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WorkZoneQ User Guide for Two-Lane Freeway Work Zones

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16. Abstract

WorkZoneQ was developed in Visual Basic for Applications (VBA) to implement the results of the previous study, “Queue and Users’ Costs in Highway Work Zones.” This report contains the WorkZoneQ user guide. WorkZoneQ consists of eight Excel worksheets and input data are traffic information, geometric characteristics, traffic control plan, and value of time figures. Then WorkZoneQ determines the capacity and computes queue length, delay, users’ costs, and congestion duration. It also determines the intervals that do not satisfy IDOT mobility standards. Eight example problems were solved. The first one is a basic example to obtain the above output data. The successive examples show the capability of the program to handle different time interval lengths, variation of volume within the interval, flagger presence, police presence, change in work intensity, temporary roadway blockage, and different speed limits.

Three workshops were conducted for IDOT engineers and their feedback was used to further improve the program.

The current version of the program was developed using field data collected from 2-to-1 freeway work zones and it is recommended that a future project expand the program for other lane configurations.

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EXECUTIVE SUMMARY

Phase 1 of this Illinois Center for Transportation (ICT) study was sponsored by the Illinois Department of Transportation (IDOT). In that study, a procedure was developed for queue analysis in Illinois work zones. The study report, "Queue and Users' Costs in Highway Work Zones," published September 2010, is available on ICT's website (http://ict.illinois.edu/publications/report%20files/FHWA-ICT-10-075.pdf). Phase 1 of the study developed a procedure consisting of 15 steps, which are not easy to calculate manually. There are interpolations along nonlinear curves that are not easy to perform without a computer program.

In Phase 2 of the study, a computer program, WorkZoneQ, was developed in Visual Basic for Applications (VBA) to automate the calculations. WorkZoneQ consists of eight Microsoft Excel worksheets and requires geometric characteristics, traffic control plan and demand data as inputs and returns queue length, delay, users' costs, and beginning and end of congestion as outputs.

This report contains the WorkZoneQ user guide, which illustrates the program features and how to input data. Eight example problems are solved, covering different work zone conditions such as presence of work activity, flagger presence, police presence, and different speed limits. Appendices provide detailed explanation of input and output data as well as basic troubleshooting tips. Moreover, the concept of the algorithm implemented in the WorkZoneQ is discussed.

Three training workshops were held for IDOT engineers in northern, southern, and central Illinois. The computer program, its user guide, and the concept of the algorithm implemented were demonstrated in the workshops. Example problems were solved to show different features of the program. The research team worked with participants to clarify the interpretation of results and to understand the needs of engineers. The program was improved based on feedback from engineers who attended the workshops.

The current WorkZoneQ tool was developed using data collected from freeway work zones where one of the two lanes was closed in a single direction (2-to-1 work zones). It is recommended that the program be expanded for the following scenarios:

- Freeway work zones with different lane configurations; for instance, 2-to-2 (two lanes open outside the work zone and two lanes open inside the work zone), 3-to-3, 3-to-2 (three lanes open outside of the work zone reduced to two lanes open inside the work zone), and 3-to-1
- Different facilities: arterials, two-lane highways, and multilane highways
- Effect of diversion of traffic away from a work zone

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CHAPTER 1 INTRODUCTION

In a report titled "Queue and Users' Costs in Highway Work Zones," Benekohal, Ramezani, and Avrenli (2010) proposed a step-by-step algorithm to estimate capacity, operating speed, queue length, delay and users' costs in freeway work zones. The methodology consists of 15 steps. However, manual application of the 15 steps is rather laborious and prone to error. To automate the calculations in the 15 steps and eliminate possible errors, WorkZoneQ was developed as a VBA (Visual Basic for Applications) workbook within Microsoft Excel 2007/2010. WorkZoneQ consists of eight linked worksheets. WorkZoneQ computes operating speed, capacity, queue length, delay, users' costs, and duration of congestion (beginning and end of it).

Please complete the Test Run (Section 1.3) before using WorkZoneQ.

1.1 Color Coding of WorkZoneQ

The following color coding scheme helps users distinguish types of cell:

Title cells

Light yellow background, black text is for TITLE of input/ output cells	User *cannot* modify these

Input cells

Light blue background, black text is for INPUT cells	User *can* modify these

Time cells

Gray background, black text shows one study period	User *cannot* modify these
Black background, white text shows another (non-consecutive) study period	User *cannot* modify these

Output cells

Dark blue background, white text	User *cannot* modify these

is for OUTPUT cells	

Error cells

Red background, white text is for ERROR message cells	User *cannot* modify these

Caution cells

Orange background, white text is for CAUTION message cells	User *cannot* modify these

Guidance cells

Green background, white text is for GUIDANCE cells	User *cannot* modify these

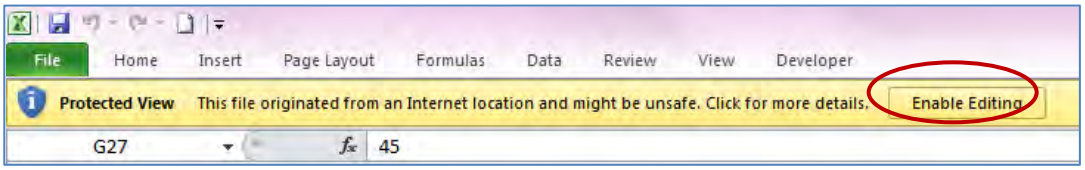
1.2 Organization of the User Guide

1. **Introduction:** Background information on WorkZoneQ, color coding used on worksheets, Test Run instructions, and software overview.
2. **Tutorials:** A step-by-step approach using WorkZoneQ to solve eight sample problems.
3. **References:** A list of references used in this manual.
4. **Appendices:**
   - **Appendix A, Description of the Input Data:** Includes detailed descriptions of the input data required to be entered by users.
   - **Appendix B, Description of the Output Data:** Covers details about the output returned by WorkZoneQ.
   - **Appendix C, Troubleshooting:** Explains possible input errors that users may make and offers solutions to those errors.
   - **Appendix D, Step-by-Step Approach:** Provides detailed explanations of the steps of the algorithm that WorkZoneQ is based on. It is the modified version of the algorithm proposed in the report "Queue and Users' Costs in Highway Work Zones" by Benekohal, Ramezani and Avrenli (2010).
   - **Appendix E, Calculation Details:** Provides more details about the calculations presented in Appendix D.

