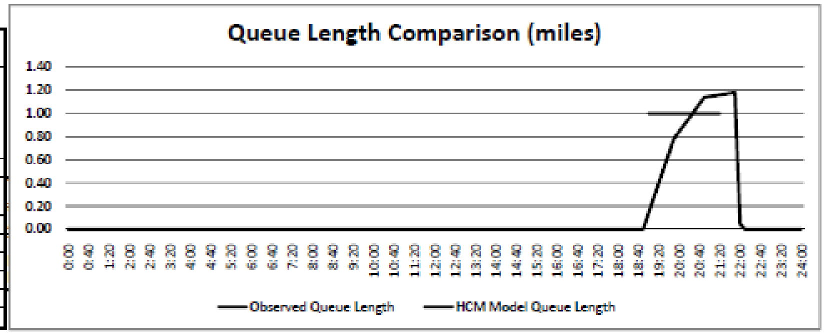
		Interstate – Urban								
Hour	# of Lanes Closed [(1)]	AADT Factor (K)	Direction Factor (D)	Volume [(2)]	Limiting Capacity	Max Cars in Queue	Delay Cost	Fuel Cost	Total Costs	Max Queue Length (mi.)
Mid.-1am	0	1.325	0.50	466	4,500	0	0	0	0	0.00
1am-2am	0	0.725	0.50	255	4,500	0	0	0	0	0.00
2am-3am	0	0.575	0.50	202	4,500	0	0	0	0	0.00
3am-4am	0	0.475	0.50	167	4,500	0	0	0	0	0.00
4am-5am	0	0.575	0.50	202	4,500	0	0	0	0	0.00
5am-6am	0	1.475	0.50	519	4,500	0	0	0	0	0.00
6am-7am	0	3.825	0.35	941	4,500	0	0	0	0	0.00
7am-8am	0	7.675	0.35	1,889	4,500	0	0	0	0	0.00
8am-9am	0	5.700	0.35	1,403	4,500	0	0	0	0	0.00
9am-10am	0	4.850	0.50	1,705	4,500	0	0	0	0	0.00
10am-11am	0	5.000	0.50	1,758	4,500	0	0	0	0	0.00
11am-Noon	0	5.500	0.50	1,934	4,500	0	0	0	0	0.00
Noon-1pm	0	5.775	0.50	2,031	4,500	0	0	0	0	0.00
1pm-2pm	0	5.725	0.50	2,013	4,500	0	0	0	0	0.00
2pm-3pm	0	5.975	0.50	2,101	4,500	0	0	0	0	0.00
3pm-4pm	0	7.050	0.60	2,975	4,500	0	0	0	0	0.00
4pm-5pm	0	8.425	0.60	3,555	4,500	0	0	0	0	0.00
5pm-6pm	0	8.675	0.60	3,660	4,500	0	0	0	0	0.00
6pm-7pm	0	5.700	0.60	2,405	4,500	0	0	0	0	0.00
7pm-8pm	1	4.125	0.50	1,450	1,340	112	0	0	0	0.21
8pm-9pm	1	3.500	0.50	1,231	1,340	94	0	0	0	0.18
9pm-10pm	1	3.025	0.50	1,064	1,340	0	0	0	0	0.00
10pm-11pm	0	2.575	0.50	905	4,500	0	0	0	0	0.00
11pm-Mid.	0	1.900	0.50	668	4,500	0	0	0	0	0.00

[(1)] One direction only.
[(2)] Passenger car volumes (adjusted for % of trucks) for one direction only

Figure 3-2. *HCM* 2000 Model input/output for Site #17.

HCM 2000 Hybrid Model
SC 17

Analysis Code (use code from table):	IU
Direction (Inbound or Outbound):	Outbound
AADT:	60,000
Percent Trucks:	17.21%
Passenger car equivalent for heavy vehicles:	2.00
Heavy vehicle adj:	0.853
Passenger cars / day:	70,326
Number of lanes (one direction):	2
Free flow speed (mph):	
Basic lane capacity (pcphpl):	2250
Max. queue length limit (miles):	99
Intensity (-500 - 0 pcphpl):	-400
Ramp adj (0-160 pcphpl):	160
Delay ($/hour) passenger car:	
Fuel costs ($/gal):	
Average # people per vehicle:	



Analysis Code (enter two-letter code above):					
IU	Interstate - Urban (ODOT)	AU	Arterial - Urban (ODOT)	UF	User Defined Factors - enter values on LR Table Sheet
IR	Interstate - Rural (ODOT)	AR	Arterial - Rural (ODOT)	UV	User Defined Volumes - enter values on LR Table Sheet

		Interstate – Urban								
Hour	# of Lanes Closed [1]	AADT Factor (K)	Direction Factor (D)	Volume [2]	Limiting Capacity	Max Cars in Queue	Delay Cost	Fuel Cost	Total Costs	Max Queue Length (mi.)
Mid.-1am	0	1.325	0.50	466	4,500	0	0	0	0	0.00
1am-2am	0	0.725	0.50	255	4,500	0	0	0	0	0.00
2am-3am	0	0.575	0.50	202	4,500	0	0	0	0	0.00
3am-4am	0	0.475	0.50	167	4,500	0	0	0	0	0.00
4am-5am	0	0.575	0.50	202	4,500	0	0	0	0	0.00
5am-6am	0	1.475	0.50	519	4,500	0	0	0	0	0.00
6am-7am	0	3.825	0.35	941	4,500	0	0	0	0	0.00
7am-8am	0	7.675	0.35	1,889	4,500	0	0	0	0	0.00
8am-9am	0	5.700	0.35	1,403	4,500	0	0	0	0	0.00
9am-10am	0	4.850	0.50	1,705	4,500	0	0	0	0	0.00
10am-11am	0	5.000	0.50	1,758	4,500	0	0	0	0	0.00
11am-Noon	0	5.500	0.50	1,934	4,500	0	0	0	0	0.00
Noon-1pm	0	5.775	0.50	2,031	4,500	0	0	0	0	0.00
1pm-2pm	0	5.725	0.50	2,013	4,500	0	0	0	0	0.00
2pm-3pm	0	5.975	0.50	2,101	4,500	0	0	0	0	0.00
3pm-4pm	0	7.050	0.60	2,975	4,500	0	0	0	0	0.00
4pm-5pm	0	8.425	0.60	3,555	4,500	0	0	0	0	0.00
5pm-6pm	0	8.675	0.60	3,660	4,500	0	0	0	0	0.00
6pm-7pm	0	5.700	0.60	2,405	4,500	0	0	0	0	0.00
7pm-8pm	1	4.125	0.50	1,450	1,040	412	0	0	0	0.78
8pm-9pm	1	3.500	0.50	1,231	1,040	602	0	0	0	1.14
9pm-10pm	1	3.025	0.50	1,064	1,040	624	0	0	0	1.18
10pm-11pm	0	2.575	0.50	905	4,500	25	0	0	0	0.05
11pm-Mid.	0	1.900	0.50	668	4,500	0	0	0	0	0.00

[1] One direction only.
[2] Passenger car volumes (adjusted for % of trucks) for one direction only

Figure 3-3. ***HCM*** **2000 Hybrid Model input/output for Site #17.**

4.0 Model Versions Verification, Testing, and Recommendation

This important chapter contains the results of extensive runs of three versions of the OkDOT spreadsheet tool. Recall that in Chapter 1, the logic employed in the work zone queue analysis of the OkDOT tool was described, along with corrections to errors we found in the coding. We describe our implementation of this baseline version, and two other versions in this chapter. The logic of the *HCM* 2000 modification is verified to be working correctly by comparing its output to that obtained by Ohio State researchers on four simulated freeway work zones. A unique tool developed prior to testing against real work zone data enabled the researchers to identify the 24-hour traffic volume profile to best match the actual hourly traffic volumes reported with each real data set, as described later in Chapter 4. Chapter 4 also contains the results of extensive testing of the three OkDOT model version applied to 32 diverse South Carolina freeway work zones. Out of this, one version was selected for recommendation to ALDOT as its future work zone queue length prediction tool; this recommended version is validated against six real work zone data sets, three from Alabama and three from North Carolina.

Three Versions of the OKDOT Spreadsheet Tool

The logic of the Baseline Version goes back to the *HCM* 1994 method of estimating work zone capacity, as described in Chapter 1. While the input-output logic applied to estimate queue formation and length remains valid, improvements are available based on *HCM* 2000. Additionally, examination of the literature on work zone capacity impacts of *work intensity* led us to create a *HCM* 2000 Hybrid Version incorporating even more recent research. *A theme of this section is that describing work zone intensity appropriately, and penalizing work zone capacity appropriately, is the key to better traffic queue predictions (e.g., queue start-time and maximum queue length).*

Baseline Version

The OkDOT tool (with errors corrected) as described in Chapter 1 is called the Baseline Version in this report. This is the tool used by planners and designers at the ALDOT today. There is a "confidence level" (CL) included in the Baseline Version that enables the user to express a degree of conservatism in the capacity (pcphpl) of an open lane through the work zone. A low level of conservatism (say CL=20%) corresponds to a capacity of 1419; a high level of conservatism (say CL=80%) corresponds to a capacity of only 1282. Because in the two other versions of the OkDOT tool, work zone intensity is going to play a major role in determining capacity, we constructed the following six-level scale which maps confidence level to intensity; the third column in Table 4-1 shows the resulting work zone lane capacity.

Table 4-1. Confidence Level Interpretation in OkDOT Baseline Version

Level	Work Intensity (example)	Confidence Level (CL)	Capacity
1	"Lightest" (e.g., guardrail repair)	0%	1465
2	"Light" (e.g., pothole repair)	20%	1419
3	"Moderate" (e.g., resurfacing)	40%	1374
4	"Heavy" (e.g., stripping)	60%	1328
5	"Very Heavy" (e.g., pavement marking)	80%	1282
6	"Heaviest" (e.g., bridge repair)	100%	1236

Should ALDOT decide to continue use of the OkDOT Baseline Version, we would recommend use of such a six-point scale to standardize the assignment of confidence level, hence the work zone lane capacity. The wording used to describe work intensity above, and the examples given, appear in research by Adeli and Jiang (2003). Work intensity is a function of several factors, which the model user will have to assess in deciding which level (1-6) to use. Such factors as reported in the literature include:

- Number and size of equipment items involved in the work
- Number of workers present and their proximity to the open lane(s)
- Width of shoulders in the work zone, if any
- Distance from work zone to open lane(s)
- Use of lighting (at night)
- Moving or fixed work zone
- Temporary or long-term work zone (long term work zones have higher capacity than those encountered by drivers for the first time)

Although assigning an intensity level may take some thought, we demonstrate throughout the remainder of this chapter that it is necessary. During our testing, we found it possible to make reasonable "calls" on intensity from fairly brief descriptions of the work which accompanied the work zone data we used in testing and validation. Of course, when in doubt in choosing between two intensity levels, the rule is to go with the more conservative (higher) level.

HCM 2000 Version

Krammes and Lopez (1994) put forth the following model for work zone capacity, which eventually became part of *HCM* 2000:

$C = (1600 \text{ pcphpl} + I - R) \times H \times N$, where:

C = estimated work zone capacity (vph)

I = adjustment factor for work intensity ranging from -160 to +160 pcphpl. Karim and Adeli (2003a) suggested a three-level I scale of Low = +160, Medium = 0, and High= -160 (e.g., a 10% penalty for high intensity work). However, a six-level I-scale originated by Dudek and Richards (1981) appears in Table 4-2 below, and was used in our testing.

Table 4-2. Work Zone Intensity (I) Scale Applied in *HCM* 2000 Version

Level	Work Intensity	I Value Used
1	Lightest	+160
2	Light	+100
3	Moderate	+40
4	Heavy	-40
5	Very Heavy	-100
6	Heaviest	-160

R = adjustment value for "presence of an entrance ramp near the starting point of the lane closure," that is in the advance warning area. R is equal to 0 if no ramp is present, and R=160 pcphpl if entrance ramp is present (following the logic than entering traffic causes turbulence in the traffic flow approaching the work zone, indirectly reducing the work zone lane capacity 10%).

H= adjustment factor for heavy vehicles, $H=100/[100 + P(E-1)]$, where

P= percentage of heavy vehicles

E= passenger car equivalent for heavy vehicles (values ranging from 2.0 to 2.5 are recommended, depending on terrain; the OkDOT baseline value is 2.0).

N= number of lanes open through the work zone.

HCM 2000 Hybrid Version

A University of Maryland research team (Kim, et al. 2001) developed an alternative work zone capacity estimation model based on multiple linear regression applied to twelve sets of measured work zone capacity data from Maryland. The six variables they chose as predictors, and the limitations of the twelve work zones used, eliminated that model from consideration. However a set of data included as a figure in the appendix to that paper (See Figure 4-1.) led us to create the *HCM* 2000 Hybrid Version of the OkDOT tool. This third version uses the *HCM* 2000 work zone lane capacity model exactly as described earlier in this chapter, except the work intensity is rescaled as shown in Table 4-3. This scale essentially stiffens the work zone lane capacity penalty for the most intense work from a maximum of 160, to 500 pcphpl; also, the lightest intensity has a penalty of zero here, whereas in the *HCM* 2000 Version, the lightest intensity actually *added* 160 pcphpl (10%) to the base lane capacity of 1600.

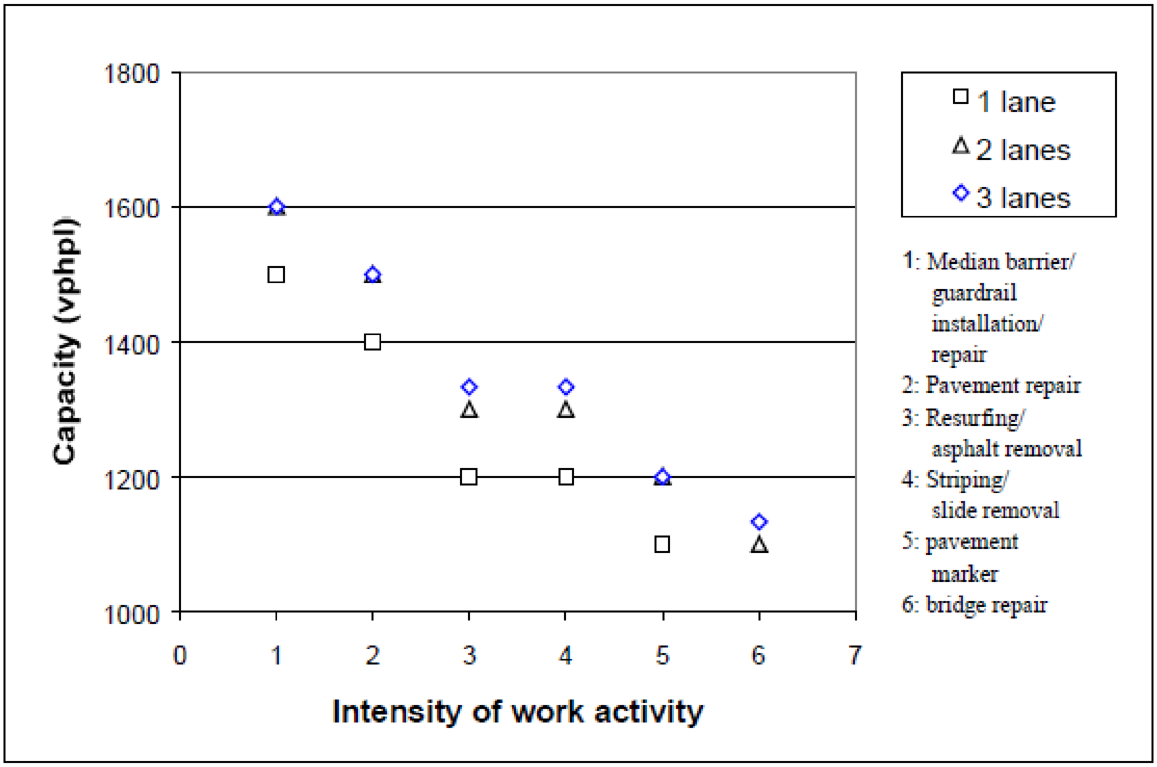


Figure 4-1. Relationship between work zone capacity and intensity of work activity by number of open lanes in California (Kim, et al. 2001).

Table 4-3. Work Zone Intensity (I) Scale Applied in *HCM* 2000 Hybrid Version

Level	Work Intensity	I (Penalty)
1	Lightest	0
2	Light	-100
3	Moderate	-200
4	Heavy	-300
5	Very Heavy	-400
6	Heaviest	-500

Note: In the analysis of predictions produced by the three versions, whenever *HCM* 2000 is used, the I values (-160 to +160) in Table 4.2 are applied. In the *HCM* 2000 Hybrid Version, the

I values (0 to -500) in Table 4.3 are applied. So, I value has a different range in the respective versions, and is in fact the only thing that differs between these two versions.

Verification of Model Logic Using Ohio State Simulated Data

Inserting *HCM* 2000 logic into the OkDOT spreadsheet tool to create the *HCM* 2000 Version was a significant change in an ALDOT standard tool. Therefore, we wanted to verify that this change was producing comparable results to some other computerized *HCM* 2000 tool, on several test data sets. We chose to use four test cases described in the article by Jiang and Adeli (2003). They ran a computerized version of *HCM* 2000 capacity estimation and recorded their results in tables and graphs. We ran our *HCM* 2000 Version of the OkDOT spreadsheet tool on the same four test cases, and produced virtually identical queue profiles over a 24-hour period (e.g., see Figure 4-2 which represents a continually growing queue from early morning hours to the final hour of the day). In our runs of their Example 1B, we first ran the OkDOT *HCM* 2000 Version at I= -160, 0, and 160. As depicted, the queue starts, grows for the next 15 hours, and then begins to dissipate. I = -160 comes closest to their simulated number of vehicles in queue. Note that when we set I = -400, our model output overlaps their model output. It turns out that the Ohio State researchers were using 1200 pcphpl as the nominal work zone lane capacity, so when we set I = -400 in our model, our output matches theirs, as it should if our model is programmed correctly.