1.3 Test Run

To verify that WorkZoneQ works properly on your PC, a test run is required.

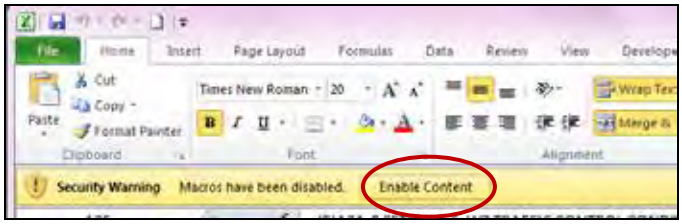
1. Download the file “WZQ_Test_Run.xlsm”. The instructor will provide the website information or CD.
2. Double click the file “WZQ_Test_Run.xlsm” and open it. If the workbook opens in protected view, click the “Enable Editing” button.



Protection Warning

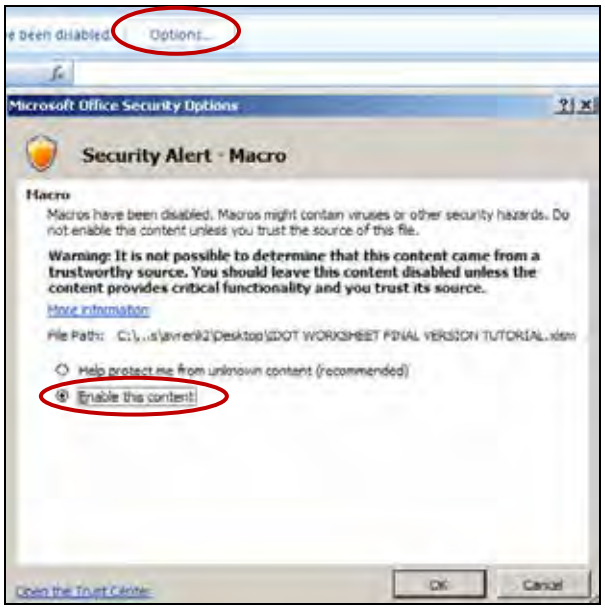
3. Enable macros in the workbook.

- If you are using MS Excel 2010, click the “Enable Content” button.



Security Warning in Excel 2010

- If you are using MS Excel 2007, click the “Options” button. The “Microsoft Office Security Options” dialog box appears. Check “Enable this content,” and click “OK”.



Security Warning in Excel 2007

4. Enter “90” in cell E4 and press the enter button.

	B	C	D	E	F	G	I
3	Average number of occupants in a passenger car. *(Default is 1.25)*	Average number of occupants in a recreational vehicle. *(Default is 2.00)*	Hourly delay cost for a single-unit truck ($/hr) *(Default is 70 $/hr)*	Hourly delay cost for a multiple-unit truck ($/hr) *(Default is 90 $/hr)*	Hourly delay cost for a recreational vehicle ($/hr) *(Default is 20 $/hr)*	Hourly delay cost for a passenger car ($/hr) *(Default is 20 $/hr)*	Speed limit outside of the work zone (mph)
4	1.25	2.00	$70			$20	65

Enter "90" here

Data Entry for Quick Test

5. In the UserComp worksheet, see whether the users’ costs in cell P299 is equal to $571.03. If it is, the workbook is working properly on your computer (note that cell M300 reads “<Working>”).

J	K	L	M	N	O	P
Average delay per vehicle in oversaturated condition (hr)	Average delay per vehicle in undersaturated conditions (hr)	Delay experienced by all vehicles (veh-hr)	Users' Costs ($)			
			Severe Queue (SQ)	Moderate Queue (MQ)	Light Queue (LQ)	All three queues
0.0001	-	0.0	-	-	$1.74	$1.74
0.0070	-	10.9	-	-	$489.90	$489.90
0.0071	0	1.6	-	-	$79.40	$79.40
		SUM Delay	SUM SQ	SUM MQ	SUM LQ	SUM All
		12.6	*$0.00*	*$0.00*	*$571.03*	*$571.03*
						<Working>

Outputs for Test Run

6. Test run is complete. Close the file and do NOT save it.

1.4 Software Overview

WorkZoneQ is a Microsoft Excel-based workbook. Users must have Microsoft Excel 2007 or higher running on a Windows-based computer. Using earlier versions of Microsoft Excel is not recommended because they may be incompatible with WorkZoneQ.

WorkZoneQ consists of eight linked worksheets:

1. **GeoCond:** In this worksheet, users enter work zone geometric data, traffic control conditions, and the data if traffic is asked to stop temporarily. It includes steps 1–7 of the approach explained in Appendix D.
2. **TrafficInfo:** Users enter traffic mix and volume data in the TrafficInfo worksheet. It contains steps 8–10 of the approach explained in Appendix D.

3. **UserComp:** Users enter occupancy data and cost figures, and the worksheet computes users' costs, delay length, and queue length. It includes steps 11–15 of the approach presented in Appendix D.
4. **Output Summary:** No data are entered by users in the Output Summary worksheet. It provides the distance queue reached, estimated start and end of congestion (if demand exceeds capacity), total delay, and total users' costs for each study period. A study period consists of consecutive intervals to be analyzed. The study period is further defined in the Note at the beginning of Chapter 2.
5. **Queue-Speed Plot:** No data entry is needed in this worksheet. It shows average speed and distance that the queue reached over time.
6. **IDOT Criteria:** There is no data entry for the IDOT Criteria worksheet. In this worksheet, average speed, delay per mile of project length, and queue length are reported to check IDOT mobility criteria.
7. **Sample ADT Dist.:** When hourly volume is not available, users may refer to the following ADT table to estimate hourly volumes for suburban interstate highways with two lanes in one direction. There are two columns: one shows distribution of traffic going toward the city (direction 1), and the other shows traffic leaving the city (direction 2).

ADT Table

	Direction 1	***Direction 2***
Mid Time	**% ADT**	**% ADT**
12:30 AM	0.5%	0.7%
1:30 AM	0.3%	0.4%
2:30 AM	0.3%	0.3%
3:30 AM	0.4%	0.4%
4:30 AM	1.0%	0.8%
5:30 AM	3.0%	2.5%
6:30 AM	7.8%	4.6%
7:30 AM	10.6%	5.4%
8:30 AM	7.7%	4.6%
9:30 AM	5.9%	4.3%
10:30 AM	5.6%	4.6%
11:30 AM	5.7%	5.3%
12:30 PM	5.5%	5.5%
1:30 PM	5.4%	5.7%
2:30 PM	6.2%	6.8%
3:30 PM	6.8%	9.8%
4:30 PM	7.7%	10.6%
5:30 PM	6.4%	9.5%
6:30 PM	3.9%	5.7%
7:30 PM	2.6%	3.9%
8:30 PM	2.3%	3.2%
9:30 PM	1.8%	2.3%
10:30 PM	1.4%	1.7%
11:30 PM	1.1%	1.2%
Sum	**1.00**	**1.00**

8. **Echo of INPUT Data:** There is no data entry for the Echo of INPUT Data worksheet. It summarizes user input data on a single page.

CHAPTER 2 TUTORIALS

In this section, eight example problems are solved using WorkZoneQ (Note: Example Problems 1 and 3 are slight variations of the same problem). The example problems become progressively more complex; therefore, it is better to start with Example Problem 1.

1. **Example Problem 1:** Three 1-hr intervals are analyzed for a work zone with a 55-mph speed limit and no flagger or work activity.
2. **Example Problem 1.1:** The same as Example Problem 1, except that ADT is used rather than hourly volumes.
3. **Example Problem 2:** Three 1-hr intervals are analyzed for the same work zone from Example Problem 1. However, the traffic demand is not uniform within the second interval.
4. **Example Problem 3:** Eight 30-minute intervals are analyzed for the work zone from Example Problem 1. However, there is a flagger and work activity during the second and third intervals, and the work zone speed limit is lowered to 45 mph.
5. **Example Problem 3.1:** The same as the Example Problem 3; however, for illustration purposes the flagger shows the “Stop” paddle for 3 minutes during the interval starting at 4:30 PM.
6. **Example Problem 4:** The same as Example Problem 3 except there is a Police patrol car in the work zone during work activity in the second and third intervals.
7. **Example Problem 5:** The same as Example Problem 3 except the lane width is reduced to 10 feet because of the construction equipment used during work activity in the second and third intervals.
8. **Example Problem 6:** In-class exercise in which a work zone with realistic traffic data from I-57 southbound are analyzed.

Each example problem consists of the following steps:

1. Getting started
2. Project information
3. Work zone geometric data (step 1 in the report)
4. Work zone traffic control conditions (steps 2–7 in the report)
5. Data on passenger car equivalent (PCE), volume, and percentage of trucks (steps 8–10 in the report)
6. Vehicle information and cost figures (steps 11–15 in the report)

IMPORTANT!

Have you completed the Test Run (Section 1.3)? If not, please do so before working on the example problems.

NOTE

The relationship between the study period and interval is shown in the table below. The table shows all 60-minute intervals in 24 hours. Suppose that the intervals from 9:00 AM to 12:00 PM, and from 3:00 PM to 6:00 PM are selected for analysis. In that case, the first study period consists of the intervals from 9:00 AM to 12:00 PM. The second study period consists of the intervals from 3:00 PM to 6:00 PM.

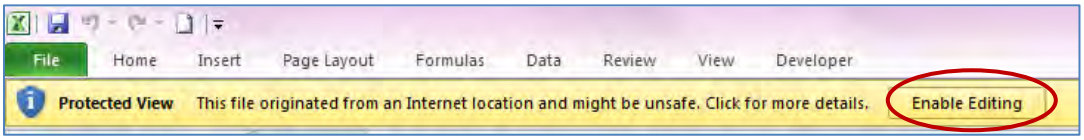
Illustration of Study Period

12:00 AM	1:00 AM	*Unselected interval*	
1:00 AM	2:00 AM	*Unselected interval*	
2:00 AM	3:00 AM	*Unselected interval*	
3:00 AM	4:00 AM	*Unselected interval*	
4:00 AM	5:00 AM	*Unselected interval*	
5:00 AM	6:00 AM	*Unselected interval*	
6:00 AM	7:00 AM	*Unselected interval*	
7:00 AM	8:00 AM	*Unselected interval*	
8:00 AM	9:00 AM	*Unselected interval*	
9:00 AM	**10:00 AM**	Selected interval	First study period
10:00 AM	**11:00 AM**	Selected interval	
11:00 AM	**12:00 PM**	Selected interval	
12:00 PM	1:00 PM	*Unselected interval*	
1:00 PM	2:00 PM	*Unselected interval*	
2:00 PM	3:00 PM	*Unselected interval*	
3:00 PM	**4:00 PM**	Selected interval	Second study period
4:00 PM	**5:00 PM**	Selected interval	
5:00 PM	**6:00 PM**	Selected interval	
6:00 PM	7:00 PM	*Unselected interval*	
7:00 PM	8:00 PM	*Unselected interval*	
8:00 PM	9:00 PM	*Unselected interval*	
9:00 PM	10:00 PM	*Unselected interval*	
10:00 PM	11:00 PM	*Unselected interval*	
11:00 PM	12:00 AM	*Unselected interval*	

2.1 Example Problem 1

2.1.1 Getting Started

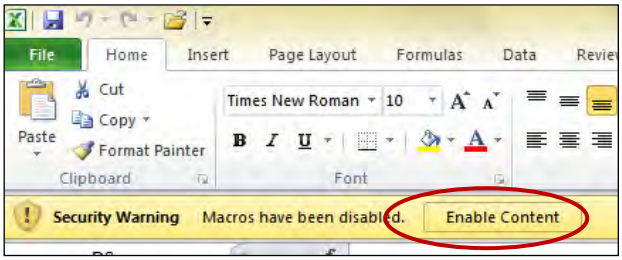
1. Double click the Excel file “WorkZoneQ.xlsm”. If the workbook opens in protected view, click the “Enable Editing” button.