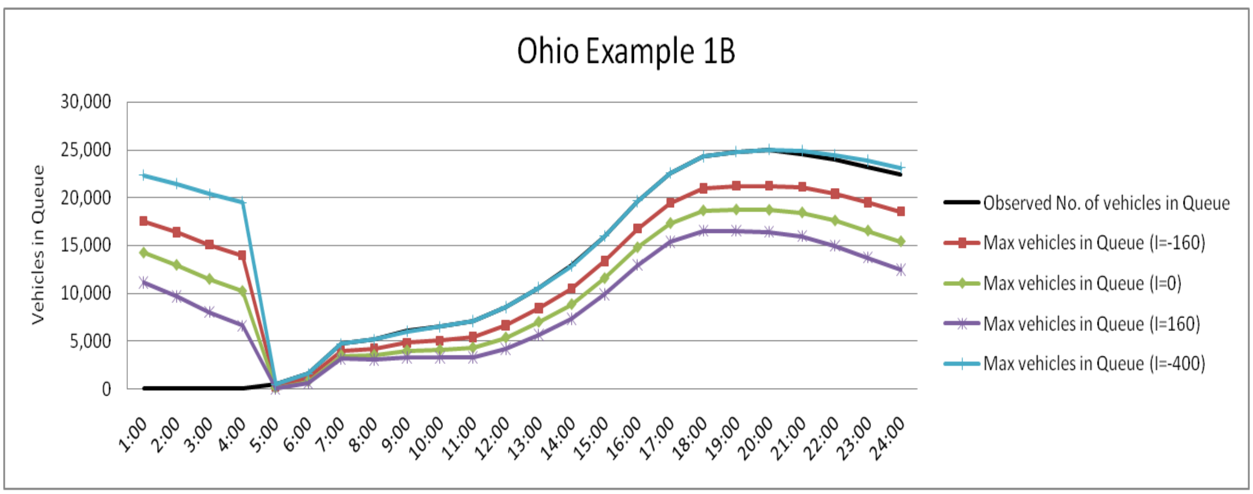


Figure 4-2. Comparison of OkDOT *HCM* 2000 predictions with output of a similar Ohio State model.

Ohio State used an "anticipated traffic flow" as input, whereas we used the "best match" IU outbound with AADT=96,000; but their flow had a morning peak 6:00 a.m.-7:00 a.m. not represented in the OkDOT method of spreading AADT over the 24-hour period based on Analysis Code (IU). In conclusion, to best match their results using *HCM* 2000-based lane capacity prediction, an intensity level penalty of I = -400 was needed; that is, work zone intensity penalties larger than -160 should be permitted in our search for the best overall work zone queue length prediction model – precisely what the *HCM* 2000 Hybrid version provides.

Tool Developed to Match Daily Traffic Volumes to Test Cases

When milepost and direction at the work zone are available, hourly traffic volume profiles are often available on-line from that state's DOT. These profiles can be obtained for a particular day of the week, or averaged over the entire week for a year. State of Alabama data is available in these forms. The traffic planner would use the day-of-week profile, if he/she knew the exact date of scheduled work. Otherwise, an average annual profile should be used. In some of the work zone test cases described above, the researchers themselves took actual hourly traffic volumes at the same time as work zone capacity and queues were measured, and these hourly data can be used either directly (if extended over entire 24 hours) or indirectly to select the most appropriate match among several candidate 24-hour profiles.

When hourly traffic volume is available, the analysis code required in each OkDOT Version is set to UV for user-defined volume, and these hourly records are used to create input. However, though on-site observations may be for 24 hours, typically they are for a continuous period of a few hours only, not 24 hours. In either case, a computer-aided visual tool was needed and developed as part of this project to help match 24-hour profiles to observed traffic volume data.

Example Application When 24-hour Profile Given

To illustrate the 24-hour matching situation, one of the Ohio data sets will be used. (See the black line profile in Figure 4-3.) We developed a visual tool to match daily traffic volume to test cases. The tool is developed based on OkDOT model and shows traffic volume pattern for sites of different type and direction. For instance, interstate urban sites have peak hours in both morning and evening; inbound sites have a higher morning peak and outbound sites have a higher evening peak. The tool helped classify work zone sites among several options and also establish the 24-hour input volumes to be used in testing the three OkDOT Versions.

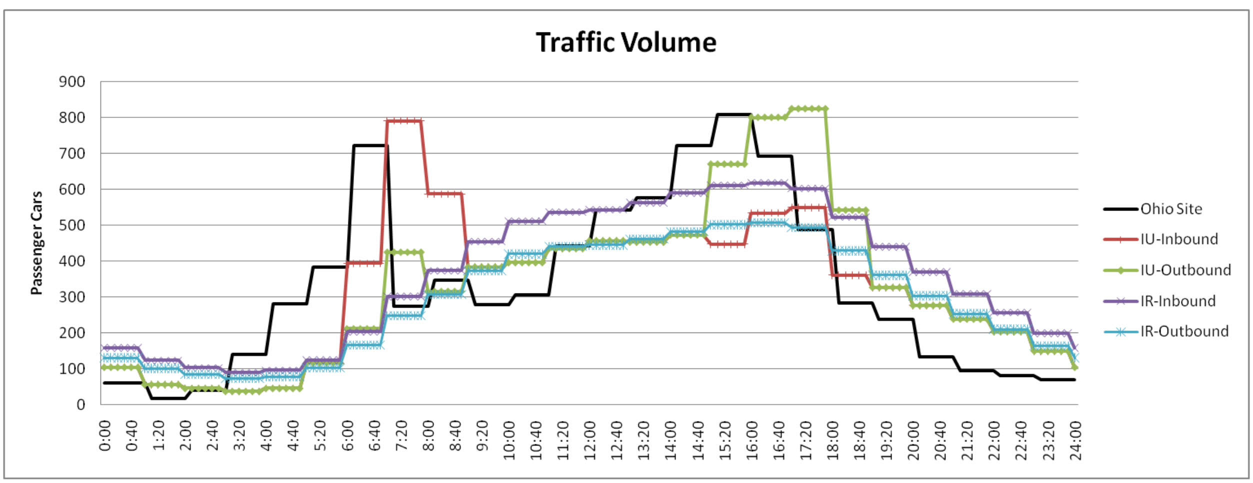


Figure 4-3. Tool used to determine Ohio site was IU-outbound.

Example Application with Less Than 24-hour Profile Given

The tool was used in our research to determine hourly traffic volume for the North Carolina, South Carolina, and Wisconsin data sets. This was an important preparation step, because the South Carolina data became the main focus to compare and calibrate the three OkDOT model versions; and, North Carolina contributed three cases to the validation data. These states' data sets have traffic volume during a data collection period, but lack traffic volume for the rest of the day. The traffic volume pattern for data collection period is compared with the patterns available by analysis code in the OkDOT model, and AADT that provides the best match during the data collection period of hours is used to determine what the 24-hour traffic volume profile looked like at the specific site that day. We shall illustrate this process with North Carolina Site #18.

The information given in the North Carolina State report includes location I-95 NB, rural area, and traffic volume during data collection period. There is no AADT and direction (meaning inbound or outbound) available. Table 4-4 contains the observed ten-minute traffic volumes approaching the work zone.

Table 4-4. North Carolina Site #18

Time	Traffic Volume	Time	Traffic Volume
8:30 a.m.	74	9:50 a.m.	215
8:40 a.m.	160	10:00 a.m.	156
8:50 a.m.	148	10:10 a.m.	211
9:00 a.m.	171	10:20 a.m.	142
9:10 a.m.	150	10:30 a.m.	110
9:20 a.m.	149	10:40 a.m.	167
9:30 a.m.	174	10:50 a.m.	180
9:40 a.m.	195	11:00 a.m.	251

The following graph, Figure 4-4, shows match pattern when AADT is set as 40,000. Traffic volume pattern for IR-Inbound and IR-Outbound are similar; with the difference that inbound volume is larger than outbound volume during the hours in which data was collected. Direction is chosen as inbound, which matches the maximum observed traffic volume better. The entire 24-hour IR-Inbound pattern with AADT = 40,000 is what was used in model runs associated with this site.

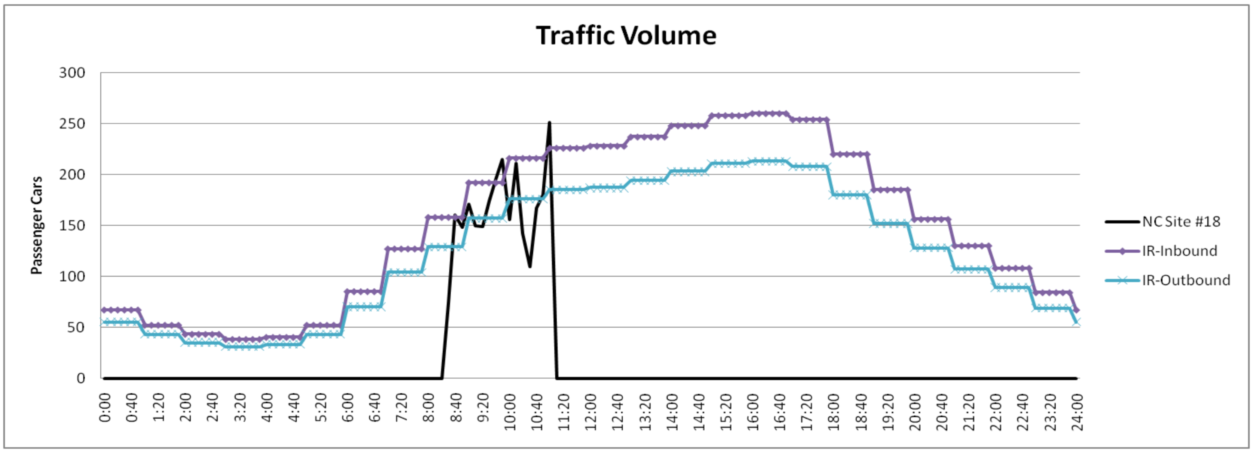


Figure 4-4. Tool used to determine North Carolina site was IR-inbound with AADT= 40,000.

Testing Results Using 32 South Carolina Work Zones

This section describes extensive testing of the three OkDOT Versions in their ability to accurately predict to accurately predict two metrics:

- Queue Start Time (QST)
- Maximum Queue Length (MQL)

across a diverse mix of 32 work zones where data was obtained from researchers in South Carolina (Sarasua, et al. 2006). Maximum queue length is considered first, and the respective model versions were run at baseline settings, then calibrated to identify the optimal setting of controllable parameters for each work zone:

- CL and PCE for OkDOT Baseline Version
- I and PCE for *HCM* 2000 and *HCM* 2000 Hybrid Versions

Additional analyses as documented below led to the conclusion that the *HCM* Hybrid Version is the most accurate of the three at predicting MQL and QST. The best level of PCE with *HCM* 2000 Hybrid is determined to be 2.1.

The South Carolina Work Zone Data Sets

Table 4-5 describes 35 freeway work zone data sets obtained from researchers at Clemson and The Citadel (Sarasua, et al. 2006). The data were collected from 2001 to 2004 all over South Carolina (SC), which fortunately has road grades similar to Alabama's (essentially level terrain – less than 2 % grade – over the entire state). It turns out that 32 of the 35 data sets were useable in our study, with sites #15, #31, and #35 omitted. We spent considerable time locating each site on a SC highway map with mileposts, and this location helped us classify each site as IR vs. IU, and outbound vs. inbound to the closet metropolitan area. A level (1-6) of work zone intensity was assigned in column seven of the table, by the UA researchers, based on work zone descriptions in columns six and nine. Note that intensity levels from 1 to 6 are included among the 32 sites.

It was determined from map study that each work zone did have an entrance ramp within one mile of the taper and of the work zone, that is, in the advanced warning area. The AADT was estimated from the volume of traffic observed during the hours of operation of each of these temporary work zones. Passenger car equivalent (PCE) was calculated from hourly vehicle volume and hourly passenger car volume. The percentage heavy vehicles is labeled %T in the table, and was calculated from direct observations by the SC researchers on-site. Queue length is measured in feet, except as noted. When the notation > 1 mile appears (four times) we treat MQL as 1 mile exactly. Finally, in six instances we modified the SC data in Table 4-5 as provided, because we had evidence from our initial model runs at those six sites that typographical errors were made in their data description. We made such modifications based on runs of our models and comparisons with their results at similar sites.

Table 4-6 summarizes the confidence level and intensity levels used in the respective models, for the 32 South Carolina work zones. Note that work intensity ranges from 1 to 6, with 3, 4, and 5 being the most frequent entries.

Table 4-5. South Carolina (SC) Data Sets

Site #	Date	Start Time	End Time	Location	Code	Direction	T%	Closure Geometry	Type of Work	Equip. Activity	WZ Intensity	Ramp	Taper Length	WZ Length	Weather Conditions	5min hourly max	5min hourly min	Hourly max	Hourly min	AADT[1]	5min hourly max	5min hourly min	Hourly max	Hourly min	PCE[2]	Queue?	Max QL
1	9/12/2001	19:15	21:15	I-85 N MPM 32	IU	Inbnd	35.67%	Inside lane of 2 closed	Median Cable Guardrail	light	Level 2	Y	863	short	Warm, Clear	1056	648	-		50,000	1560	1044	-		2.53	none	-
2	9/13/2001	19:45	20:45	I-26 W MPM 54	IU	Outbnd	28.95%	Inside lane of 2 closed	Median Cable Guardrail	light	Level 2	Y	795	short	Warm, Clear	648	324	497	445	25,000	882	492	702	640	2.47	none	-
3	9/16/2001	19:40	21:15	I-85 S MPM 8.5	IU	Outbnd	12.75%	Inside lane of 2 closed	Median Cable Guardrail	light	Level 2	Y	600	short	Warm, Clear	1572	636	1221	767	55,000	1824	726	1414	918	2.39	few	3200
4	9/30/2001	19:05	22:30	I-85 N MPM 0	IR	Inbnd	17.37%	Inside lane of 2 closed	Median Cable Guardrail	light	Level 2	Y	665	short	Warm, Clear	1440	324	1320	995	50,000	1728	534	1540	1243	2.20	continuous	>1 mile
5	10/1/2001	9:00	18:00	I-77 N MPM 80	IU	Outbnd	15.44%	Inside 2 lanes of 4 closed	Paving (OGFC)	heavy	Level 4	Y	675, 1475, 850	long	Warm, Clear	1140	636	930	802	25,000	1389	765	1112	954	2.25	none	-
6	10/3/2001	17:00	22:30	I-385 N MPM 40	IU	Outbnd	3.17%	Outside lane of 2 closed	Paving (surface)	heavy	Level 4	Y	446	long	Warm, Clear	744	60	553	458	20,000	768	60	572	479	2.27	none	-
7	11/5/2001	20:00	22:00	I-26 W MPM 208	IU	Outbnd	12.38%	Outside 2 lanes of 3 closed	Final striping	heavy	Level 5	Y	668, 1544, 684	short	Cold, Clear	1308	576	1124	735	60,000	1506	666	1310	871	2.42	none	-
8	1/31/2002	15:30	16:00	I-26 E MPM 178	IU	Inbnd	15.55%	Outside lane of 2 closed	Conc Pvmt Repair	heavy	Level 3	Y	800	medium	Cool, Clear	1128	720	927	871	32,000	1416	864	1107	1059	2.32	none	-
9	3/11/2002	16:00	18:10	I-385 N MPM 2	IU	Inbnd	15.51%	Inside lane of 2 closed	Median Cable Guardrail	light	Level 2	Y	950	long	Cool, Clear	696	276	565	509	20,000	918	312	689	608	2.33	none	-
10	4/3/2002	8:30	10:30	I-26 E MPM 104	IU	Inbnd	11.32%	Inside lane 2 of 3 closed [3]	Median Cleanup	light	Level 1	Y	-	short	Warm, Clear	2016	1266	1041	1041	40,000	2262	1446	1178	1178	2.16	continuous	>4500
11	4/8/2002	8:42	11:10	I-26 E MPM 107	IU	Inbnd	8.94%	Inside lane of 4 closed	Median Cleanup	light	Level 1	Y	575	short	Warm, Clear	1480	1044	1308	1152	40,000	1620	1152	1437	1284	2.19	none	-
12	6/3/2002	19:00	21:15	I-85 S MPM 28	IU	Outbnd	31.39%	inside lane 1 of 3 closed	Paving	light	Level 3	Y	800		clear	1284	636	1090	820	60,000	1758	1056	1518	1217	2.40	none	-
13	6/4/2002	19:00	20:30	I-85 S MPM 28	IU	Outbnd	27.32%	Inside lane 2 of 3 closed [3]	Rumble Strips	light	Level 3	Y	-		clear	1668	756	1251	976	60,000	2232	960	1640	1428	2.42	Discontinuous	500
14	6/6/2002	19:00	19:00	I-85 S MPM 28	IU	Outbnd	26.31%	Inside lane 2 of 3 closed		light	Level 3	Y	800		clear	1524	1008	1357	1141	60,000	2202	1428	1836	1574	2.39	Discontinuous	800 [3]
15	6/7/2002			I-85 S				RAINED OUT							Rain												
16	6/13/2002	19:00	21:00	I-85 S MPM 28	IU	Outbnd	26.58%	Inside 2 lanes of 3 closed [3]		heavy	Level 5	Y			Warm, Clear	1500	936	1341	1047	60,000	2100	1296	1844	1441	2.41	Discontinuous	>1 mile
17	6/14/2002	19:00	21:20	I-85 S MPM 28	IU	Outbnd	17.21%	Outside lane of 2 closed	Concrete Paving	heavy	Level 5	Y	-	long	Warm, Clear	1680	660	1504	1240	60,000	2070	768	1793	1564	2.32	continuous	>1 mile
18	6/20/2002	20:00	22:00	I-85 S MPM 28	IU	Outbnd	30.33%	Outside lane of 2 closed	Concrete Paving	heavy	Level 5	Y	800	long	Warm, Clear	1452	732	1110	916	60,000	1998	1056	1552	1331	2.40	continuous	3000
19	7/9/2002	19:15	20:15	I-85 S MPM 02	IR	Outbnd	33.07%	Outside lane of 2 closed	Bridge Maintenance	light	Level 6	Y		long	Warm, Clear	1236	636	672	672	35,000	1674	930	995	995	2.45	none	-
20	7/21/2002	19:03	21:08	I-85 N MPM 179	IR	Inbnd	14.04%	Outside lane of 2 closed	Bridge Maintenance	light	Level 6	Y		long	Warm, Clear	1032	648	903	799	40,000	1500	978	1332	1198	4.47	continuous	>1mile
21	7/22/2002	18:56	20:30	I-85 N MPM 179	IR	Inbnd	34.43%	Outside lane of 2 closed	Bridge Deck Maintenance [3]	light	Level 2	Y		long	clear	1548	384	1339	867	40,000	1830	558	1536	1065	1.55	none	-
22	8/23/2002	21:00	22:00	I-26 W	IU	Outbnd	9.60%	Outside 2 lanes of 3 closed	Concrete Paving	light	Level 4	Y	800	long	clear	1104	948	920	131	70,000	1338	1110	1038	149	2.38	Discontinuous	250 [3]
23	8/14/2002	19:17	21:00	I-95 N MPM165	IR	Outbnd	30.65%	Inside 1 lane of 2 closed	Barrier Wall Erection	light	Level 2	Y	800	long	clear	1032	648	907	815	40,000	1500	924	1276	1179	2.39	Discontinuous	5000
24	10/14/2003	21:00	23:35	I-85 S MPM 54	IU	Inbnd	36.39%	Inside 2 lanes of 3 closed	Milling	heavy	Level 4	Y		long	Clear	1068	540	916	712	70,000	1650	870	1407	1131	2.55	continuous	3300
25	3/12/2004	20:15		I-85 S MPM 54	IU	Inbnd	31.70%	Inside 2 lanes of 3 closed	Paving	heavy	Level 4	Y	800, 1200, 800	long	Clear	1176	540	899	838	70,000	1564	752	1347	1201	2.47	continuous	4100
26	3/17/2004	21:35	0:11	I-85 N MPM 54	IU	Outbnd	40.69%	Inside 2 lanes of 3 closed	Milling	heavy	Level 4	Y		long	Clear	1188	504	860	639	70,000	1734	714	1224	1092	2.39	continuous	5033
27	5/13/2004	20:40	22:35	I-77 N	IU	Outbnd	14.59%	Outside 1 lane of 3 closed	Bridge Widening	light	Level 5	Y	800	medium	Warm, Clear	1734	726	1600	1083	90,000	1945	943	1816	1324	2.23	none	-
28	5/13/2004	16:15	18:15	I-77 S	IU	Inbnd	17.42%	Outside lane 1 of 3 closed	Bridge Widening	light	Level 5	Y	750	medium	Warm, Clear	1596	936	1380	1221	50,000	2002	1165	1712	1475	2.29	continuous	5000
29	5/14/2004	16:10	18:25	I-77 S	IU	Inbnd	14.08%	Outside lane 1 of 3 closed	Bridge Widening	light	Level 5	Y	750	medium	Warm, Clear	1824	1224	1533	1356	50,000	2124	1423	1795	1594	2.23	continuous	4000
30	5/14/2004	6:52	8:25	I-77 N	IU	Outbnd	22.06%	Outside 1 lane of 3 closed	Bridge Widening	light	Level 5	Y	800	medium	Warm, Clear	1572	852	1394	1237	60,000	1912	1099	1786	1575	2.26	continuous	4167
31	6/24/2004	19:00	19:00	I-20 W				RAINED OUT	Paving						Rain												
32	7/9/2004	21:25	22:10	I-20 W	IU	Outbnd	14.03%	Outside 2 lanes of 3 closed	Paving	heavy	Level 4	Y		long	Clear	1836	1224	1609	1343	100,000	2141	1423	1905	1578	2.28	continuous	3800
33	10/12/2004	7:15	9:00	I-26 E MPM 76	IU	Inbnd	14.89%	Outside lane of 2 closed	Milling	light	Level 3	Y	800	short	Warm, Clear	1464	660	1068	858	25,000	1644	846	1268	1047	2.37	discontinuous	3500
34	10/20/2004	20:50	23:30	I-85 S MPM 54	IU	Inbnd	14.03%	Inside 2 lanes of 3 closed	Paving	heavy	Level 4	Y	800	long	Warm, Clear	1836	1224	1609	1343	70,000	2130	1428	1902	1587	2.30	continuous	4000
35	12/13/2004			I-20 MPM 70				Inside 2 lanes of 3 closed	Paving	heavy	Level 4		800	medium	Clear												

(1) AADT is estimated from hourly vehicle volume with the exception of site one, whose AADT is estimated from 5min hourly vehicle volume.

(2) PCE is calculated from hourly vehicle volume and hourly pc volume with the exception of site one, whose PCE is calculated from 5min hourly volume.

(3) Change is made from original data.

Table 4-6. Confidence Level (CL) and Intensity Level (I) for the 32 South Carolina (SC) Work Zones

SC Work Zone	Work Intensity Level	OKDOT CL (%)	*HCM* 2000 I (-160,160)	*HCM* 2000 Hybrid I (-500,0)
1	2	20	100	-100
2	2	20	100	-100
3	2	20	100	-100
4	2	20	100	-100
5	4	60	-40	-300
6	4	60	-40	-300
7	5	80	-100	-400
8	3	40	40	-200
9	2	20	100	-100
10	1	0	160	0
11	1	0	160	0
12	3	40	40	-200
13	3	40	40	-200
14	3	40	40	-200
15	NA	NA	NA	NA
16	5	-100	-100	-400
17	5	-100	-100	-400
18	5	-100	-100	-400
19	6	-160	-160	-500
20	6	-160	-160	-500
21	2	100	100	-100
22	4	-40	-40	-300
23	2	100	100	-100
24	4	-40	-40	-300
25	4	-40	-40	-300
26	4	-40	-40	-300
27	5	-100	-100	-400
28	5	-80	-100	-400
29	5	80	-100	-400
30	5	-80	-100	-400
31	NA	NA	NA	NA
32	4	60	-40	-300
33	3	40	40	-200
34	4	-60	-40	-300
35	NA	NA	NA	NA

Method of Prediction Error Analysis and Calibration

Each of the j =1,..., 32 work zones described above was submitted to the method of error analysis and model calibration described in Table 4-7. The calibration analysis was performed to see if there were any obvious trends or tendencies that suggested some other values of baseline parameters (e.g., PCE at a level other than 2.0) that might improve accuracy. In all error analysis (QST and MQL), note that we use the error measurement "difference" defined to be:

Difference = Observed - Predicted

Table 4-7. Method to Find Best Version of OkDOT Spreadsheet Tool

Consider work zone j
Run each version of three versions of model with inputs as indicated by work zone configuration, traffic volumes, percent heavy vehicles, work intensity, etc. and get predicted queue start time and maximum queue length.
For each of these baseline runs: Compare predicted queue start time (QST) and maximum queue length (MQL) with actual values from observers, and record difference (observed - predicted); e.g., +75 minutes (75 minutes early start time), - 1000 ft (predicted queue length 1000 feet too long).
Through trial and error, find combinations of changes in each version that makes predictions come closest to actual QST and MQL. Record these changes and the resulting improved "differences"; e.g., +15 minutes, -100 feet.
Go to work zone j + 1. At j = 32, end.

Analysis and Calibration Results

Table 4-8 reports the results of our prediction error analysis (line one for each site), calibration analysis (line two for each site), and associated with this "best calibrated" result is line three for each site, the optimal setting of parameters used. Some of the optimal settings are baseline (e.g., whenever PCE = 2.0) but others are not. Note that occasionally, the term "miss" is recorded under QST or MQL, for either the baseline run or even the optimized run. The entry "miss" means that either a queue occurred, but none was predicted; or, a queue was predicted, but none occurred. Of course, from the point of view of the mobility planner, the former prediction error "miss" is more serious. We analyze these misses later in this discussion.

Table 4-8. South Carolina (SC) Queue Length Analysis

Work Zone	Queue Start Time (QST)	Max. Queue Length (MQL)	Model Run	OkDOT Prediction				HCM 2000 Prediction				HCM 2000 Hybrid Prediction			
				QST	Diff.	MQL	Diff.	QST	Diff.	MQL	Diff.	QST	Diff.	MQL	Diff.
Site 1	none	-	Baseline(1)	none	-	0	0	none	-	0	0	19:00	miss	580	-580
			Optimal	none	-	0	0	none	-	0	0	none	-	0	0
			Optimal Definition	CL=20% and PCE=2.0				I=100 and PCE=2.0				I=0 and PCE=2.0 or I= -100 and PCE=1.8			
Site 2	none	-	Baseline(1)	none	-	0	0	none	-	0	0	none	-	0	0
			Optimal	none	-	0	0	none	-	0	0	none	-	0	0
			Optimal Definition	CL=20% and PCE=2.0				I=100 and PCE=2.0				I= -100 and PCE=2.0			
Site 3	after 19:40	3200'	Baseline(1)	none	miss	0	3200	none	miss	0	3200	none	miss	0	3200
			Optimal	19:00	+:40	1140	+2060	19:00	+:40	700	2500	19:00	+:40	3160	+40
			Optimal Definition	CL=20% and PCE=2.5				I= -160 and PCE=2.5				I= -350 and PCE=2.5			
Site 4	after 19:05	>5280'	Baseline(1)	19:00	+:05	2130	3150	19:00	+:05	920	4360	19:00	+:05	3260	2020
			Optimal	19:00	+:05	5270	+10	19:00	+:05	5480	-200	19:00	+:05	5480	-200
			Optimal Definition	CL=50% and PCE=2.5				I= -100 and PCE=2.5				I= -100 and PCE=2.5			
Site 5	none	-	Baseline(1)	none	-	0	0	none	-	0	0	none	-	0	0
			Optimal	none	-	0	0	none	-	0	0	none	-	0	0
			Optimal Definition	CL=60% and PCE=2.0				I= -40 and PCE=2.0				I= -300 and PCE=2.0			
Site 6	none	-	Baseline(1)	none	-	0	0	none	-	0	0	none	-	0	0
			Optimal	none	-	0	0	none	-	0	0	none	-	0	0
			Optimal Definition	CL=60% and PCE=2.0				I= -40 and PCE=2.0				I= -300 and PCE=2.0			
Site 7	none	-	Baseline(1)	20:00	miss	934	-934	none	-	0	0	20:00	miss	947	-947
			Optimal	none	-	0	0	none	-	0	0	none	-	0	0
			Optimal Definition	CL=40% and PCE=2.0				I= -100 and PCE=2.0				I= -200 and PCE=2.0			
Site 8	none	-	Baseline(1)	none	-	0	0	none	-	0	0	none	-	0	0
			Optimal	none	-	0	0	none	-	0	0	none	-	0	0
			Optimal Definition	CL=40% and PCE=2.0				I=40 and PCE=2.0				I= -200 and PCE=2.0			
Site 9	none	-	Baseline(1)	none	-	0	0	none	-	0	0	none	-	0	0
			Optimal	none	-	0	0	none	-	0	0	none	-	0	0
			Optimal Definition	CL=20% and PCE=2.0				I=100 and PCE=2.0				I= -100 and PCE=2.0			

Table 4-8. South Carolina (SC) Queue Length Analysis (continued)

Work Zone	Queue Start Time (QST)	Max. Queue Length (MQL)	Model Run	OkDOT Prediction				HCM 2000 Prediction				HCM 2000 Hybrid Prediction			
				QST	Diff.	MQL	Diff.	QST	Diff.	MQL	Diff.	QST	Diff.	MQL	Diff.
Site 10	after 8:30	>4500'	Baseline[(1)]	none	miss	0	4500	none	miss	0	4500	16:00	+:30	1401	3099
			Optimal	16:00	+:30	4289	+211	16:00	+:30	4762	-262	16:00	+:30	4842	-342
			Optimal Definition	CL=60% and PCE=2.5				I= -160 and PCE=5.0				I= -400 and PCE=2.0			
Site 11	none	-	Baseline[(1)]	none	-	0	0	none	-	0	0	none	-	0	0
			Optimal	none	-	0	0	none	-	0	0	none	-	0	0
			Optimal Definition	CL=0% and PCE=2.0				I=160 and PCE=2.0				I=0 and PCE=2.0			
Site 12	none	-	Baseline[(1)]	none	-	0	0	none	-	0	0	none	-	0	0
			Optimal	none	-	0	0	none	-	0	0	none	-	0	0
			Optimal Definition	CL=40% and PCE=2.0				I=40 and PCE=2.0				I= -200 and PCE=2.0			
Site 13	after 19:00	500'	Baseline[(1)]	none	miss	0	500	19:00	0	654	-154	19:00	0	2908	-2408
			Optimal	19:00	0	507	-7	19:00	0	537	-37	19:00	0	560	-60
			Optimal Definition	CL=0% and PCE=1.7				I=40 and PCE=1.95				I=0 and PCE=1.85			
Site 14	after 19:00	800'	Baseline[(1)]	19:00	0	2301	-1501	19:00	0	860	-60	19:00	0	2165	-1365
			Optimal	19:00	0	667	133	19:00	0	860	-60	19:00	0	840	-40
			Optimal Definition	CL=0% and PCE=1.9				I=40 and PCE=2.0				I=0 and PCE=2 or I= -100 and PCE=1.8			
Site 15	no data abailable		Baseline[(1)]												
			Optimal												
			Optimal Definition												
Site 16	after 19:00	>5280'	Baseline[(1)]	19:00	0	5423	-143	19:00	0	1507	3773	19:00	0	5456	-176
			Optimal	19:00	0	5423	-143	19:00	0	5056	224	19:00	0	5216	+74
			Optimal Definition	CL=80% and PCE=2.0				I= -160 and PCE=2.7				I= -400 and PCE=1.95			
Site 17	after 19:00	>5280'	Baseline[(1)]	19:00	0	1700	3580	19:00	0	1120	4160	19:00	0	6240	-960
			Optimal	19:00	0	4020	1260	19:00	0	3140	2140	19:00	0	5420	-140
			Optimal Definition	CL=100% and PCE=2.5				I= -160 and PCE=2.5				I= -400 and PCE=1.85			
Site 18	after 20:00	3000'	Baseline[(1)]	20:00	0	860	2140	20:00	0	280	2720	20:00	0	4700	-1700
			Optimal	20:00	0	2860	140	20:00	0	2900	100	20:00	0	3000	0
			Optimal Definition	CL=80% and PCE=2.5				I= -160 and PCE=2.5				I= -400 and PCE=1.7 or I= -300 and PCE=2.05			

Table 4-8. South Carolina (SC) Queue Length Analysis (continued)

Work Zone	Queue Start Time (QST)	Max. Queue Length (MQL)	Model Run	OkDOT Prediction				HCM 2000 Prediction				HCM 2000 Hybrid Prediction			
				QST	Diff.	MQL	Diff.	QST	Diff.	MQL	Diff.	QST	Diff.	MQL	Diff.
Site 19	none	-	Baseline(1)	none	-	0	0	none	-	0	0	19:00	miss	1160	-1160
			Optimal	none	-	0	0	none	-	0	0	none	-	0	0
			Optimal Definition	CL=100% and PCE=2.0				I= -160 and PCE=2.0				I= -400 and PCE=1.95			
Site 20	after 19:03	>5280'	Baseline(1)	19:00	:03	300	4980	none	miss	0	5280	19:00	:03	4540	740
			Optimal	19:00	:03	1080	4200	19:00	:03	640	4640	19:00	:03	5260	20
			Optimal Definition	CL=100% and PCE=2.5				I= -160 and PCE=2.5				I= -500 and PCE=2.25			
Site 21	none	-	Baseline(1)	19:00	miss	1210	-1210	none	-	0	0	19:00	miss	1540	-1540
			Optimal	none	-	0	0	none	-	0	0	none	-	0	0
			Optimal Definition	CL=40% and PCE=1.7 or CL=20% and PCE=1.8				I=100 and PCE=2.0				I=0 and PCE=1.85			
Site 22	after 21:00	250'	Baseline(1)	21:00	0	173	72	none	miss	0	250	21:00	0	120	130
			Optimal	21:00	0	253	-3	none	miss	0	250	21:00	0	240	10
			Optimal Definition	CL=60% and PCE=2.1				I= -160 and PCE=2.0				I= -300 and PCE=2.15			
Site 23	after 19:17	5000'	Baseline(1)	none	miss	0	5000	none	miss	0	5000	none	miss	0	5000
			Optimal	19:00	:17	900	4100	19:00	:17	460	4540	19:00	:17	5140	-140
			Optimal Definition	CL=100% and PCE=2.5				I= -160 and PCE=2.5				I= -500 and PCE=2.4			
Site 24	21:00	3300'	Baseline(1)	21:00	0	2748	552	21:00	0	307	2993	21:00	0	2641	659
			Optimal	21:00	0	3188	112	21:00	0	3135	165	21:00	0	3322	-22
			Optimal Definition	CL=60% and PCE=2.1				I= -160 and PCE=2.5				I= -300 and PCE=2.15			
Site 25	20:15	4100'	Baseline(1)	20:00	:15	3215	885	20:00	0	1427	2673	20:00	0	3162	938
			Optimal	20:00	:15	3975	125	20:00	0	3508	592	20:00	0	3922	178
			Optimal Definition	CL=60% and PCE=2.2				I= -160 and PCE=2.5				I= -300 and PCE=2.3			
Site 26	21:35	5033'	Baseline(1)	21:00	:35	3268	1765	21:00	:35	587	4446	21:00	:35	3162	1871
			Optimal	21:00	:35	4909	124	21:00	:35	3975	1058	21:00	:35	5043	-10
			Optimal Definition	CL=60% and PCE=2.3				I= -160 and PCE=2.5				I= -300 and PCE=2.35			
Site 27	none	-	Baseline(1)	none	-	0	0	none	-	0	0	none	-	0	0
			Optimal	none	-	0	0	none	-	0	0	none	-	0	0
			Optimal Definition	CL=80% and PCE=2.0				I= -100 and PCE=2.0				I= -400 and PCE=2.0			

Table 4-8. South Carolina (SC) Queue Length Analysis (continued)

Work Zone	Queue Start Time (QST)	Max. Queue Length (MQL)	Model Run	OkDOT Prediction				HCM 2000 Prediction				HCM 2000 Hybrid Prediction			
				QST	Diff.	MQL	Diff.	QST	Diff.	MQL	Diff.	QST	Diff.	MQL	Diff.
Site 28	16:15	5000'	Baseline(1)	none	miss	0	5000	none	miss	0	5000	16:00	:15	0	5000
			Optimal	none	miss	0	5000	none	miss	0	5000	16:00	:15	3695	1305
			Optimal Definition	CL=100% and PCE=2.5				I= -160 and PCE=2.5				I= -500 and PCE=2.5			
Site 29	16:10	4000'	Baseline(1)	none	miss	0	4000	none	miss	0	4000	none	miss	0	4000
			Optimal	none	miss	0	4000	none	miss	0	4000	16:00	:10	2535	1465
			Optimal Definition	CL=100% and PCE=2.5				I= -160 and PCE=2.5				I= -500 and PCE=2.5			
Site 30	6:52	4167'	Baseline(1)	none	miss	0	4167	none	miss	0	4167	none	miss	0	4167
			Optimal	none	miss	0	4167	none	miss	0	4167	7:00	-:08	1788	2379
			Optimal Definition	CL=100% and PCE=2.5				I= -160 and PCE=2.5				I= -500 and PCE=2.5			
Site 31	no data abailable		Baseline(1)												
			Optimal												
			Optimal Definition												
Site 32	21:25	3800'	Baseline(1)	21:00	:25	6190	2390	21:00	:25	2615	1185	21:00	:25	6083	-2283
			Optimal	21:00	:25	3809	-9	21:00	:25	3695	105	21:00	:25	3695	105
			Optimal Definition	CL=20% and PCE=2.0				I= -100 and PCE=2.1				I= -100 and PCE=2.1			
Site 33	7:15	3500'	Baseline(1)	7:00	:15	610	2890	none	miss	0	3500	7:00	:15	1940	1560
			Optimal	7:00	:15	2880	620	7:00	:15	2440	1060	7:00	:15	3600	-100
			Optimal Definition	CL=100% and PCE=2.5				I= -160 and PCE=2.5				I= -300 and PCE=2.35			
Site 34	20:50	4000'	Baseline(1)	21:00	-:10	494	3506	none	miss	0	4000	21:00	-:10	440	3560
			Optimal	21:00	-:10	3135	865	21:00	-:10	4	3996	21:00	-:10	3308	692
			Optimal Definition	CL=100% and PCE=2.5				I= -160 and PCE=2.5				I= -500 and PCE=2.5			
Site 35	no data abailable		Baseline(1)												
			Optimal												
			Optimal Definition												

(1) Baseline Input: PCE is set as default value 2.0 and Confidence (CL) in OkDOT model, Intensity (I) in HCM 2000 and HCM 2000 Hybrid models are set by work zone description

Table 4-9 summarizes the results from Table 4-8 for the metric MQL (maximum queue length). Note that 20 of the 32 work zones had queues; the other 12 did not. At the bottom of the table, appear lines for: total error (sum of errors), average error across all 32 work zones, and average error across the 20 work zones with queues. It is clear that the *HCM* 2000 Hybrid Version produces the smallest average error, for all 32 work zones or the 20 with queues. In fact, *HCM* Hybrid is roughly twice as good as the *HCM* 2000 Version at minimizing prediction error. Furthermore, at their optimized settings, *HCM* 2000 Hybrid provided the best estimate of queue length in 70% of the cases; OkDOT baseline was most accurate for 30% of the 20 cases with queues. *HCM* 2000 Hybrid predicted a queue when none formed 33% of the 12 cases; when optimized, it predicted no queue would form in all 12 such cases, a 100% performance. Finally, there were three cases (Sites #28, #29, and #30) with really odd queue lengths for their situational description. If these three "outliers" are removed from the data set, *HCM* 2000 Hybrid predicts the actual length within an average error of 333 feet over all 29 cases, and to within 568 feet for the 17 with queues; that is, to within 33 and 57 vehicles respectively. Optimized *HCM* 2000 Hybrid actually has on average error less than one car length, but of course, these optimized settings were settings that many not have exactly matched the work zone description and traffic parameters a planner would be using.