Protection Warning

2. Enable macros in the workbook.

- If you are using MS Excel 2010, click the “Enable Content” button.

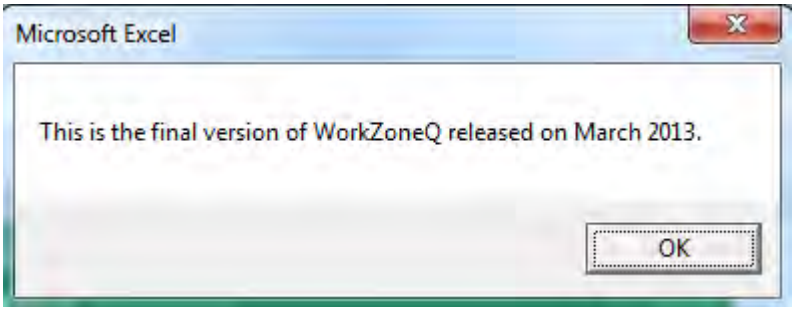


Security Warning in Excel 2010

- If you are using MS Excel 2007, click the “Options” button. The “Microsoft Office Security Options” dialog box appears. Check “Enable this content”, and click “OK”.

Security Warning in Excel 2007

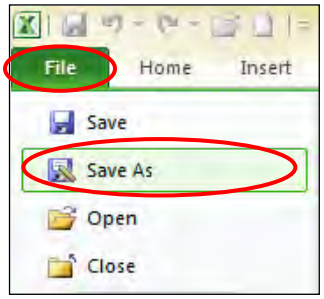
3. Once you enabled macros, you will see the following message box. Read the message and press “OK” to continue.



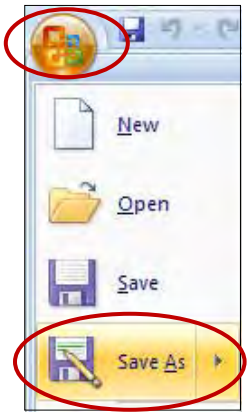
WorkZoneQ Message

4. Save the file as “Example1WZ.xlsm”.

· If you are using MS Excel 2010, click the “File” button in the upper left corner of the workbook. Choose “Save As” from the drop-down menu and save your file as “Example1WZ.xlsm”.



· If you are using MS Excel 2007, click the MS Office button in the upper left corner. Choose “Save As” from the drop-down menu and save your file as “Example1WZ.xlsm”.

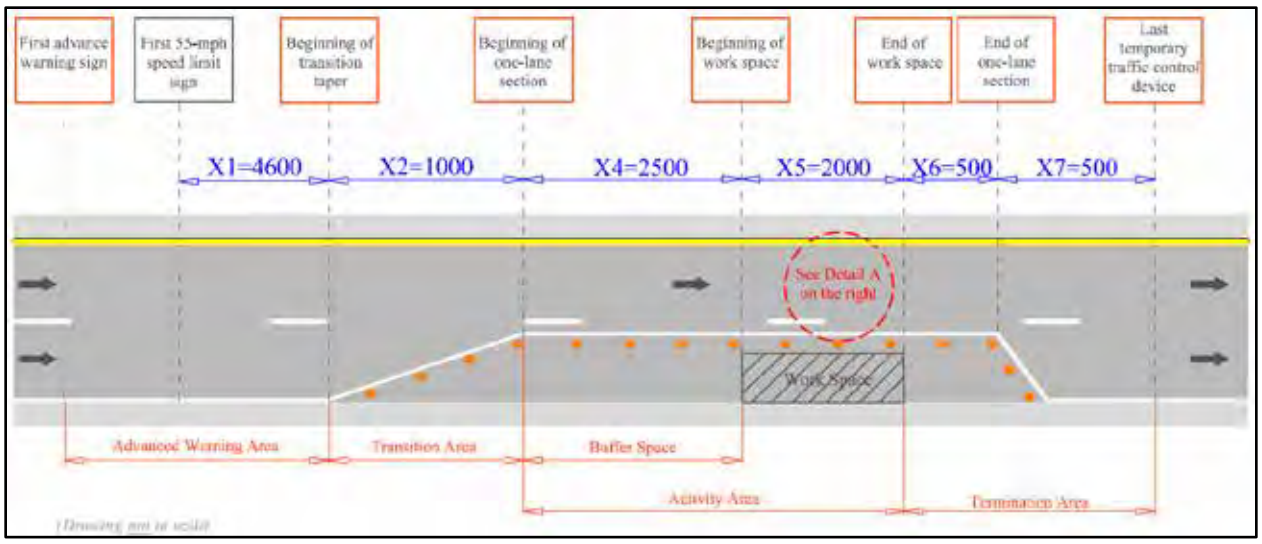


2.1.2 Input Data for Example Problem 1

A work zone is located on an interstate highway with one lane open and one lane closed. The speed limit outside of the work zone is 65 mph, but inside it is 55 mph. The lane width is reduced from 12 feet to 11 feet, and the right shoulder width is only 1 foot. There is no work activity and no flagger in the work zone. The study period is from 4 to 7 PM, and it is composed of three 1-hour intervals during daytime. Additional information about the work zone is shown in the chart below. Compute the total delay and users' costs.