Turning now to queue start time (QST), consider Table 4-10 which summarizes the QST results from Table 4-8. The average QST error for all three models was less than five minutes. In part, this is an artifact of the way work zone data was reported, and the way the three OkDOT versions report a queue start time (to the nearest hour, only). The label "miss" used in Table 4.8 was explained earlier. To clarify, we define:

Miss 1: There was a queue, but none was predicted.

Miss 2: There was no queue, but one was predicted.

As we stated earlier, Miss 1 is a more serious predictive error, and the conservative mobility planner would rather make a type 1 error than a type 2 error; or, at least balance these errors. As can be seen at the bottom of Table 4-10, *HCM* 2000 Hybrid does the best job of minimizing the total number of misses, and the number of "Miss 1" instances, across the 32 South Carolina work zones.

Table 4-9. Maximum Queue Length Prediction Error (Feet) for 32 South Carolina (SC) Work Zones; 20 with Queues

SC Work Zone	OKDOT		*HCM* 2000		*HCM* 2000 Hybrid		Maximum Queue Length
	Baseline	Optimal	Baseline	Optimal	Baseline	Optimal	
1	0	0	0	0	-580	0	
2	0	0	0	0	0	0	
3	3200	2860	3200	2500	3200	40	3200'
4	3150	10	4360	-200	2020	-200	5280'
5	0	0	0	0	0	0	
6	0	0	0	0	0	0	
7	-934	0	0	0	-947	0	
8	0	0	0	0	0	0	
9	0	0	0	0	0	0	
10	4500	211	4500	-262	3099	-342	4500'
11	0	0	0	0	0	0	
12	0	0	0	0	0	0	
13	560	-7	-154	-37	-2408	-60	500'
14	-1501	133	-60	-60	-1365	-40	800'
15	NA	NA	NA	NA	NA	NA	
16	-143	-143	3773	224	-176	74	5280'
17	3580	1260	4160	2140	-960	-140	5280'
18	2140	140	2720	100	-1700	0	3000'
19	0	0	0	0	-1160	0	
20	4980	4200	5280	4640	740	20	5280'
21	-1210	0	0	0	-1540	0	
22	72	-3	250	250	130	10	250'
23	5000	4100	5000	4540	5000	-140	5000'
24	552	112	2993	165	659	-22	3300'
25	885	125	2673	592	938	178	4100'
26	1765	124	4446	1058	1871	-10	5033'
27	0	0	0	0	0	0	
28	5000	5000	5000	5000	5000	1305	5000'
29	4000	4000	4000	4000	4000	1465	4000'
30	4167	4167	4167	4167	4167	2379	4167'
31	NA	NA	NA	NA	NA	NA	
32	2390	-9	1185	105	-2283	105	3800'
33	2890	620	3500	1060	1560	-100	3500'
34	3506	865	4000	3996	3560	692	4000'
35	NA	NA	NA	NA	NA	NA	
Total Error	48549	27765	64993	33978	22825	5214	
Average (n=32)	1517.2	867.7	2031	1061.8	713.3	162.9	
Average (n=20)	2427.5	1388.3	3249.7	1698.9	1141.3	260.7	
	Best estimate 6/20 = 30% of queues				Best estimate 14/20 = 70% of queues		
Predicted Queue when none formed					4/12 = 33%	0/12 = 0%	
Total without Sites #28, #29 & #30 -------------------------------->					9656	65	
Average (n=29)					333	2.2	
Average (n=17)					568	3.8	

Table 4-10. Queue Start Time (QST) Prediction Error (Minutes) with Models at Baseline Settings

SC Work Zone	OkDOT	*HCM* 2000	*HCM* 2000 Hybrid
1	0	0	miss 2
2	0	0	0
3	miss 1	miss 1	miss 1
4	5	5	5
5	0	0	0
6	0	0	0
7	miss 2	0	miss 2
8	0	0	0
9	0	0	0
10	miss 1	miss 1	30
11	0	0	0
12	0	0	0
13	miss 1	0	0
14	0	0	0
15	NA	NA	NA
16	0	0	0
17	0	0	0
18	0	0	0
19	0	0	miss 2
20	3	miss 1	3
21	miss 2	0	miss 2
22	0	miss 1	0
23	miss 1	miss 1	miss 1
24	0	0	0
25	15	0	0
26	35	35	35
27	0	0	0
28	miss 1	miss 1	15
29	miss 1	miss 1	miss 1
30	miss 1	miss 1	miss 1
31	NA	NA	NA
32	25	25	25
33	15	miss 1	15
34	-10	miss 1	-10
35	NA	NA	NA
Average	88/23=3.8 min 7 miss 1 2 miss 2	65/22=3.0 min 10 miss 1 0 miss 2	118/24=4.9 min 4 miss 1 4 miss 2

miss 1: There was a queue, but none was predicted.
miss 2: There was no queue, but one was predicted.

As it became apparent that the *HCM* 2000 Hybrid version would be our recommended version, we reviewed the “optimal settings” found in Table 4-8 to see if any fine tuning could be used to improve the predictive ability of the *HCM* 2000 Hybrid with baseline settings, in particular using the passenger car equivalent (PCE) value of 2.0 assumed. We noted quite a few instance where PCE = 2.5 was optimal for *HCM* 2000 Hybrid in Table 4-7. The *Highway Capacity Manual* actually states that PCE values from 2.0 to 2.5 should be considered, the higher values however being more representative in mountainous terrain. Other researchers have suggested that PCE values of 2.5 apply when traffic speed has dropped into the range 0 - 20 mph, because in such stop and start conditions, trucks do require more spacing then at moderate speeds of 20 - 50 mph.

We decided to conduct a parametric analysis of the MQL prediction performance of the *HCM* 2000 Hybrid Version, using PCE values of 2.0 (baseline), 2.2, and 2.4. The results of this parametric analysis are shown in Table 4-11. Just as in the MQL Analysis above, we calculate average error for all work zones, then only for work zones with queues. In addition, we calculated the standard deviation of error in case confidence intervals were to be constructed. Also, we considered a reduced set of work zones – first eliminating Sites #28, #29, and #30; then eliminating Sites #23, #28, #29, and #30. The problem at these four work zones is that all three models failed to predict queue formation, whereas the work site data showed a queue forming; furthermore, these four had the largest prediction errors (4000-5000 feet) of the 32 work zones. A term used for such data that appear different in character from the vast majority, is “outlier.”

While it appears from Table 4-11 that PCE = 2.4 might be best from an average error viewpoint (actually, Figure 4-5 points to 2.36 as best), the elimination of Sites #28, #29, and #30 as outliers points to PCE = 2.2 (actually 2.16 according to Figure 4-6) as best. Finally, when Site #23 is eliminated as well, PCE = 2.0 produces the smallest average error considering the remaining 16 sites with queues. (See Figure 4-7.) A plot showing 95% confidence interval on the mean prediction error with four outliers eliminated (Figure 4-8) shows PCE = 2.1 matches up well with zero average prediction error for the 28 runs, with reasonable uncertainty in the average error for an infinite number of cases of character similar to these runs.

Table 4-11. Maximum Queue Length Prediction Error in *HCM* 2000 Hybrid Model with Intensity as Assigned by Site and PCE as Indicated in Column

SC Work Zone	PCE=2.0(Baseline)	PCE=2.2	PCE=2.4
1	-580	-1300	-2080
2	0	0	0
3	3200	3200	3200
4	2020	1180	280
5	0	0	0
6	0	0	0
7	-947	-1134	-1414
8	0	0	0
9	0	0	0
10	3099	2859	2659
11	0	0	0
12	0	0	0
13	-2408	-3209	-4049
14	-1365	-1775	-2215
15	NA	NA	NA
16	-176	-976	-1777
17	-960	-2040	-3180
18	-1700	-2900	-4040
19	-1160	-1700	-2620
20	740	200	-400
21	-1540	-2320	-3500
22	130	-30	-150
23	5000	5000	5000
24	659	-302	-1222
25	938	418	-102
26	1871	751	-290
27	0	0	0
28	5000	4867	4373
29	4000	4000	4000
30	4167	4167	3954
31	NA	NA	NA
32	-2283	-2843	-3364
33	1560	1200	840
34	3560	3360	3160
35	NA	NA	NA
Total Error	22825	10673	-2937
Average (n=32)	713.3	333.5	-91.8
Std. Dev.(n=32)	2073	2259	2495
Average (n=20)	1353	856	334
Std. Dev.(n=20)	2383	2674	2952
Eliminating Sites #28, #29, & #30			
Average (n=29)	333	-81	-526
Std. Dev.(n=29)	1771	1932	2191
Average (n=17)	817	241	-332
Std. Dev.(n=17)	2162	2404	2683
Eliminating Sites #23, #28, #29 & #30			
Average (n=28)	166	-263	-724
Std. Dev.(n=28)	1555	1697	1952
Average (n=16)	555	-57	-666
Std. Dev.(n=16)	1936	2136	2380

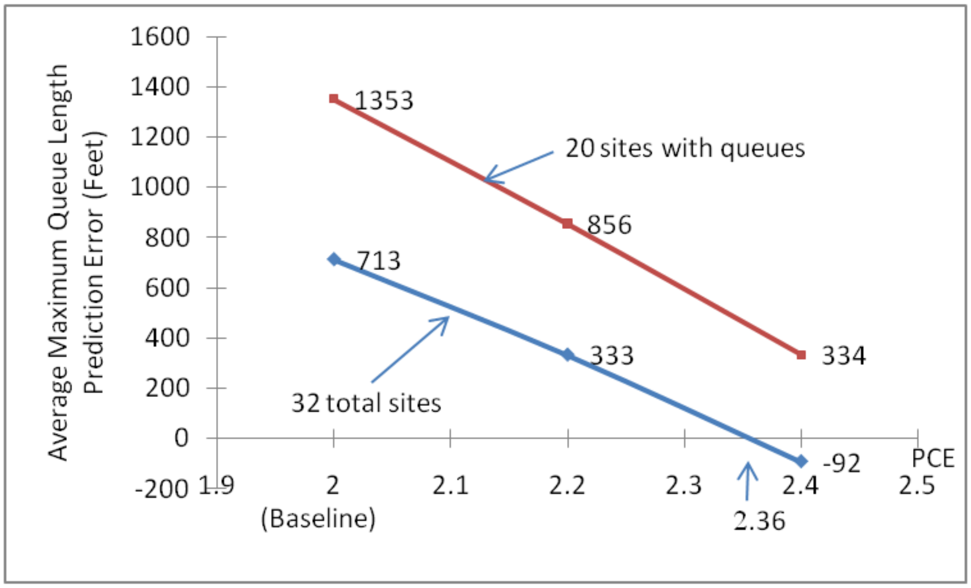


Figure 4-5. ***HCM*** **2000 Hybrid Model with intensity assigned by site and PCE as indicated: 32 total South Carolina sites, 20 with queues.**

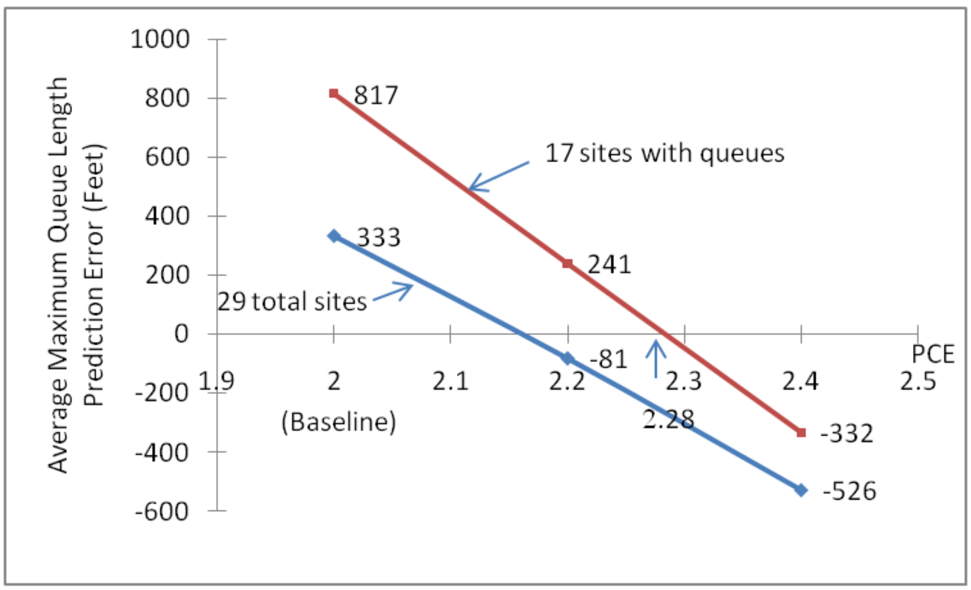


Figure 4-6. ***HCM*** **2000 Hybrid Model with intensity assigned by site and PCE as indicated: (Sites #28, #29, and #30 eliminated) 29 total South Carolina sites, 17 with queues.**

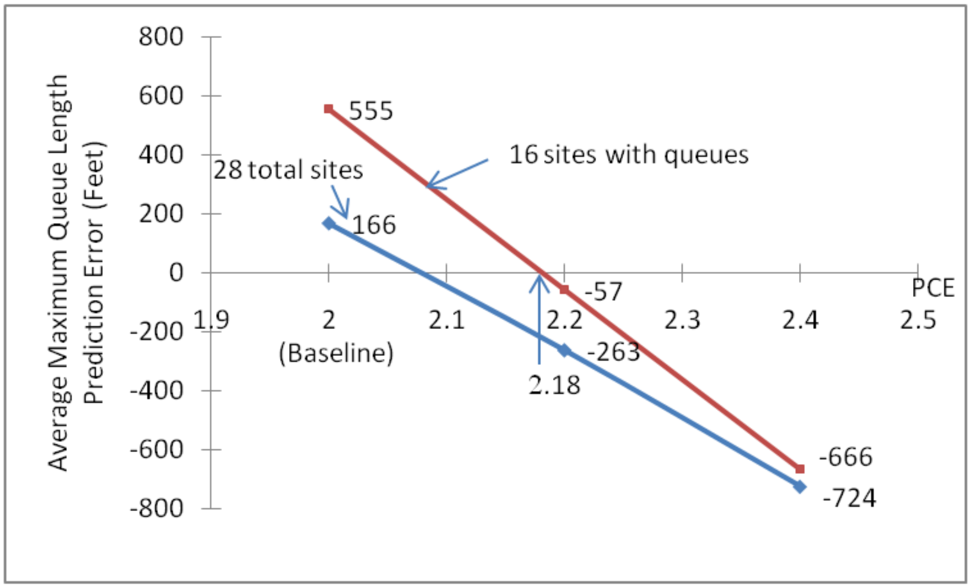


Figure 4-7. ***HCM*** **2000 Hybrid Model with intensity assigned by site and PCE as indicated: (Sites #23, #28, #29, and #30 eliminated) 28 total South Carolina sites, 16 with queues.**

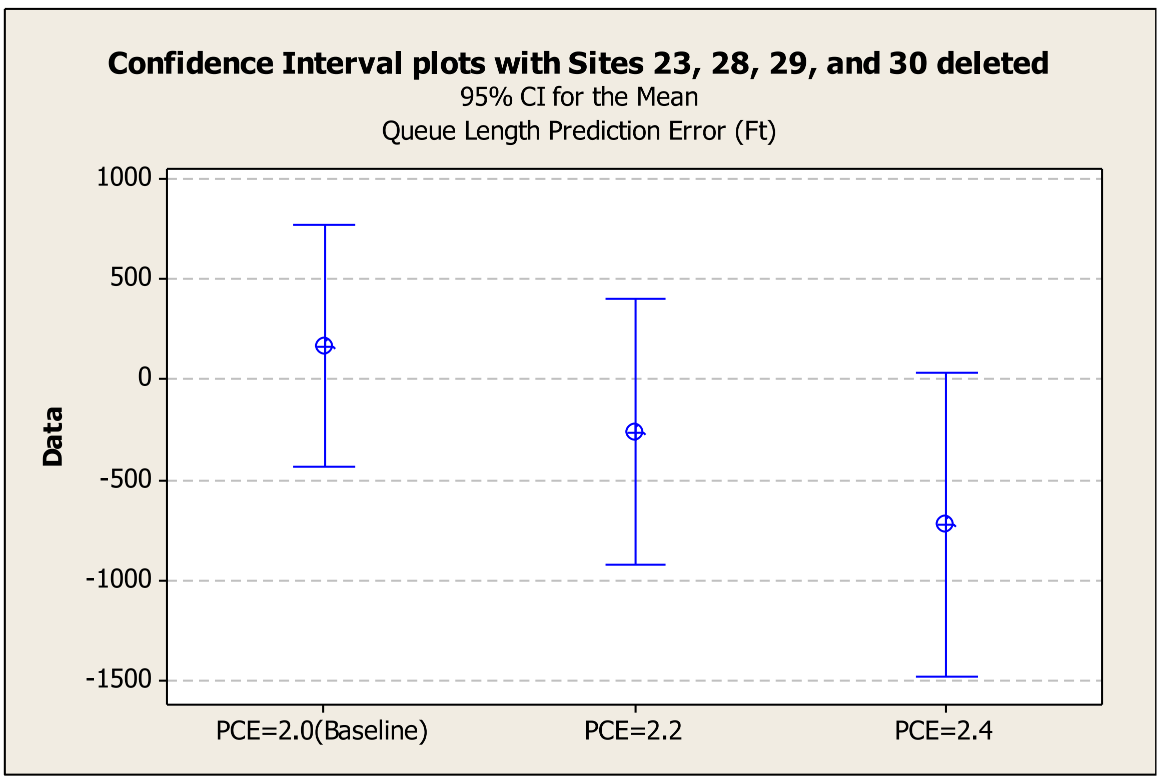


Figure 4-8. CI plots on mean queue length prediction error with Sites #23, #28, #29, and #30 deleted.

5.0 Research Conclusions and Validation Runs

Based on the analysis and evaluation in Chapter 4, we conclude below that the current tool should be replaced by the *HCM* 2000 Hybrid Version we developed and tested. This tool is validated below using six work zone cases, three from Alabama and three from North Carolina.

Research Conclusions

Based on the analysis and evaluation in Chapter 4, the strong conclusion is that the current tool should be replaced by the *HCM* 2000 Hybrid Version we have developed and tested. *HCM* Hybrid Version minimized error in predicting actual MQL at the 32 South Carolina work zones, and minimized the error of not predicting a queue, when one actually formed. Additional testing revealed a PCE = 2.1 minimized error in MQL among typical PCE values in the range [2.0, 2.5]. This tool was validated using six work zone cases, three from Alabama and three from North Carolina. In addition to modification of the capacity estimation method in the OkDOT tool, we endeavored to make it more useful for mobility impact assessment by including a graphical depiction of the queue profile. Additional guidance will be provided in Chapter 6 for cases of planning work zones whose conditions fall outside the normal conditions expected by the model.

Validation Runs

To validate these findings, we examined data we had from Illinois (three data sets), Wisconsin (five useable data sets), Alabama (three data sets we collected ourselves), and North Carolina (three data sets). It turns out the Illinois data was not applicable, and the Wisconsin data was collected on a long-term urban interstate project where commuters had many alternative routes to use whenever queuing began. Such actions meant the queues grew but inexplicably "leveled off," completely out of character with what the University of Wisconsin input-output model, and our models, predicted. So, we ended up with the six work zones from Alabama and North Carolina reported in Table 5-1 as our validation data sets.

We ran *HCM* 2000 Hybrid with PCE =2.1 using the description data for each of these six work zones. The results of these runs are shown in Table 5-2. For the three Alabama work zones, *HCM* 2000 Hybrid with PCE = 2.1 accurately predicted no queue would form at AL Work Zone #2, missed a very short queue that formed at AL Work Zone #3, and predicted a 0.63 mile queue would form at AL Work Zone #1, when no queue was observed. This conservative behavior at AL Work Zone #1 and essentially accurate prediction at AL Work Zone #2 and AL Work Zone #3 are what should be expected. All three of North Carolina work zone predictions resulted in queue patterns (start, build up, and decline to end) that matched the actual data (queues did form at each site), but over-predicted queue length in the first two cases and slightly under-predicted queue length in North Carolina Site #3, as shown in Figure 5-1.

Table 5-1. Validation Data Sets

Site #	Date	Start Time	End Time	Location	Code	Direction	AADT	T%	Original # of lanes	# of lanes Closed	Closure Geometry	Type of Work	WZ Intensity	Ramp	Queue?	Max QL
AL #1	7/28/2008	18:30	21:00	I-65 NB 176	IU	Outbound	76,170 (1)	20	3	1	Outside	Bridge deck patching	2	Y	N	0
AL #2	10/27/2008	8:50	12:30	I-65 NB 317	IR	Outbound	35,930 (2)	20	2	1	Outside	Paving asphalt-bridge interface	3	Y	N	0
AL #3	1/7/2009	10:00	15:50	I-65 SB 209	IR	Outbound	36,210 (3)	16.6	2	1	Outside	Bridge deck patching	2	N	Y	400'
NC #1	Spring 1995	8:30	11:00	I-95 NB*	IR	Inbound	40,000	26.2	2	1	Inside	Heavy with 2' clearance	6	Y	Y	1.55 mi
NC #2	Spring 1995	8:00	11:00	I-95 NB*	IR	Inbound	40,000	24.6	2	1	Outside	Heavy with 2' clearance	6	Y	Y	1.4 mi
NC #3	Spring 1995	8:30	11:00	I-95 NB*	IR	Inbound	40,000	18.8	2	1	Outside	Heavy with 2' clearance	6	Y	Y	2.9 mi

* Johnston County, NC, but no MP given

(1) AADT 2007 for site I-65 at mile marker 172.295 in Montgomery county.

(2) AADT 2007 for site I-65 at mile marker 308.275 in Cullman county is 37,360; for site I-65 at mile marker 326.23 in Morgan county is 34,490. Mile marker 317 is between 308 and 326, use average AADT.

(3) AADT 2007 for site I-65 at mile marker 210.115 in Chilton county.

Table 5-2. Validation Queue Length Analysis

Work Zone	Queue Start Time (QST)	Max. Queue Length (MQL)	Model Run	*HCM* 2000 Hybrid Prediction			
				QST	Diff.	MQL	Diff.
AL 1	none	0	Baseline(1)	18:00	miss	3335	-3335
			Optimal				
			Comment:	Predicts 0.63 mi queue when none forms			
AL 2	none	0	Baseline(1)	none	–	0	0
			Optimal				
			Comment:	Accurately predicts no queue forms			
AL 3	15:20	400'	Baseline(1)	none	miss	0	400
			Optimal				
			Comment:	Predicts no queue (just barely) when 400' queue forms			
NC 1	9:40	1.55 mi	Baseline(1)	9:00	:40	12700	-4501
			Optimal				
			Comment:	Over-predicts max, but pattern is correct			
NC 2	8:30	1.4 mi	Baseline(1)	8:00	:30	14880	-7488
			Optimal				
			Comment:	Over-predicts max, but pattern is correct			
NC 3	8:35	2.9 mi	Baseline(1)	8:00	:30	12660	2652
			Optimal				
			Comment:	Under-predicts max, but pattern is correct			

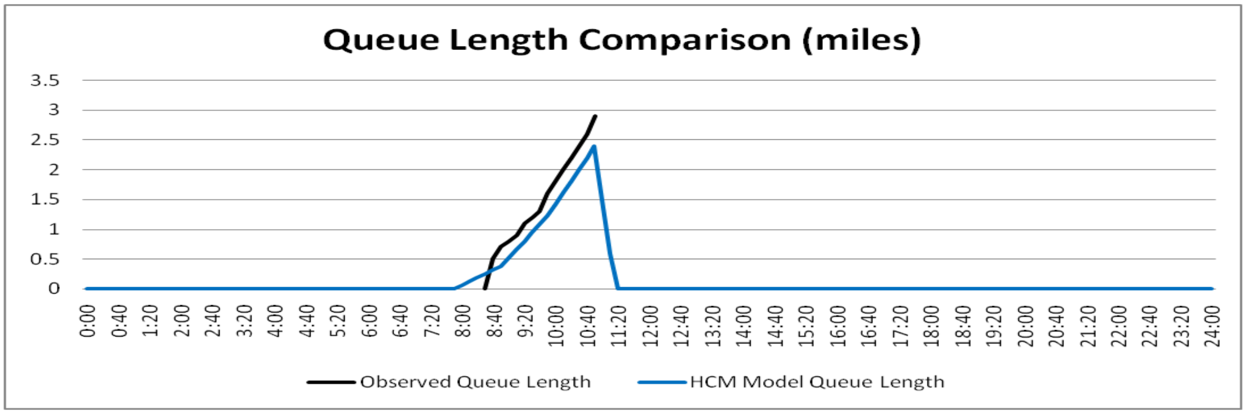


Figure 5-1. *HCM* 2000 Hybrid closely predicts queue growth at North Carolina (NC) Work Zone #3.

6.0 Guidelines for Use of *HCM* 2000 Hybrid Version of OkDOT Tool

This chapter provides guidelines for an Excel-based tool developed in 2009 to assist ALDOT engineers and managers in mobility and safety planning for temporary freeway work zones. The software is written in Excel 2007. An Excel 2003 file with the same software was delivered to ALDOT along with the Excel 2007 file; or, the user can simply convert the file themselves without any loss of functionality. Detailed instructions for how to use the mobility planning (queue formation and delay cost) worksheet are provided herein, along with examples. Instruction sheets are found among the software tabs as well. Users who have experience with the Oklahoma Department of Transportation (OkDOT) Lane Rental Model should find the layout and use of this updated model version very transparent. In fact, the only changes from the version previously in use at ALDOT are:

- Use of the *Highway Capacity Manual* (*HCM*) 2000 formula to calculate open lane capacity in work zones, replacing the *HCM* 1994 tabular data in the Lane Rental Model.

- A six-point scale for selecting and inputting work zone intensity (I), which replaces the use of a "confidence level" in the former version. Also, the capacity penalty for work zone intensity ranges from 0 to -500 passenger cars per hour per lane (pcphpl), a more severe scale than prescribed in *HCM* 2000 – hence the nomenclature OkDOT *HCM* 2000 Hybrid.

- Addition of a simple graph linked to the queue formation table, which depicts the 24-hour queue profile under the input conditions.

The *HCM* 2000 Hybrid Version of OkDOT Tool was developed from the OkDOT Lane Rental Model to predict queue length and provide other information to assist in mobility planning for temporary freeway work zones in Alabama. The University of Alabama's University Transportation Center for Alabama modified how work zone capacity is calculated, and added a graphical 24-hour queue length profile, to the version in use at ALDOT through mid-2009. There are a total of five worksheets in the revised tool: "Information and Instructions," "ODOT LR Model Version History," "Input and Output Sheet," "Reference Table Sheet," and "Calculation Sheet." The first worksheet is new; the next four are carried over from the pre-2009 version.

The "Information and Instructions Sheet" provides users with basic information and instructions on how to use the model. "Input and Output Sheet" is where users provide basic inputs required to run the model; queue length prediction output appears in both tabular and graphical forms. "Reference Table Sheet" contains reference information needed to do the calculation; this sheet is not visible to users unless the user wants to use their own hourly traffic volume. "Calculation

Sheet" is where the calculation is conducted; the user does not need to study this sheet unless they want to know the underlying logic of the calculation. Figures 6-1, 6-2, 6-3, 6-4, and 6-5 provide the layouts of the first five spreadsheets.

HCM 2000 Hybrid Version of OkDOT Tool

Information:

HCM 2000 Hybrid Version of OkDOT Tool is a modification of Version 3.2 (August 2001) ODOT Lane Rental Model, prepared in May 2009, by Dr. Robert G. Batson, Professor of Civil, Construction, and Environmental Engineering Department, University of Alabama.

ODOT Lane Rental Model was created by Karl Zimmerman, Oklahoma Department of Transportation, 1997, and modified by Richard Jurey, Federal Highway Administration, in October 2000, January 2001, February 2001, and August 2001.

Changes made to Version 3.2 (August 2001) ODOT Lane Rental Model:

- Work zone capacities were calculated by referring to the 2000 Highway Capacity Manual formula, but with work intensity on a six-level scale ranging from 0 to -500 pcphpl.
- Replaced "Confidence Level" input with "Work Intensity" and "Ramp adj." inputs (see below).
- Added "Passenger car equivalent for heavy vehicles" input to allow user-defined PCE.
- Graphical output was added to show queue length prediction (in addition to tabular output).
- A more user-friendly interface was created.
- Two minor software bugs were corrected.

- **Disclaimer: This spreadsheet is provided "AS-IS" to the user. The user assumes all risk and agrees not to hold the author(s) of the current or previous versions liable for any consequential or incidental damages arising from the use of this spreadsheet.**

Instructions for use of OkDOT HCM 2000 Hybrid Version:

- Input data into the yellow cells.
- "Max. queue length limit" input is used to limit queue length.
  If there is no limit in queue length, input a large number (99 for example).
- Spreadsheet can currently calculate costs for one direction only.
- "Work Intensity" input: Set I=0, -100, …, -500 according to the table below.

Level	Intensity	I-values (pcphpl)	Work Type Examples
1	Lightest	0	Guardrail repair/installation, Median cleanup
2	Light	-100	Pothole repair, bridge deck patching, bridge deck inspection and maintenance, barrier wall erection
3	Moderate	-200	Resurfacing/asphalt removal, paving (w/light equipment activity), milling (w/light equipment activity)
4	Heavy	-300	Stripping/slide removal, paving (w/heavy equipment activity), milling (w/heavy equipment activity)
5	Very Heavy	-400	Pavement marking, final striping, Concrete paving (w/heavy equipment activity), Bridge widening (w/light equipment activity)
6	Heaviest	-500	Bridge repair, bridge widening (w/heavy equipment activity)

- "Ramp adj." input: If there is an entrance ramp one mile or less upstream of the work zone, set R=160; otherwise, set R=0.

Figure 6-1. OkDOT *HCM* 2000 Hybrid Version: Information and instructions sheet.

ODOT Lane Rental Model

Versiton History

- All modifications were done by Richard Jurey, FHWA Oklahoma Division, unless otherwise noted.
- **Disclaimer: This spreadsheet is provided "AS-IS" to the user. The user assumes all risk and agrees not to hold the author(s) liable for any damages arising from the use of this spreadsheet.**

Proposed changes

- This model should be fairly easy to use. However, I do plan to eventually write a complete set of instructions.
- Allow the user to define the reset time on the queue length. The original ODOT model resets the queue length to zero at 3:50 AM, which works fine for daytime lane rental and should work for most nighttime lane rental. However, this will cause a problem during a nighttime closure if there is a built-up queue at 3:50 AM. The reset is necessary to avoid recursive formulas (which spreadsheets can't handle), and spillover of the queue from one day to the next. This spillover would lead to an infinite queue length.
- Allow the user to adjust the truck percentages on a per hour basis rather than use one value for the whole day.

Version 3.2: August 2001

- Changed the K factor input to a decimal value to match the format in the Highway Capacity Manual. The K factor was entered as a percentage (but entered without the % sign) on the origianl ODOT spreadsheet, whereas the D factor was entered as a decimal value. This is confusing, especially since there are no complete instructions to go with the spreadsheet.

Version 3.1: August 2001

- Version history added. I intended to do this a long time ago, but never had the time to do it.
- Modified the formulas to account for trucks with user-defined volumes. I had intended the user to adjusted their per hour volumes for trucks before they entered them under the use-defined volumes. Steve Mills, FHWA Alabama Division, noted that the users were not doing this, which caused problems with their analysis.
- Added a factor to allow the user to adjust the number of passenger cars equivalents per truck; the default is 2.0. The original ODOT model calculated the adjusted passenger car volume based on ADT*(1+%trucks), which represents 2.0 passenger car equivalents per truck.

Version 3.0: February 2001 - change from ODOT capacity factors to 98 HCM

- The lane rental costs are summarized by four peak periods during the day on the **Lane Rental Input** sheet. ODOT generally defines the lane rental based on these peak periods.
- The lane capacity factors have been changed to the 1998 Highway Capacity Model. Kevin Harrington, FHWA South Carilona Division, was comparing the result of the ODOT model with another that he was using. He noted some discrepancies with the lane capacities. Some of ODOT's capacities are considerably different from the 98 HCM, and they don't allow any adjustment based on a confidence level (see Figure 6-12 in the 98 HCM). I cannot determine the source of ODOT's lane capacity factors,

Figure 6-2. ODOT LR Model Version history sheet.

but they are likely based on information from the early 90's.

Version 2.0: December-January 2001 - a major overhaul

- A new user-interface (the **Lane Rental Input** and **Lane Rental Table** sheets) was grafted onto the original ODOT lane rental model. The original ODOT model wasn't easy to use. The detailed calculations from the ODOT spreadsheet are shown on the **Lane Rental Calculation** sheet.
- ODOT's origianl spreadsheet contained separate analysis for urban interstate, rural interstate, urban arterial, and rural arterial. This version cuts this down to one analysis, which is selected in the **Lane Rental Input** sheet.
- Two new analysis have been added to allow user-defined hourly volumes or factors. Select the appropriate model on the **Lane Rental Input** sheet, then enter the user-defined information on the **Lane Rental Table** sheet.
- The 10-minute road user costs and volumes from the **Lane Rental Calculation** sheet are now summarized hourly on the **Lane Rental Input** sheet.
- Non-input cells were protected to prevent accidental user modification or deletion.

Version 1.1: October 2000

- Added a queue length limiting factor as suggested by Steve Mills, FHWA Oklahoma Division. You can use this to limit the queue length. The assumption behind this is some areas have parallel frontage roads or alternate freeway routes, and the traffic will use these rather than wait in the queue. I'll leave it up to the user to determine the validity of this assumption. Enter a large number (ex.: 99) to avoid limiting the queue length.

Version 1.0: June 2000 - original release

- The original lane rental spreadsheet was created by Karl Zimmerman, Oklahoma Department of Transportation, in 1997.
- The original spreadsheet was converted from Quattro Pro to Microsoft Excel 97.
- Custom number formatting was added for easier readability.
- Some minor reference/calculation errors were fixed on the original spreadsheet.
- Input cells were color-coded to aid with user input.

Version numbering

X.0 A change in the integer portion of the version number represents a new version of the spreadsheet. A new version may be created for a major change in the user interface or methodology

0.X A change in the decimal portion of the version number represents a "point" release. This may be for formala or spelling corrections, or for changed or added user input features.

Figure 6-2. ODOT LR Model Version history sheet (continued).