Example Problem 1 Input Data

	Interval 1	**Interval 2**	**Interval 3**
Start of interval	4:00 PM	5:00 PM	6:00 PM
End of interval	5:00 PM	6:00 PM	7:00 PM
Is there work activity?	No	No	No
Is there flagger?	No	No	No
Speed limit in the work zone (mph)	55	55	55
Will traffic be asked to stop temporarily?	No	No	No
Volume (veh)	1400	1600	1200
Percentage of single-unit trucks	2%		
Percentage of combination trucks	21%		
Percentage recreational vehicles	1%		
Lane width (ft)	11		
Right shoulder width (ft)	1		
Left shoulder width (ft)	2		
Terrain type	Level		
Average number of occupants in each passenger car	1.25 *(default)*		
Average number of occupants in each recreational vehicle	2.00 *(default)*		
Hourly delay cost for a single-unit truck ($/hr)	70 *(default)*		
Hourly delay cost for a combination truck ($/hr)	90 *(default)*		
Hourly delay cost for a passenger car ($/hr)	20 *(default)*		
Hourly delay cost for a recreational vehicle ($/hr)	20 *(default)*		



Work Zone Sketch for Example 1

2.1.3 Project Information

5. Go to GeoCond worksheet.

GeoCond Worksheet Selection

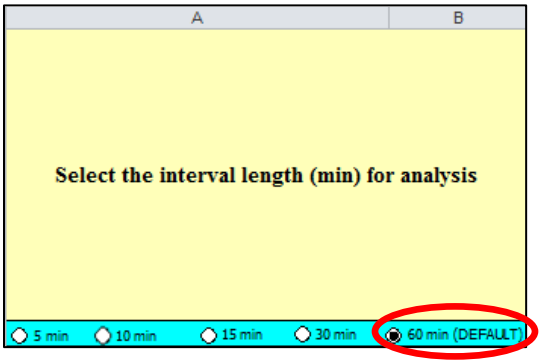
6. Write “Example 1” in cell B20 for the project name, and fill out the rest of information as you like.

A	B	C	D	E	F	G	H
Project Name	Example 1				**Date**	9/26/2012	
Project Number	237-12				**Year of Analysis**	2014	
Site	I-57				**Analyst Name**	Joe Smith	

Project Information

2.1.4 Work Zone Geometric Data (Step 1 of the Report)

7. Select “60 min” for the interval length.



Interval Length Selection

8. Enter the geometric data as shown (detailed information about the input data is provided in Appendix A).

C	D	E	F	G	H	I
Distance X1 (ft)	Distance X2 (ft)	Distance X3 (Write "0" if there is no 45-mph speed limit)	Distance X4 (ft)	Distance X5 (ft)	Distance X6 (ft)	Distance X7 (ft)
4,600	1,000	0	2,500	2,000	500	500

Geometric Input Data (Part 1)

J	K	L
Lane width Y1 (ft) *(Default is 12 ft)*	Right shoulder width Y2 (ft) *(Default is 6 ft)*	Left shoulder width Y3 (ft) *(Default is 2 ft)*
11.0	1.0	2.0

Geometric Input Data (Part 2)

Based on the input data, the following speed reductions are calculated (detailed information about the output data is provided in Appendix B):

M	N	O
Speed reduction due to lane width (mph)	Speed reduction due to right shoulder (mph)	Speed reduction due to left shoulder (mph)
1.9	3.6	0.0

Speed Reductions Due to Lane and Shoulder Widths

2.1.5 Work Zone Traffic Control Conditions (Steps 2–7 of the Report)

9. Select the intervals “4:00 PM–5:00 PM”, “5:00 PM–6:00 PM”, and “6:00 PM–7:00 PM” by choosing “Y” in column D.

B	C	D
4:00 PM	5:00 PM	Y
5:00 PM	6:00 PM	Y
6:00 PM	7:00 PM	Y

Selected Intervals

10. Click the

button. The workbook hides the unselected intervals.
11. There is no work activity and no flagger, so skip columns E–I. The speed limit is 55 mph, so verify that “55” is selected in column G.
12. There is no speed-reduction treatment or other speed-reducing factors, so skip columns J and K. Because traffic is not going to be stopped temporarily, make sure that “N” is selected in column L. (If traffic were asked to stop temporarily, put “Y” in column L.)

B	C	D	E	F	G
Start of Interval	End of Interval	Put "Y" if this interval is analyzed.	Put "W" if crew or construction equipment is closer than 9 ft to edge of travel lane.	Put "F" if flagger is present.	Put "45" if the speed limit is not 55 mph.
4:00 PM	5:00 PM	Y	N	N	55
5:00 PM	6:00 PM	Y	N	N	55
6:00 PM	7:00 PM	Y	N	N	55

Work Zone Condition Inputs (Part 1)

H	I	J	K	L	M
Put "C" if concrete barriers are used, and "O" for other devices. *(e.g. cones, drums)*	Put "L" for low work intensity, "M" for moderate work intensity, "H" for high work intensity.	Select the Speed Control Technique (if any) from the drop down menue. Otherwise, leave it blank.	If there is any additional speed reduction due to any other factors not considered so far, enter here. *Otherwise, leave it blank.*	Put "Y" if the traffic will be asked to stop temporarily in this interval.	For how many minutes will the traffic be stopped in this interval?
				N	
				N	
				N	

Work Zone Condition Inputs (Part 2)

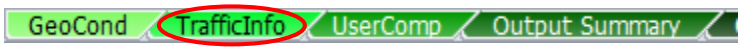
The worksheet computes the following outputs in columns N–S (detailed information about input and output data is provided in Appendix A and Appendix B, respectively).

N	O	P	Q	R	S
Free flow speed (mph)	Speed reduction due to work intensity (mph)	Adjusted free-flow speed (mph)	Maximum flow rate (pcphpl)	Speed at maximum flow rate (mph)	Prevailing capacity (pcphpl)
62.0		56.5	1,657	48.1	1,657
62.0		56.5	1,657	48.1	1,657
62.0		56.5	1,657	48.1	1,657

Estimated Capacity and Corresponding Speed

2.1.6 PCE, Traffic Volume, and Percentage of Trucks (Steps 8–10 of the Report)

13. Go to the TrafficInfo worksheet.



TrafficInfo Worksheet Selection

14. The work zone is located on level terrain, so enter the HCM 2010-suggested PCE values of “1.5” and “1.2” in cells B3 and C3, respectively. Because there is no variation in traffic demand within an interval, make sure “N” is selected in cell D3. Write “NA” in cell E3 because you have hourly volumes.

B	C	D	E	F
PCE for heavy vehicles *(Default is 1.5)*	PCE for recretional vehicles *(Default is 1.2)*	Put "Y" if there is variation in traffic demand within an interval	Enter the ADT for the direction analyzed if you don't have hourly volumes; Otherwise write "NA"	Select the direction of traffic analyzed
1.5	1.2	N	NA	1

Traffic Inputs (Part 1)

15. Enter the percentage of single-unit trucks, combination trucks, and recreational vehicles in columns D–F. Enter the traffic volume for each interval in column G.