HCM 2000 Hybrid Version of OkDOT Tool
SC 1

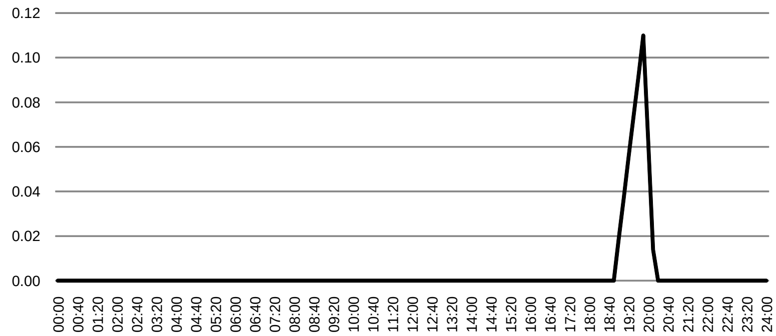
Analysis Code (use code from table below):	IU
Direction (Inbound or Outbound):	Inbound
AADT (both directions):	50,000
Percent of heavy vehicles:	35.67%
Passenger car equivalent for heavy vehicles	2.00
Passenger cars per day:	67,835
Number of lanes (one direction):	2
Free flow speed (mph):	50
Basic lane capacity (pcphpl):	2250
Work Intensity (-500 - 0 pcphpl):	-100
Ramp adjustment (0-160 pcphpl):	160
Max. queue length limit (miles):	99
Delay ($/hour) passenger car:	$10.00
Fuel costs ($/gal):	$2.00
Average # people per vehicle:	1.2

	Morning Peak 6am-9am	Daytime Non-Peak 9am-3pm	Evening Peak 3pm-7pm	Nighttime Non-Peak 7pm-6am	Daily (24 Hr.) Summary
Total Cost of Delay ($):	0	0	0	683	683
# of Hrs. Lanes Closed:	0	0	0	3	3
Ave Cost of Delay/Hr. ($):	0	0	0	62	28
Traffic Volume:	7,584	11,133	8,099	6,877	33,694
Max # of Cars in Queue:	0	0	0	58	58
Max Queue Length (mi.):	0.0	0.0	0.0	0.1	0.1

Analysis Code (enter two-letter code above):	
IU	Interstate - Urban (ODOT)
IR	Interstate - Rural (ODOT)
AU	Arterial - Urban (ODOT)
AR	Arterial - Rural (ODOT)
UF	User Defined Factors
UV	User Defined Volumes

* Enter values on Reference Table Sheet if Analysis Code is UF or UV.

Queue Length Prediction (miles)



		Interstate – Urban								
Hour	# of Lanes Closed [(1)]	AADT Factor (K)	Direction Factor (D)	Volume [(2)]	Limiting Capacity	Max Cars in Queue	Delay Cost	Fuel Cost	Total Costs	Max Queue Length (mi.)
Mid.-1am	0	1.325	0.50	449	4,500	0	0	0	0	0.00
1am-2am	0	0.725	0.50	246	4,500	0	0	0	0	0.00
2am-3am	0	0.575	0.50	195	4,500	0	0	0	0	0.00
3am-4am	0	0.475	0.50	161	4,500	0	0	0	0	0.00
4am-5am	0	0.575	0.50	195	4,500	0	0	0	0	0.00
5am-6am	0	1.475	0.50	500	4,500	0	0	0	0	0.00
6am-7am	0	3.825	0.65	1,687	4,500	0	0	0	0	0.00
7am-8am	0	7.675	0.65	3,384	4,500	0	0	0	0	0.00
8am-9am	0	5.700	0.65	2,513	4,500	0	0	0	0	0.00
9am-10am	0	4.850	0.50	1,645	4,500	0	0	0	0	0.00
10am-11am	0	5.000	0.50	1,696	4,500	0	0	0	0	0.00
11am-Noon	0	5.500	0.50	1,865	4,500	0	0	0	0	0.00
Noon-1pm	0	5.775	0.50	1,959	4,500	0	0	0	0	0.00
1pm-2pm	0	5.725	0.50	1,942	4,500	0	0	0	0	0.00
2pm-3pm	0	5.975	0.50	2,027	4,500	0	0	0	0	0.00
3pm-4pm	0	7.050	0.40	1,913	4,500	0	0	0	0	0.00
4pm-5pm	0	8.425	0.40	2,286	4,500	0	0	0	0	0.00
5pm-6pm	0	8.675	0.40	2,354	4,500	0	0	0	0	0.00
6pm-7pm	0	5.700	0.40	1,547	4,500	0	0	0	0	0.00
7pm-8pm	1	4.125	0.50	1,399	1,340	58	348	97	445	0.11
8pm-9pm	1	3.500	0.50	1,187	1,340	33	138	57	195	0.06
9pm-10pm	1	3.025	0.50	1,026	1,340	0	0	43	43	0.00
10pm-11pm	0	2.575	0.50	873	4,500	0	0	0	0	0.00
11pm-Mid.	0	1.900	0.50	644	4,500	0	0	0	0	0.00

[(1)] One direction only.

[(2)] Passenger car volumes (adjusted for % of heavy vehicles) for one direction only

Figure 6-3. Input and output sheet.

Inputs (carried over from Input & Output Sheet)	
Analysis Code:	IU
Direction (Inbound or Outbound):	Inbound
AADT (both directions):	50,000
Percent of heavy vehicles:	35.67%
Passenger car equivalent for heavy vehicles:	2.00
Passenger cars per day:	67,835
Number of lanes (one direction):	2
Free flow speed (mph):	50
Basic lane capacity (pcphpl):	2250
Work Intensity (-500 - 0 pcphpl):	-100
Ramp adjustment (0-160 pcphpl):	160
Max. queue length limit (miles):	99
Delay ($/hour) passenger car:	$10.00
Fuel costs ($/gal):	$2.00
Average # people per vehicle:	1.2

Highway Capacities		
Original # of Lanes (1)	# of Lanes Closed (1)	Capacity pcphpl
2	0	4500
2	1	1340*
3	0	6750
3	1	2680*
3	2	1340*
4	0	9000
4	1	4020*
4	2	2680*
4	3	1340^

(1) one direction only
* Based on 2000 Highway Capacity Manual.
^ Copied from 3 lanes with 2 lanes closed (HCM doesn't have this distribution).

If using defined values, enter them into the colums marked with arrows.
↓

	User	User Defined Factors:			ODOT Default Factors:											
	Defined	(enter description)			Interstate – Urban			Interstate – Rural			Arterial – Urban			Arterial – Rural		
Hour	Volumes (2)	K	D (inbnd)	D (outbnd)	K	D (inbnd)	D (outbnd)	K	D (inbnd)	D (outbnd)	K	D (inbnd)	D (outbnd)	K	D (inbnd)	D (outbnd)
Midnight-1am					1.325	0.50	0.50	1.830	0.55	0.45	0.980	0.50	0.50	0.930	0.55	0.45
1am-2am					0.725	0.50	0.50	1.420	0.55	0.45	0.640	0.50	0.50	0.570	0.55	0.45
2am-3am					0.575	0.50	0.50	1.180	0.55	0.45	0.470	0.50	0.50	0.420	0.55	0.45
3am-4am					0.475	0.50	0.50	1.030	0.55	0.45	0.380	0.50	0.50	0.370	0.55	0.45
4am-5am					0.575	0.50	0.50	1.100	0.55	0.45	0.530	0.50	0.50	0.520	0.55	0.45
5am-6am					1.475	0.50	0.50	1.430	0.55	0.45	1.140	0.50	0.50	1.330	0.55	0.45
6am-7am					3.825	0.65	0.35	2.330	0.55	0.45	3.150	0.65	0.35	2.780	0.55	0.45
7am-8am					7.675	0.65	0.35	3.470	0.55	0.45	5.920	0.65	0.35	4.820	0.55	0.45
8am-9am					5.700	0.65	0.35	4.300	0.55	0.45	5.240	0.65	0.35	5.400	0.55	0.45
9am-10am					4.850	0.50	0.50	5.230	0.55	0.45	4.880	0.50	0.50	6.200	0.55	0.45
10am-11am					5.000	0.50	0.50	5.880	0.55	0.45	5.210	0.50	0.50	6.430	0.55	0.45
11am-Noon					5.500	0.50	0.50	6.170	0.55	0.45	5.880	0.50	0.50	6.450	0.55	0.45
Noon-1pm					5.775	0.50	0.50	6.230	0.55	0.45	6.310	0.50	0.50	6.480	0.55	0.45
1pm-2pm					5.725	0.50	0.50	6.470	0.55	0.45	6.120	0.50	0.50	6.680	0.55	0.45
2pm-3pm					5.975	0.50	0.50	6.770	0.55	0.45	6.170	0.50	0.50	6.970	0.55	0.45
3pm-4pm					7.050	0.40	0.60	7.030	0.55	0.45	7.020	0.40	0.60	7.550	0.55	0.45
4pm-5pm					8.425	0.40	0.60	7.100	0.55	0.45	7.610	0.40	0.60	7.930	0.55	0.45
5pm-6pm					8.675	0.40	0.60	6.920	0.55	0.45	8.240	0.40	0.60	7.600	0.55	0.45
6pm-7pm					5.700	0.40	0.60	6.000	0.55	0.45	6.540	0.40	0.60	6.070	0.55	0.45
7pm-8pm					4.125	0.50	0.50	5.050	0.55	0.45	5.060	0.50	0.50	4.350	0.55	0.45
8pm-9pm					3.500	0.50	0.50	4.250	0.55	0.45	4.610	0.50	0.50	3.450	0.55	0.45
9pm-10pm					3.025	0.50	0.50	3.550	0.55	0.45	3.750	0.50	0.50	2.900	0.55	0.45
10pm-11pm					2.575	0.50	0.50	2.950	0.55	0.45	2.540	0.50	0.50	2.280	0.55	0.45
11pm-Midnight					1.900	0.50	0.50	2.300	0.55	0.45	1.630	0.50	0.50	1.520	0.55	0.45

(2) Enter passenger car volumns (adjusted for % of heavy vehicles) for one direction only.

Figure 6-4. Reference table sheet.

Analysis Code:	IU
Direction (Inbound or Outbound):	Inbound
AADT (both directions):	50,000
Percent of heavy vehicles:	35.67%
Passenger car equivalent for heavy vehicles:	2.00
Passenger cars per day:	67,835
Number of lanes (one direction):	2
Free flow speed (mph):	50
Basic lane capacity (pcphpl):	2250
Work Intensity (-500 - 0 pcphpl):	-100
Ramp adjustment (0-160 pcphpl):	160
Max. queue length limit (miles):	99
Delay ($/hour) passenger car:	$10.00
Fuel costs ($/gal):	$2.00
Average # people per vehicle:	1.2

Highway Capacities		
Original # of Lanes (1)	# of Lanes Closed (1)	Capacity pcphpl
2	0	4500
2	1	1340
3	0	6750
3	1	2680
3	2	1340
4	0	9000
4	1	4020
4	2	2680
4	3	1340

(1) one direction only

Time Slice	AADT Factor (K)	Direction Factor (D)	Original # of Lanes *	# of Lanes Closed *	10 min volume	Capacity Limit	Queue at slice end	Delay Cost	Fuel Cost	Total Costs	Queue Length
00:00	1.325	0.50	2	0	75	750	0	0	0	0	0.00
00:10	1.325	0.50	2	0	75	750	0	0	0	0	0.00
00:20	1.325	0.50	2	0	75	750	0	0	0	0	0.00
00:30	1.325	0.50	2	0	75	750	0	0	0	0	0.00
00:40	1.325	0.50	2	0	75	750	0	0	0	0	0.00
00:50	1.325	0.50	2	0	75	750	0	0	0	0	0.00
01:00	0.725	0.50	2	0	41	750	0	0	0	0	0.00
01:10	0.725	0.50	2	0	41	750	0	0	0	0	0.00
23:00	1.900	0.50	2	0	107	750	0	0	0	0	0.00
23:10	1.900	0.50	2	0	107	750	0	0	0	0	0.00
23:20	1.900	0.50	2	0	107	750	0	0	0	0	0.00
23:30	1.900	0.50	2	0	107	750	0	0	0	0	0.00
23:40	1.900	0.50	2	0	107	750	0	0	0	0	0.00
23:50	1.900	0.50	2	0	107	750	0	0	0	0	0.00
24:00	1.325	0.50	2	0	75	750	0	0	0	0	0.00
							Totals	486	197	683	0.11

Figure 6-5. LR calculation sheet.

To run the model, users need to fill in all yellow cells on the "Input and Output Sheet." Cells with no fill are protected; the users cannot change them unless they unprotect the sheet. The traffic planning model contains two parts, queue length prediction and delay cost prediction. Inputs used to predict queue length fall into three categories – traffic volume, work zone capacity, and queue length limitation. The following subsections provide information on the categories of traffic volume inputs and work zone capacity inputs. Queue length limitation is controlled by the input "Maximum queue length limit." The users can decide queue length limitation according to the work zone situation; for example, queue length can be limited by the existence of upstream exit ramp(s). If there is no known queue length limitation, set maximum queue length to a large number, such as 99 (miles). The following guidelines are focused on inputs needed to predict if and when a queue will form, and hourly queue length. For those interested in cost of delay due to work zones, one can decide the inputs on cost of delay according to current economic inputs; these inputs include "Delay cost per hour for a passenger car," "Fuel costs per gallon," and "Average number of people per vehicle."

Layouts for Inputs and Outputs

Basic inputs and outputs are contained in "Input and Output Sheet." The structure of "Input and Output Sheet" is illustrated in Figure 6-6.

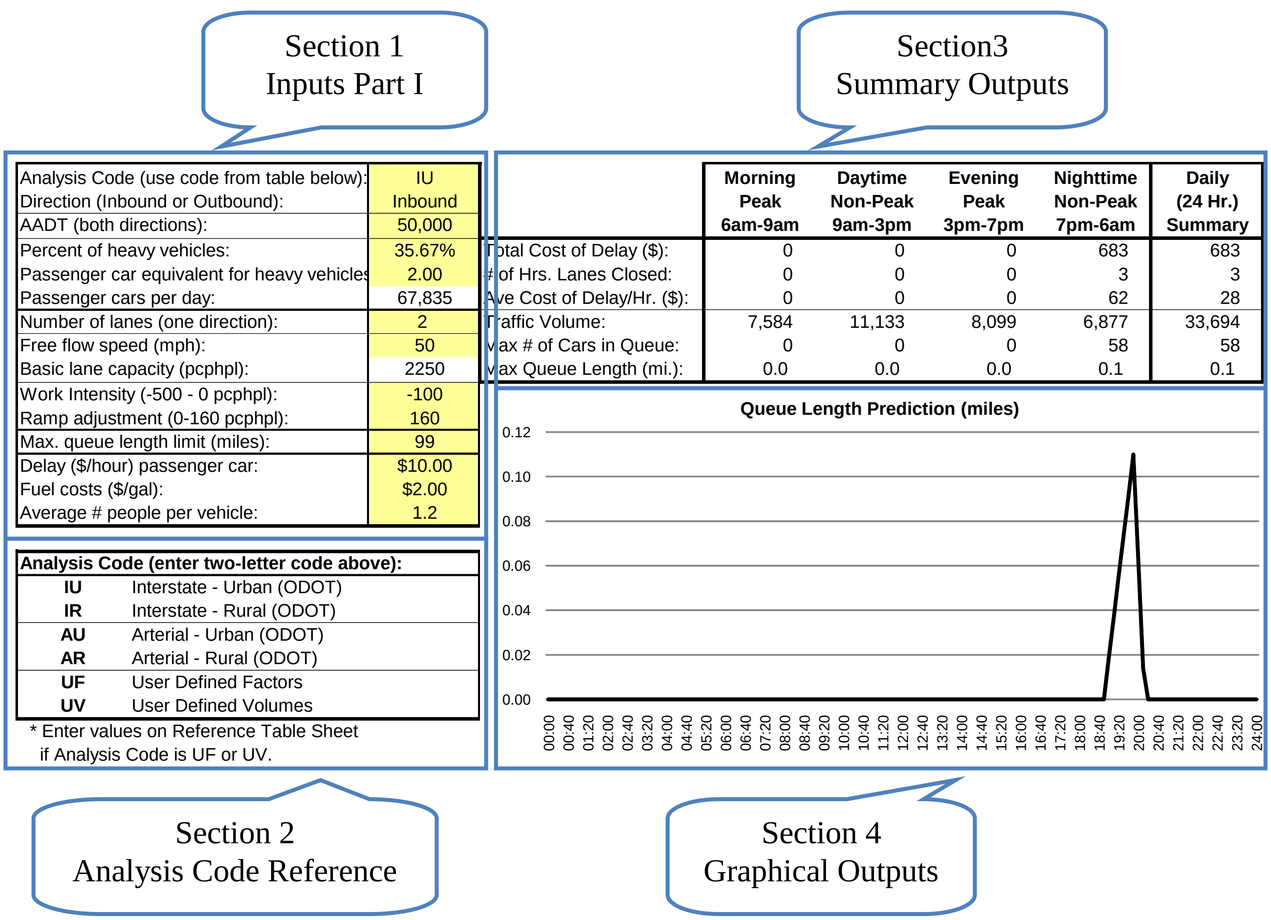


Figure 6-6. Inputs and outputs in "Input and Output Sheet."

Section 5
Inputs Part II

Section 6
Hourly Outputs

Hour	# of Lanes Closed [(1)]	Interstate – Urban			Limiting Capacity	Max Cars in Queue	Delay Cost	Fuel Cost	Total Costs	Max Queue Length (mi.)
		AADT Factor (K)	Direction Factor (D)	Volume [(2)]						
Mid.-1am	0	1.325	0.50	449	4,500	0	0	0	0	0.00
1am-2am	0	0.725	0.50	246	4,500	0	0	0	0	0.00
2am-3am	0	0.575	0.50	195	4,500	0	0	0	0	0.00
3am-4am	0	0.475	0.50	161	4,500	0	0	0	0	0.00
4am-5am	0	0.575	0.50	195	4,500	0	0	0	0	0.00
5am-6am	0	1.475	0.50	500	4,500	0	0	0	0	0.00
6am-7am	0	3.825	0.65	1,687	4,500	0	0	0	0	0.00
7am-8am	0	7.675	0.65	3,384	4,500	0	0	0	0	0.00
8am-9am	0	5.700	0.65	2,513	4,500	0	0	0	0	0.00
9am-10am	0	4.850	0.50	1,645	4,500	0	0	0	0	0.00
10am-11am	0	5.000	0.50	1,696	4,500	0	0	0	0	0.00
11am-Noon	0	5.500	0.50	1,865	4,500	0	0	0	0	0.00
Noon-1pm	0	5.775	0.50	1,959	4,500	0	0	0	0	0.00
1pm-2pm	0	5.725	0.50	1,942	4,500	0	0	0	0	0.00
2pm-3pm	0	5.975	0.50	2,027	4,500	0	0	0	0	0.00
3pm-4pm	0	7.050	0.40	1,913	4,500	0	0	0	0	0.00
4pm-5pm	0	8.425	0.40	2,286	4,500	0	0	0	0	0.00
5pm-6pm	0	8.675	0.40	2,354	4,500	0	0	0	0	0.00
6pm-7pm	0	5.700	0.40	1,547	4,500	0	0	0	0	0.00
7pm-8pm	1	4.125	0.50	1,399	1,340	58	348	97	445	0.11
8pm-9pm	1	3.500	0.50	1,187	1,340	33	138	57	195	0.06
9pm-10pm	1	3.025	0.50	1,026	1,340	0	0	43	43	0.00
10pm-11pm	0	2.575	0.50	873	4,500	0	0	0	0	0.00
11pm-Mid.	0	1.900	0.50	644	4,500	0	0	0	0	0.00

[(1)] One direction only.
[(2)] Passenger car volumes (adjusted for % of heavy vehicles) for one direction only

Figure 6-6. Inputs and outputs in "Input and Output Sheet" (continued).

Traffic Volume Inputs

Traffic volume can also be called incoming traffic volume or traffic demand. It is a key factor in deterministic queue length models such as this one. Inputs affecting traffic volume include "Analysis Code," "Direction," "AADT," "Percent of heavy vehicles," and "Passenger car equivalent for heavy vehicles" as shown in Figure 6-7. We discuss each of these five inputs below.

Analysis Code (use code from table below):	IU
Direction (Inbound or Outbound):	Inbound
AADT (both directions):	50,000
Percent of heavy vehicles:	35.67%
Passenger car equivalent for heavy vehicles:	2.00
Passenger cars per day:	67,835

Figure 6-7. Traffic volume inputs.

1. *Analysis Code*: This input is about information on highway type and location: interstate or arterial, urban or rural. Highway type and location determines the traffic volume pattern and distributes daily traffic volume to each hour. The general pattern is that an urban area has obvious morning and evening peaks; rural areas have a continuous increase in volume from early morning and reach a peak in the evening. These patterns are depicted in Figure 6-8.

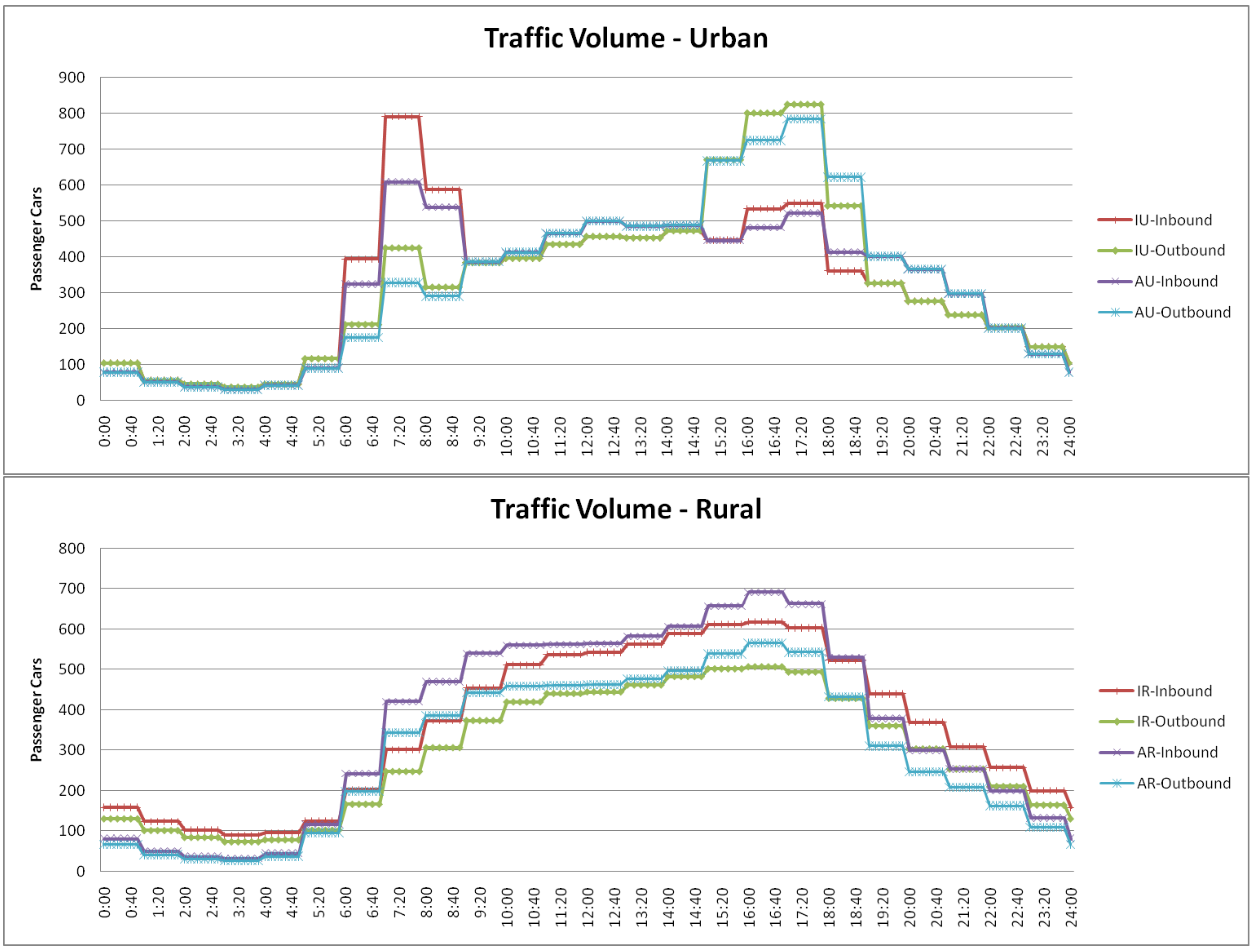


Figure 6-8. Traffic volume pattern.

There are three cases for this input: (1) Users have their own hourly traffic volume, (2) Users have their own traffic volume distribution factors, and (3) Users prefer to use historical traffic volume distribution factors provided by OkDOT. For case (1), input UV for Analysis Code and input hourly traffic volume in the column “User Defined Volumes” in “Reference Table Sheet,” attention is needed to assure the inputs are the volume for passenger cars, with more details given in the following section. For case (2), input UF here and input traffic volume distribution factors in the yellow cells under columns “User Defined Factors” in “Reference Table.” For case (3), input the appropriate two-letter code by referring the table below the input box.

2. *Direction*: This input is also used to distribute daily volume to each hour; it works together with Analysis Code. If users use their own hourly traffic volume and use UV for Analysis Code, this cell does not need input. Otherwise, users need to input Inbound or Outbound. The choice depends on whether traffic flow affected by the work zone enters or comes out of city center. If the traffic flow enters the city center, choose Inbound; otherwise, choose Outbound. For rural freeways, the work zone will be situated between two urban areas: considering the direction of flow, if the work zone is closer to the "source" city, call it IR-outbound; if the work zone is closer to the "destination" city, call it IR-inbound.

3. *AADT*: AADT (Annual Average Daily Traffic) is used to calculate incoming traffic volume; it is the daily traffic volume that is distributed by the previous two inputs. If users use their own hourly traffic volume, no input is needed here; otherwise, they need to input AADT here. AADT value for a given MP can be obtained on the ALDOT website.

4. *Percent of heavy vehicles*: Two types of vehicles are considered in the model, heavy vehicles and passenger cars. This input is used to consider the different effect of heavy vehicles and passenger cars on queue formation and queue length; it works together with the next input PCE. Percent of heavy vehicles can be obtained by referring to historical records or by direct observation, say, counting the number of heavy vehicles and passenger cars by visiting the site in a previous week on the same day of week when work is expected. A heavy vehicle includes 18-wheelers, panel trucks, trucks or cars hauling trailers, recreational vehicles, etc.

5. *Passenger car equivalent for heavy vehicles*: Heavy vehicles contribute to a longer queue length than passenger cars, due to their length and slower acceleration/deceleration characteristics. The model considers this effect by converting the number of heavy vehicles to an appropriate number of passenger cars using the PCE factor. For example, the recommended PCE factor is 2.1; this means that the contribution to queue length caused by one heavy vehicle in the traffic volume can be viewed as the equivalent of 2.1 passenger cars. Since the queue length is calculated based on the space taken by passenger cars (20 feet per lane per passenger car), users need to consider both vehicle length and immobility effect to decide this input. If two lanes are open upstream of the work zone, one passenger car joining the queue extends the queue length by 10 feet; if three lanes are open, one additional passenger car extends the queue length by 6.66 feet. The next item "Passenger cars per day" does not need input and is protected; it is calculated from traffic volume, percent of heavy vehicles, and PCE factor.

Work Zone Capacity Inputs

Work zone capacity is the ability of the work zone to process incoming traffic; it works together with the previously mentioned incoming traffic volume to decide queue formation, increase, and decrease, hence queue length. Work zone capacity is determined by many factors, such as work intensity, whether there is an upstream ramp, weather condition, light condition, etc. This model considers only the two most influential factors, work intensity and ramp existence. Inputs affecting work zone capacity include “Number of lanes,” “Free flow speed,” “Work Intensity,” “Ramp adjustment,” and “# of lanes closed each hour” as shown in Figure 6-9. We discuss each of these inputs below.

Number of lanes (one direction):	2
Free flow speed (mph):	50
Basic lane capacity (pcphpl):	2250
Work Intensity (-500 - 0 pcphpl):	-100
Ramp adjustment (0-160 pcphpl):	160

Figure 6-9. Work zone capacity inputs.

6. *Number of lanes*: Input the original number of lanes upstream from the work zone.

7. *Free flow speed*: This input is used for the hours when there is no lane closure; when there is lane closure the factor of intensity and ramp come into effect. The speed unit is miles per hour; the speed can be obtained by referring state speed limit or observing the normal traffic speed when there is no work zone. Free flow speed value affects the next item “Basic lane capacity.” “Basic lane capacity” is not an input and thus protected; it varies according to the value of free flow speed with the tendency that within the range, the increase in free flow speed leads to the increase in basic lane capacity.

8. *Work Intensity*: This input reflects the effect of work intensity on work zone capacity. The relation between work intensity and capacity is that within the range, the increase in work intensity will lead to the decrease in work zone capacity; and vice versa. The model considers this relation by dividing work intensity into six levels from level 1 to level 6. Level 1 corresponds to the slightest work intensity and level 6 corresponds to the heaviest intensity. Level 1 is viewed as no effect on work zone capacity, thus is given the adjust factor 0. Level 6 is given an adjust factor -500, which is the maximum decrease in capacity. Between these two extremes, each increase in one level of intensity corresponds to a predicted reduction in work zone lane capacity of one hundred. The unit for this input is passenger cars per hour per lane; more detailed guideline for this input is provided next.

9. *Selection of Intensity Level:* The OkDOT *HCM* 2000 Hybrid Version is called “hybrid” because it uses a different range of intensity level penalty I to adjust the basic work zone lane capacity of 1600, than the adjustments published in *HCM* 2000. Specifically, there are six work intensity levels with corresponding I value and work type examples, as shown in Table 6-1.

Table 6-1. Work Intensity Levels, I values, and Work Type Examples

Intensity Level	I Values (pcphpl)	Work Type Examples
1 "Lightest"	0	**Guardrail repair/installation**, median cleanup
2 "Light"	-100	**Pothole repair**, bridge deck patching, bridge deck inspection and maintenance, barrier wall erection
3 "Moderate"	-200	**Resurfacing/asphalt removal**, paving (w/light equipment activity), milling (w/light equipment activity)
4 "Heavy"	-300	**Stripping/slide removal**, paving (w/heavy equipment activity), milling (w/heavy equipment activity)
5 "Very Heavy"	-400	**Pavement marking**, final striping, concrete paving (w/heaving equipment activity), bridge widening (w/light equipment activity)
6 "Heaviest"	-500	**Bridge repair**, bridge widening (w/heavy equipment activity)

The terminology used in the first column of Table 6-1 to describe each of the six work zones dates back to Dudek and Richards (1981) and is retained for this reason. The initial item (in bold) in the work type examples again is historical, and will be referred to as the prototypical example of the respective intensity level.

The selection of intensity level for a planned work zone should be made based on as much information as available about the work type, work zone configuration, and equipment and crew present, with work type being the main factor. Certainly experience and engineering judgment may play a part. If the user is wavering between two intensity levels, one might choose the *higher* level to be more conservative, in that as intensity increases by one level, open lane capacity will decrease by 100 pcphpl, and so there will be an increased chance that the input hourly traffic volumes will exceed the work zone capacity C. What factors beside work type should be factored into the selection of intensity level? First, assume work is done in daylight, with good weather (no precipitation), on flat or gently rolling terrain. If the work zone is urban, assume that it is of length less than 0.25 miles. Then consider adjusting work zone intensity up one level from the level suggested by the prototypical example in the presence of:

- Heavy equipment activity
- Narrow clearance between work and open lane (s) through the work zone
- Numerous workers in the work zone, or workers positioned close to the open lanes.

Adjustments for heavy or light equipment activity are actually suggested in the work type examples provided in Table 6-1. *Adjustments for night work*, *work in rain or snow*, *work on significant grades, and work in longer (> 0.25 mile) urban work zones* is addressed later in this chapter.

10. *Ramp Adjustment*: The existence of an entrance ramp in the approach sector of the work zone is another factor that affects work zone intensity, in two ways: the increase in incoming traffic volume it contributes, and the turbulence effect caused by the merging of traffic from the ramp to the main lane. The existence of such an upstream ramp is predicted to decrease work zone capacity. When there is no upstream ramp, input 0; when there is, input 160. The model will reduce work zone capacity by 160 passenger cars per hour per lane when there is ramp.

Further Information

This part is provided for users who are interested in the underlying structure and logic of the *HCM* 2000 Hybrid Model. Most users can safely omit or skim this material, and proceed to **Special Situations** on page 86.

Layouts for "Reference Table Sheet"

The "Reference Table Sheet" (See Figure 6-10.) contains reference information upon which the traffic input-output calculation is conducted. These references include highway capacity reference and traffic volume factor reference:

a. Highway capacity reference: In "Input and Output Sheet," users input free flow speed, work intensity, ramp, and lane closure information; the highway capacity reference table derives capacity from these inputs. The reference is based on *HCM* 2000 capacity formula.

b. Traffic volume factor reference: In "Input and Output Sheet," users input AADT, percent of heavy vehicles, and PCE; the model use these inputs to get passenger cars per day. Then the model uses passenger cars per day together with inputs analysis code and direction to get hourly traffic volume from the traffic volume factor reference table.

Copied Inputs from "LR Input Sheet"

Inputs (carried over from Input & Output Sheet)	
Analysis Code:	IU
Direction (Inbound or Outbound):	Inbound
AADT (both directions):	50,000
Percent of heavy vehicles:	35.67%
Passenger car equivalent for heavy vehicles:	2.00
Passenger cars per day:	67,835
Number of lanes (one direction):	2
Free flow speed (mph):	50
Basic lane capacity (pcphpl):	2250
Work Intensity (-500 - 0 pcphpl):	-100
Ramp adjustment (0-160 pcphpl):	160
Max. queue length limit (miles):	99
Delay ($/hour) passenger car:	$10.00
Fuel costs ($/gal):	$2.00
Average # people per vehicle:	1.2

Highway Capacity

Highway Capacities		
Original # of Lanes [1]	# of Lanes Closed [1]	Capacity pcphpl
2	0	4500
2	1	1340*
3	0	6750
3	1	2680*
3	2	1340*
4	0	9000
4	1	4020*
4	2	2680*
4	3	1340^

[1] one direction only
* Based on 2000 Highway Capacity Manual.
^ Copied from 3 lanes with 2 lanes closed (HCM doesn't have this distr

Traffic Volume Factor Reference

If using defined values, enter them into the colums marked with arrows.

	User Defined Volumes [2]	User Defined Factors: (enter description)			ODOT Default Factors: Interstate – Urban			Interstate – Rural			Arterial – Urban			Arterial – Rural		
Hour		K	D (inbnd)	D (outbnd)	K	D (inbnd)	D (outbnd)	K	D (inbnd)	D (outbnd)	K	D (inbnd)	D (outbnd)	K	D (inbnd)	D (outbnd)
Midnight-1am					1.325	0.50	0.50	1.830	0.55	0.45	0.980	0.50	0.50	0.930	0.55	0.45
1am-2am					0.725	0.50	0.50	1.420	0.55	0.45	0.640	0.50	0.50	0.570	0.55	0.45
2am-3am					0.575	0.50	0.50	1.180	0.55	0.45	0.470	0.50	0.50	0.420	0.55	0.45
3am-4am					0.475	0.50	0.50	1.030	0.55	0.45	0.380	0.50	0.50	0.370	0.55	0.45
4am-5am					0.575	0.50	0.50	1.100	0.55	0.45	0.530	0.50	0.50	0.520	0.55	0.45
5am-6am					1.475	0.50	0.50	1.430	0.55	0.45	1.140	0.50	0.50	1.330	0.55	0.45
6am-7am					3.825	0.65	0.35	2.330	0.55	0.45	3.150	0.65	0.35	2.780	0.55	0.45
7am-8am					7.675	0.65	0.35	3.470	0.55	0.45	5.920	0.65	0.35	4.820	0.55	0.45
8am-9am					5.700	0.65	0.35	4.300	0.55	0.45	5.240	0.65	0.35	5.400	0.55	0.45
9am-10am					4.850	0.50	0.50	5.230	0.55	0.45	4.880	0.50	0.50	6.200	0.55	0.45
10am-11am					5.000	0.50	0.50	5.880	0.55	0.45	5.210	0.50	0.50	6.430	0.55	0.45
11am-Noon					5.500	0.50	0.50	6.170	0.55	0.45	5.880	0.50	0.50	6.450	0.55	0.45
Noon-1pm					5.775	0.50	0.50	6.230	0.55	0.45	6.310	0.50	0.50	6.480	0.55	0.45
1pm-2pm					5.725	0.50	0.50	6.470	0.55	0.45	6.120	0.50	0.50	6.680	0.55	0.45
2pm-3pm					5.975	0.50	0.50	6.770	0.55	0.45	6.170	0.50	0.50	6.970	0.55	0.45
3pm-4pm					7.050	0.40	0.60	7.030	0.55	0.45	7.020	0.40	0.60	7.550	0.55	0.45
4pm-5pm					8.425	0.40	0.60	7.100	0.55	0.45	7.610	0.40	0.60	7.930	0.55	0.45
5pm-6pm					8.675	0.40	0.60	6.920	0.55	0.45	8.240	0.40	0.60	7.600	0.55	0.45
6pm-7pm					5.700	0.40	0.60	6.000	0.55	0.45	6.540	0.40	0.60	6.070	0.55	0.45
7pm-8pm					4.125	0.50	0.50	5.050	0.55	0.45	5.060	0.50	0.50	4.350	0.55	0.45
8pm-9pm					3.500	0.50	0.50	4.250	0.55	0.45	4.610	0.50	0.50	3.450	0.55	0.45
9pm-10pm					3.025	0.50	0.50	3.550	0.55	0.45	3.750	0.50	0.50	2.900	0.55	0.45
10pm-11pm					2.575	0.50	0.50	2.950	0.55	0.45	2.540	0.50	0.50	2.280	0.55	0.45
11pm-Midnight					1.900	0.50	0.50	2.300	0.55	0.45	1.630	0.50	0.50	1.520	0.55	0.45

[2] Enter passenger car volumns (adjusted for % of heavy vehicles) for one direction only.

Figure 6-10. Layouts for reference table sheet.