B	C	D	E	F	G
Start of Interval	End of Interval	Percentage of single-unit trucks (%)	Percentage of combination trucks (%)	Percentage of recreational vehicles (%)	Expected traffic volume during the interval (veh)
4:00 PM	5:00 PM	2.0	21.0	1.0	1,400
5:00 PM	6:00 PM	2.0	21.0	1.0	1,600
6:00 PM	7:00 PM	2.0	21.0	1.0	1,200

Traffic Inputs (Part 2)

The worksheet shows the following outputs (detailed information about the input and output data is provided in Appendix A and Appendix B, respectively):

K	L	T
Heavy vehicle adjustment factor	**Adjusted demand (pcphpl)**	**Adjusted capacity (vphpl)**
0.90	1,564	1,484
0.90	1,787	1,484
0.90	1,340	1,484

Converted Capacity and Demand

2.1.7 Occupancy and Cost Figures (Steps 11–15 of the Report)

16. Go to the UserComp worksheet.

UserComp Worksheet Selection

17. Enter the values for occupancy and cost figures as shown (detailed information about the input data is provided in Appendix A).

B	C	D	E	F	G	H
Average number of occupants in a passenger car. *(Default is 1.25)*	**Average number of occupants in a recreational vehicle.** *(Default is 2.00)*	**Hourly delay cost for a single-unit truck** ($/hr) *(Default is 70 $/hr)*	**Hourly delay cost for a combination truck** ($/hr) *(Default is 90 $/hr)*	**Hourly delay cost for a recreational vehicle** ($/hr) *(Default is 20 $/hr)*	**Hourly delay cost for a passenger car** ($/hr) *(Default is 20 $/hr)*	**Speed limit outside of the work zone** (mph)
1.25	**2.00**	**$70**	**$90**	**$20**	**$20**	**65**

Cost Figure Inputs

The worksheet calculates the output values shown below (detailed information about the output data is provided in Appendix B).

B	C	D	E	F	G	H	I
Start of Interval	End of Interval	No. of study period	No. of vehicles in queue	Average spacing between vehicles in queue (ft)	Occupied length of queued vehicles stacked in a single lane* (ft)	Distance queue reached* (ft)	Average speed (mph)
4:00 PM	5:00 PM	1	43	170	7,327	5,414	52.4
5:00 PM	6:00 PM	1	116	171	19,913	11,707	48.1
6:00 PM	7:00 PM	1	0	-	0	0	53.9
						MAXIMUM DISTANCE QUEUE REACHED (ft)	
						11,707	

**: At the end of the corresponding interval or when there is no more vehicle in queue*

Queue and Speed Computations

J	K	L	M	N	O	P
Average delay per vehicle in oversaturated condition (hr)	Average delay per vehicle in undersaturated conditions (hr)	Delay experienced by all vehicles (veh-hr)	Users' Costs ($)			
			Severe Queue (SQ)	Moderate Queue (MQ)	Light Queue (LQ)	All three queues
0.0013	-	1.4	-	-	$57.30	$57.30
0.0207	-	30.7	-	-	$1,217.77	$1,217.77
0.0191	0	11.7	-	-	$464.77	$464.77
		SUM Delay	SUM SQ	SUM MQ	SUM LQ	SUM All
		43.8	*$0.00*	*$0.00*	*$1,739.83*	*$1,739.83*

Delay and Users' Costs Computations

2.1.8 Output Summary

18. Go to the Output Summary worksheet to see the output values shown below (detailed information about the output data is provided in Appendix B).

Output Summary Worksheet Selection

C	D	E	F	G	H	I
Start time	End time	No. of study period	Maximum distance queue reached in this study period (mi)	Minimum speed in queue in this study period (mph)	Approximate start of congestion#	Approximate end of congestion#
4:00 PM	7:00 PM	1	2.2	48.1	4:25 PM	6:24 PM
			MAX	MIN		
			2.2	48.1		

#: Uniform arrival/ departure rate is assumed within each time period.

Output Summary (Part 1)

J	K	L	M	N
Total delay in this study period (veh-hr)	Total users' costs ($) in this study period for			
	SQ	MQ	LQ	All
43.82	$0.00	$0.00	$1,739.83	$1,739.83
SUM	SUM	SUM	SUM	SUM
43.82	$0.00	$0.00	$1,739.83	$1,739.83

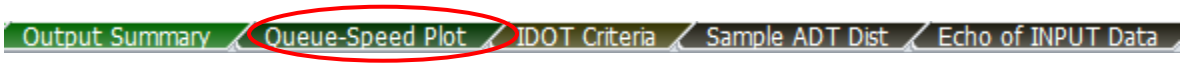
Output Summary (Part 2)

To compute total users' costs for X number of days like this (with the same traffic pattern and work zone conditions), multiply the total daily cost by X.

For instance, if you have 20 days with the same work zone and traffic conditions, then multiply the total daily users' costs by 20.

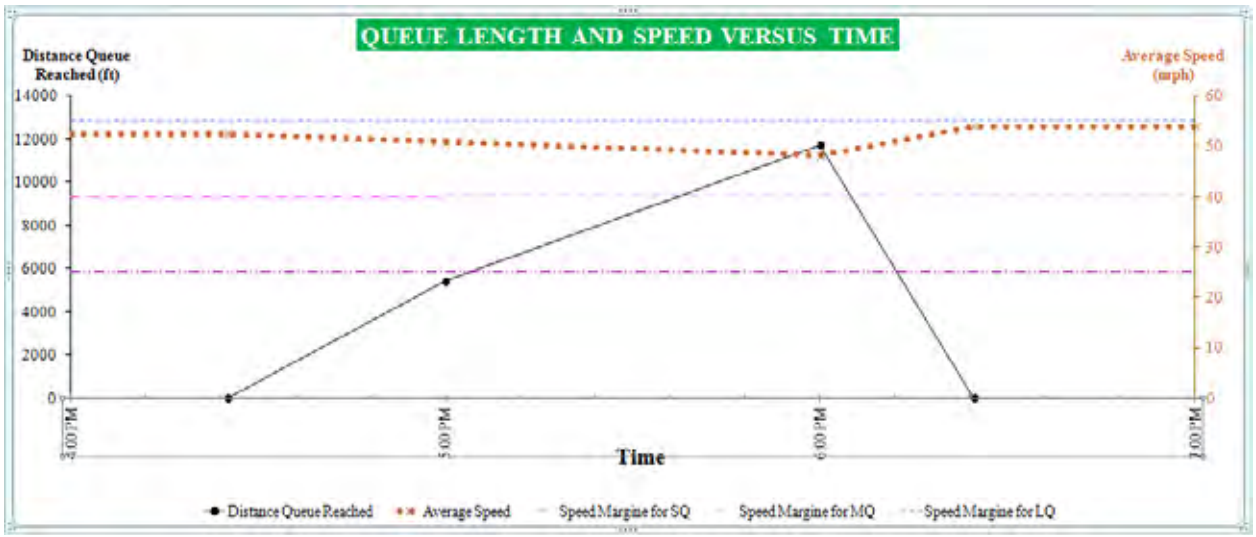
In this example, if the total daily users' costs are $1,739.83, the total users' costs for those 20 days will be 20 × $1,739.83= $34,796.60.

19. Go to the Queue-Speed Plot worksheet to see average speed and the distance that the queue reached.

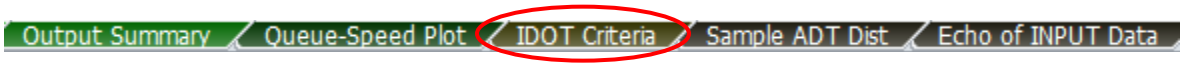


Queue-Speed Plot Worksheet Selection

This chart shows average speed of vehicles over time. When traffic slows down, the chart shows the distance that the queue reached over time.



20. Go to the IDOT Criteria worksheet to check whether the IDOT mobility criteria are satisfied (IDOT mobility criteria are provided in Appendix B).



IDOT Criteria Worksheet Selection

A	B	C	D	E	F	G
Start of Interval	End of Interval	Average speed (mph)	Delay in min. per mile of project length*	Distance severe queue reached (mi)	Distance moderate queue reached (mi)	Distance light queue reached (mi)
4:00 PM	5:00 PM	52.4	0.0	-	-	1.03
5:00 PM	6:00 PM	48.1	0.6	-	-	2.22
6:00 PM	7:00 PM	53.9	0.5	-	-	0.00

**The project length starts from the first 55-mph speed limit sign and extends to the end of the termination area*

IDOT Criteria Table

In this example, vehicles slowed down, but there was no severe or moderate queue (based on the assumed IDOT definition), so there is no value in columns E and F for the distance queue reached. The red cell in Column G indicates that light queue length exceeds 1.5 miles and the following message is displayed at the bottom of the table.

You can also go to the Echo of INPUT Data worksheet to see a summary of the input data.

Echo of INPUT Data Worksheet Selection

At this point, you can save and close the file.

2.1.9 Example Problem 1.1

Example Problem 1.1 is the same as Example Problem 1 except it uses ADT instead of hourly volumes. The purpose of this example is to show how to estimate arrival volumes from ADT. An ADT of 22,000 is selected for direction 1.

2.1.9.1. Getting Started

1. Follow the same steps in Section 2.1.1 to get started, except save the file as "Example1.1WZ.xlsm".

2.1.9.2 Project Information

2. Write "Example 1.1" in cell B20 for the project name, and fill out the rest of information as you like.

A	B	C	D	E	F	G	H
Project Name	Example 1.1				**Date**	9/26/2012	
Project Number	237-12				**Year of Analysis**	2014	
Site	I-57				**Analyst Name**	Joe Smith	

Project Information

2.1.9.3 Work Zone Geometric Data (Step 1 of the Report)

3. It is the same as used in Section 2.1.4.

2.1.9.4 Work Zone Traffic Control Conditions (Steps 2–7 of the Report)

4. It is the same as used in Section 2.1.5.

2.1.9.5 PCE, Traffic Volume, and Percentage of Trucks (Steps 8–10 of the Report)

5. Go to the TrafficInfo worksheet.

TrafficInfo Worksheet Selection

6. The work zone is located on level terrain, so enter the HCM 2010-suggested PCE values of "1.5" and "1.2" in cells B3 and C3, respectively. There is no variation in traffic demand within an interval, so make sure "N" is selected in cell D3. Enter the ADT of 22,000 in cell E3. It is assumed that traffic moves in direction 1, so direction 1 is selected from the drop-down menu in cell F3. Hourly volumes are estimated in column G.

B	C	D	E	F
PCE for heavy vehicles *(Default is 1.5)*	PCE for recretional vehicles *(Default is 1.2)*	Put "Y" if there is variation in traffic demand within an interval	Enter the ADT for the direction analyzed if you don't have hourly volumes; Otherwise write "NA"	Select the direction of traffic analyzed
1.5	1.2	N	22,000	1

Traffic Inputs (Part 1)

7. Enter the percentage of single-unit trucks, combination trucks, and recreational vehicles in columns D–F. Do not enter any hourly volume in column G because those amounts are automatically computed based on the ADT entered in cell E3. You can overwrite the values in column G, but the hourly volumes might not match the ADT.

B	C	D	E	F	G
Start of Interval	End of Interval	Percentage of single-unit trucks (%)	Percentage of combination trucks (%)	Percentage of recreational vehicles (%)	Expected traffic volume during the interval (veh)
4:00 PM	5:00 PM	2.0	21.0	1.0	1,690
5:00 PM	6:00 PM	2.0	21.0	1.0	1,402
6:00 PM	7:00 PM	2.0	21.0	1.0	869

Traffic Inputs (Part 2)

The worksheet provides the following outputs:

K	L	T
Heavy vehicle adjustment factor	Adjusted demand (pcphpl)	Adjusted capacity (vphpl)
0.90	1,888	1,484
0.90	1,566	1,484
0.90	970	1,484

Converted Capacity and Demand

2.1.9.6 Occupancy and Cost Figures (Steps 11–15 of the Report)

8. Go to the UserComp worksheet.

UserComp Worksheet Selection

9. Enter the same occupancy and cost figures that you entered in Section 2.1.7 (detailed information about the input data is provided in Appendix A).