Calculation Procedure and Formula

The calculation procedure and formula behind the model is introduced as following:

- Step 1: Using inputs "AADT," "Percent of heavy vehicles," and "Passenger car equivalent for heavy vehicles," the model calculates "Passenger cars per day" with the formula Passenger cars per day = AADT*(1+Percent of heavy vehicles*(PCE-1)).
- Step 2: According to "Analysis Code" and "Direction," the model determines the values for "AADT Factor" and "Direction Factor" in Section 6 of "Input and Output Sheet." The determination is made by referring to the traffic volume factor reference table in "Reference Table Sheet." If the analysis code is UV, no AADT Factor or Direction Factor is output; otherwise, the outputs are from "User Defined Factors" column or "ODOT Default Factors" column in "Reference Table Sheet."

- Step 3: Traffic volume is output in this step. If the analysis code is UV, traffic volume is directly output from “User Defined Volume” in “Reference Table Sheet”; otherwise, using “Passenger cars per day” calculated from Step 1 together with “AADT Factor” and “Direction Factor” from Step 2, the model calculates hourly traffic volume, output as the column “Volume” in Section 6 of “Input and Output Sheet.” The formula is Hourly Traffic Volume = Passenger cars per day*(Factor K/100)*Factor D. In this way, hourly traffic volume is determined. The next task is to determine work zone capacity.

- Step 4: Using the input “Free flow speed,” the model outputs “Basic lane capacity” by following the rule that “If Free Flow Speed >=70, Basic Lane Capacity=2400; else if FFS>=65, BLC=2350; else if FFS>=60, BLC=2300; else BLC=2250.” Basic lane capacity is the capacity for one lane, which is used to calculate highway capacity when there is no lane closure.

- Step 5: Hourly work zone capacity is output as the column “Limiting Capacity” in Section 6 of “Input and Output Sheet” by referring to the Highway Capacity Reference Table in “Reference Table Sheet.” The underlying logic of Highway Capacity Reference Table is that “If Original # of Lanes is 2 (3, 4), # of Lanes Closed is 0, Capacity= 2 (3, 4)* Passenger Cars per day; if # of Lanes Closed is 1 (2), Capacity is calculated based on 2000 *Highway Capacity Manual* (See **Additional Information** in this chapter for the formula.); if # of Lanes Closed is 3, Capacity is copied from 3 lanes with 2 lanes closed.” The traffic volume and work zone capacity calculated by Step 4 and 5 is the hourly value; the model conducts further calculation to get values for ten-minute intervals in the “Calculation Sheet.” The following calculation is directed to the “Calculation Sheet.”

- Step 6: Ten-minute interval volume and capacity are output in “Calculation Sheet” as the columns “10 min volume” and “Capacity Limit” by dividing hourly value by 6. After the above preparation, the model comes to the final queue length calculation by using traffic volume and work zone capacity.

- Step 7: Number of passenger cars in queue is termed “Queue at slice end” in the model. It is calculated with the formula Queue at Slice End = Minimum { Maximum{Queue at Slice End in the beginning of current interval+10 min Volume-10 min Capacity Limit, 0}, Queue at Slice End limited by Max Queue Length Limit}. The logic behind this formula is that if the calculated car number is negative, which means there is no car in queue, Queue at slice end is set to zero. When the calculated number of cars in queue is not negative, Queue at slice end will also be limited by Max queue at slice end limit; when queue at slice end is within the limitation, output the calculated number; otherwise, the output would be the maximum queue at slice end limit. Max queue at slice end limit is determined by maximum queue length limit, and calculated with the formula Max Queue at Slice End Limit= (Max Queue Length Limit* Original # of Lanes)/ (20/2580) using “Max Queue Length Limit” input in “LR Input Sheet.”

- Step 8: Queue Length is calculated with the formula Queue Length = (Queue at Slice End/Original # of Lanes)*(20/2580) and output as the column “Queue Length” in “LR

Calculation Sheet." Now the ten-minute interval number of passenger cars in queue and ten-minute interval queue length is calculated, the task of "Calculation Sheet" is finished. Go back to "Input and Output Sheet" and decide Max Cars in Queue and Max Queue Length in each hour by using Max function.

- Step 9: The final step is to summarize calculation results to peak hours and non-peak hours. Daily hours are divided into morning peak hours from 6:00 a.m. to 9:00 a.m., daytime non-peak hours from 9:00 a.m. to 3:00 p.m., evening peak hours from 3:00 p.m. to 7:00 p.m., and nighttime non-peak hours from 7:00 p.m. to 6:00 a.m. Traffic Volume is the sum of hourly volume during corresponding hours. Max # of Cars in Queue and Max Queue Length are max value during corresponding hours. Finally Daily Summary is given by following the same procedure.

Additional Information

The following points took extra time before our project team could understand their impact on queue analysis, so we present them here to help users who might have the same questions.

- Point 1: Conversion of Heavy Vehicles to Passenger Cars

  One factor in the calculation of queue length is the handling of heavy vehicles. The user decides whether to use vehicles or passenger cars for three parameters – traffic volume, highway capacity, and space taken by each vehicle or passenger car in a queue. The model uses passenger cars as its unit and sets 20 feet as the space in queue taken by each passenger car. Now this 20 feet is typically spread over 2 or 3 lanes moving upstream from the work zone, so for example with 2 lanes, the queue length grows by 10 feet per passenger car joining the queue. The model converts heavy vehicles to passenger cars before distributing daily traffic volume to hourly volume, using the formula Passenger cars per day = AADT*[1+Percent of heavy vehicles*(PCE-1)]. The formula is derived from weighted average formula AADT*[(1-Percent of heavy vehicles)*1+ Percent of heavy vehicle*PCE]. This conversion spares the user the work to convert passenger cars to vehicles using the heavy vehicle adjustment factor in the *HCM* 2000 formula. *HCM* 2000 highway capacity formula is Capacity = (1600+Work intensity–Ramp adj.) * (Heavy vehicle adj.)*(# of remaining lanes), where Heavy vehicle adj. = 100/ [100 + Percentage of heavy vehicles*(PCE-1)]. The unit for 1600, Work intensity, and Ramp adj. is passenger cars. Therefore, the formula used by our model in highway capacity reference table is Capacity = (1600+Work intensity–Ramp adj.)*(# of remaining lanes), where the unit is passenger cars.

- Point 2: Using Original Number of Lanes to Calculate Queue Length

  The formula used to calculate queue length is Queue Length = (Queue at Slice End/Original # of Lanes)*(20/2580). There are two assumptions behind this formula. The first one is that the drivers will choose the lane with the shortest queue to wait; therefore, the length for each lane would be equal. The second one is that the traffic taper has no effect in the capacity. As illustrated in Figure 6-11, original number (#) of lanes is 2, yet the capacity of lanes from point A to point B is less than that of two lanes due to the existence of the traffic taper. Therefore, this assumption creates a tendency to slightly underestimate the true queue length.

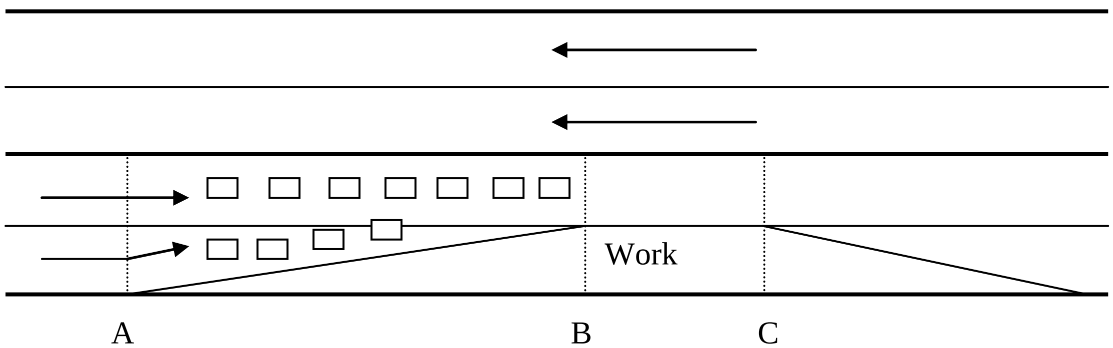


Figure 6-11. Queue length formula illustration.

- Point 3: Time Period and Time Point

  Strictly speaking, when calculating ten-minute interval volume and capacity, time slices corresponding to each hour should be from :10 time slice of this hour to the :00 time slice of the next hour, since traffic volume is cumulated during ten-minute intervals. For example, the distribution of traffic volume from 1:00 a.m. to 2:00 a.m. should be from time slice 1:10 a.m. to 2:00 a.m.; volume at time slice 1:10 a.m. is cumulated during the time period from 1:00 a.m. to 1:10 a.m. The OkDOT model uses time slice volume to represent traffic cumulated during the following ten-minute period for the convenience of expression; since the model handled this issue consistently, there is no difference in the final results.

- Point 4: Two special time points

  There are two special time points in the calculation of ten-minute interval values. The first one is time slice 3:50, in which queue at slice end is set back to zero no matter whether there is queue in previous time period. This gives the model a one-day cycle. The second point is 00:00, whose value is set as equal to 24:00. This shows the fact that the point of 00:00 and 24:00 is the same point; the model includes the point 00:00 simply for the convenience of Excel formula expression.

Special Situations

There are certain conditions that, if they are known to apply to the work zone under planning, carry suggestions from *HCM* 2000 and other traffic engineering literature for potential adjustments to the work zone capacity equation used in the OkDOT *HCM* 2000 Hybrid Version. For instance, if the work zone will be active in heavy rain or snow, adjustment factors are known. In the first subsection below, we present a new result for maximum queue length in urban work zones.

Urban Work Zones

As described in Chapter 2, observed queue lengths on several Milwaukee, WI urban freeway work zones did not behave in accordance with standard *HCM*-type input-output predictions of queue length. At all these work zone sites, queue length would grow at first then stabilize. Several explanations are given that may be useful for ALDOT as well:

1. In urban traffic flow, the driver may well be able to see a queue forming miles ahead of him, at least at certain points in his drive.

2. Even if he cannot see the queue ahead, he may receive advance warning from electronic message boards, the radio, or even cell phone communications from friends or family.

3. There are numerous exits and entrances on urban interstates, with many alternative "surface street" routes that can be taken by those experienced with the roadway system, or even by those simply "passing through" who have a navigation system in their vehicle.

Only six of the Wisconsin urban work zones had complete data on work zone length, intensity, and maximum queue length. Five of those six were either 3-to-1 or 3-to-2 type closures. When the maximum queue length observed was plotted versus work zone length (See Figure 6-12.), a strong linear relationship (R^2 = 95.2 %) emerged, which suggests that maximum queue length should be estimated at:

1.85 * work zone length (mi).

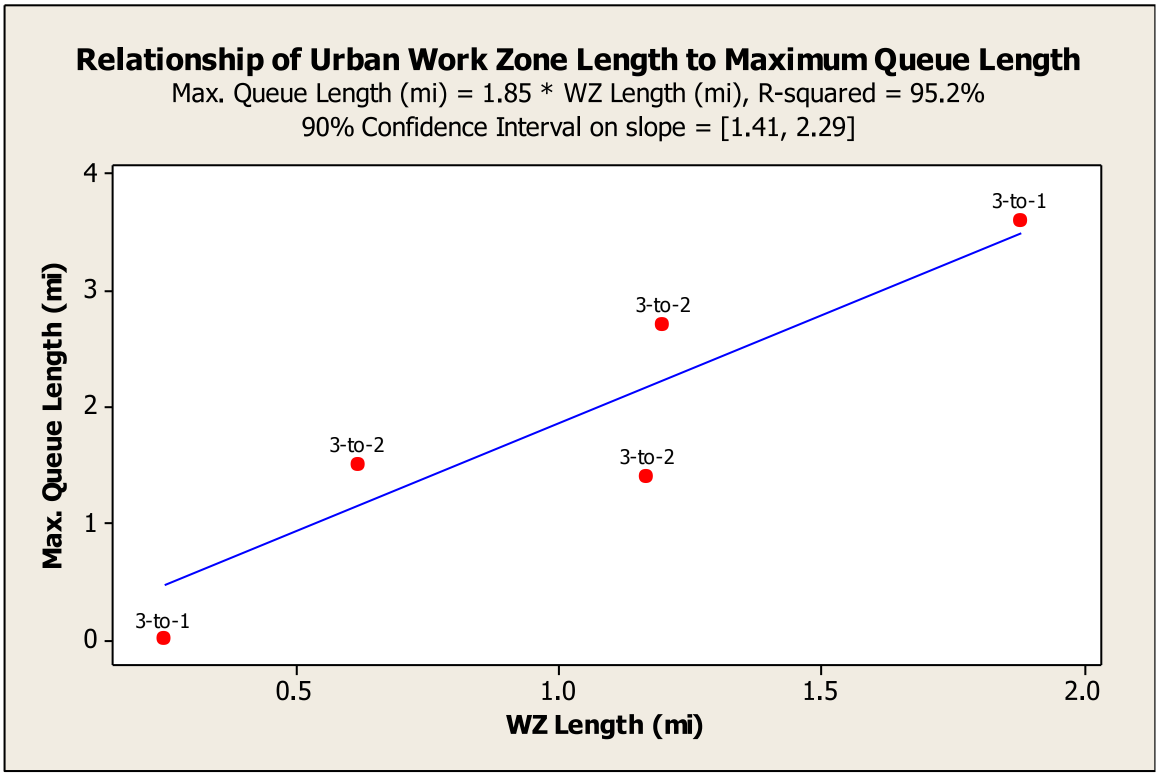


Figure 6-12. Maximum queue length as a function of work zone length.

This relationship applies for work zones of length 0.25 mi to 1.88 mi, based on the lengths in this sample. It is unknown it he relationship would extend to shorter or longer work zones. Concerning the multiplicative factor (slope), a 90% confidence interval on slope for all such urban work zones is calculated to be [1.41, 2.29]; so, to be more conservative, the maximum queue length could be estimated at 2.3 * work zone length. Adjoining the sixth work zone (a 2-to-1 lane closure) with work zone length = 0.8 mi and maximum queue length of 3.48 mi, and refitting the line yields a slope of 2.07, but R^2 drops to 86.8 %. The 1.85 factor seems a good rule of thumb. So, for ***urban*** work zones longer than 0.25 mi, it is recommended that after running the *HCM* 2000 Hybrid Version, should the queue lengths predicted seem excessive, consider using the following to estimate maximum queue length for the work zone, as an *input* to the OkDOT *HCM* 2000 Hybrid version:

- Optimistic 1.40 * WZ length (mi)
- Most Likely 1.85 * WZ length (mi)
- Conservative 2.30 * WZ length (mi)

The queue start time and growth profile up to the maximum are trustworthy, as is the queue dissipation profile and end time in the OkDOT *HCM* 2000 Hybrid *output*.

The researchers are uncertain whether the relationship indicated above would hold for work zones shorter than 0.25 mi. Certainly, work zones shorter than 0.25 mi can produce queues on urban freeways; so, our recommendation is to trust the queue profile output by the OkDOT *HCM* 2000 Hybrid, but if queue lengths seems excessive, then use a limiting value for maximum queue length consistent with the number of upstream exits and capacity of the surface street network to carry the exiting traffic past the work zone.

Weather and Darkness Effects

It is well known that adverse weather will reduce capacity in freeways, and in freeway work zones. Specifically, *HCM* 2000 says:

- Light rain will not have much effect on speed, hence not on capacities.

- Heavy rain affects visibility and can be expected to have a noticeable effect on traffic flow. Capacities might drop as much as 15% on average or 12-18% in general. Hence an adjustment factor (AF) of AF = 0.15 might be considered if heavy rain is predicted, or might occur while the temporary lane closure remains in effect. The only way to incorporate AF into the OkDOT Hybrid work zone capacity calculation is to take N = number of lanes open, and adjust it by a factor (1-AF):

N	N’= N (1-AF)
1	0.85
2	1.70
3	2.55

- Light snow has been observed to drop capacity be 5-10%, with AF = 0.075 a good average.

- Heavy snow is reputed to drop capacity by 30% on urban freeways that have been plowed and remain open, and presumably in work zones. Rural temporary work zones would be discontinued in the presence of heavy snow. Heavy snow in general is not an issue for ALDOT.

Most *temporary* night work zones in Alabama are scheduled at times when traffic volume is substantially below work zone capacity, so an adjustment factors for darkness does not seem necessary. As for *permanent* night work zones, one paper (Al-Kaisy and Hall, 2006) reported work zone capacity darkness adjustment factors in the range of 3-7.5% were observed. This might be important when permanent work zones force lane closures to remain in effect during morning and evening rush hours, because some of those times may be dawn or dusk situations.

Grade Effects

Alabama freeways are predominately on level terrain, which is defined in *HCM* 2000 to be “any combination of grades and horizontal and vertical alignment that permits heavy vehicles to maintain the same speed as passenger cars. This type of terrain includes short grades of no more than 2%.” Thus, the OkDOT *HCM* 2000 Hybrid, which was tested on 32 work zones from a state of similar terrain to Alabama (South Carolina), needs no adjustment for terrain.

The only non-level freeways in Alabama are probably I-65 as it goes over Red Mountain, I-20 just east of Birmingham, and I-59 between Gadsden and the Georgia line. In these few situations where the terrain is judged rolling, causing heavy vehicles to reduce their speeds substantially below those of passenger cars, a passenger car equivalent (PCE) of 2.5 is recommended in *HCM* 2000; this compares with 2.0 for level terrain in *HCM* 2000, and the 2.1 recommended by the developers of the OkDOT *HCM* 2000 Hybrid.

Long-Term Construction

The OkDOT *HCM* 2000 Hybrid Version is only for short-term work zone analysis. Long-term construction is characterized by work over weeks or months, with portable concrete barriers to delineate and protect the work zone. *HCM* 2000 has special tables and graphs for these situations:

Table 6-2. Characteristics of Long-term Construction

Number of Normal Lanes	Lanes Open	Lane Capacity (vphpl)
3	2	1860
2	1	1750*

* 1550 if traffic crosses over to lanes that are normally used by the opposite direction of travel.

OkDOT *HCM* 2000 Hybrid Version on CD

As required in the contract, and as described in the introduction to this chapter, the updated work zone land closure analysis Excel 2007 software "OkDOT *HCM* 2000 Hybrid Version" is provided on a CD accompanying this final report. Also, an Excel 2003 version is included on that same CD.

User's Guide on CD

As required in the contract, a *User's Guide* was prepared for the updated work zone lane closure analysis software developed by this project, and recommended for future use at ALDOT in place of the older OkDOT Lane Rental Model. The *User's Guide* is simply Chapter 6 repackaged as a separate, stand-alone document. It does not depend on the user having access to this report. This *User's Guide* is provided as a project deliverable on the same CD with the Excel-based tool, and may be provided in written form or on-line to ALDOT users, should the recommended OkDOT *HCM* 2000 Hybrid model replace the OkDOT Lane Rental Model. The *User's Guide* could also be used in training sessions. Simplified instruction for users are provided as tabs in the Excel software itself.

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