B	C	D	E	F	G	H
Average number of occupants in a passenger car. *(Default is 1.25)*	**Average number of occupants in a recreational vehicle.** *(Default is 2.00)*	**Hourly delay cost for a single-unit truck** ($/hr) *(Default is 70 $/hr)*	**Hourly delay cost for a combination truck** ($/hr) *(Default is 90 $/hr)*	**Hourly delay cost for a recreational vehicle** ($/hr) *(Default is 20 $/hr)*	**Hourly delay cost for a passenger car** ($/hr) *(Default is 20 $/hr)*	**Speed limit outside of the work zone** (mph)
1.25	**2.00**	**$70**	**$90**	**$20**	**$20**	**65**

Cost Figure Inputs

The worksheet computes the following outputs:

B	C	D	E	F	G	H	I
Start of Interval	End of Interval	No. of study period	No. of vehicles in queue	Average spacing between vehicles in queue (ft)	Occupied length of queued vehicles stacked in a single lane* (ft)	Distance queue reached* (ft)	Average speed (mph)
4:00 PM	5:00 PM	1	207	171	35,382	19,441	48.1
5:00 PM	6:00 PM	1	125	171	21,393	12,447	48.1
6:00 PM	7:00 PM	1	0	-	0	0	55.2
						MAXIMUM DISTANCE QUEUE REACHED (ft)	
						19,441	

**: At the end of the corresponding interval or when there is no more vehicle in queue*

Queue and Speed Computations

J	K	L	M	N	O	P
Average delay per vehicle in oversaturated condition (hr)	Average delay per vehicle in undersaturated conditions (hr)	Delay experienced by all vehicles (veh-hr)	Users' Costs ($)			
			Severe Queue (SQ)	Moderate Queue (MQ)	Light Queue (LQ)	All three queues
0.0371	-	55.1	-	-	$2,185.69	$2,185.69
0.0611	-	90.7	-	-	$3,600.67	$3,600.67
0.0207	0	6.3	-	-	$248.36	$248.36
		SUM Delay	SUM SQ	SUM MQ	SUM LQ	SUM All
		152.0	*$0.00*	*$0.00*	*$6,034.73*	*$6,034.73*

Delay and Users' Costs Computations

2.1.9.7 Output Summary

10. Go to the Output Summary worksheet to see the output values shown below (detailed information about the output data is provided in Appendix B).

Output Summary Worksheet Selection

C	D	E	F	G	H	I
Start time	End time	No. of study period	Maximum distance queue reached in this study period (mi)	Minimum speed in queue in this study period (mph)	Approximate start of congestion#	Approximate end of congestion#
4:00 PM	7:00 PM	1	2.4	48.1	4:00 PM	6:12 PM
			MAX	MIN		
			2.4	48.1		

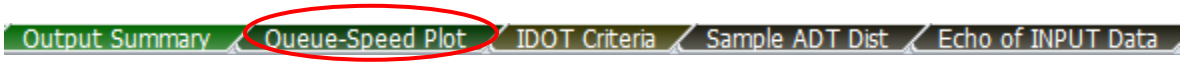
#: Uniform arrival/ departure rate is assumed within each time period.

Output Summary (Part 1)

J	K	L	M	N
Total delay in this study period (veh-hr)	Total users' costs ($) in this study period for			
	SQ	MQ	LQ	All
152.01	$0.00	$0.00	$6,034.73	$6,034.73
SUM	SUM	SUM	SUM	SUM
152.01	$0.00	$0.00	$6,034.73	$6,034.73

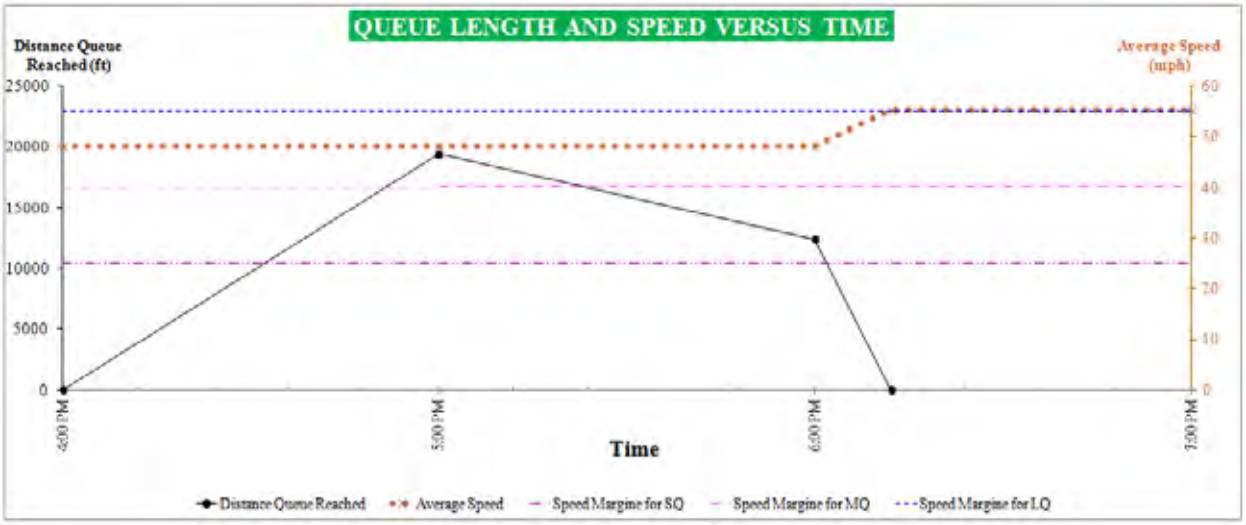
Output Summary (Part 2)

11. Go to the Queue-Speed Plot worksheet to see average speed and the distance that the queue reached.

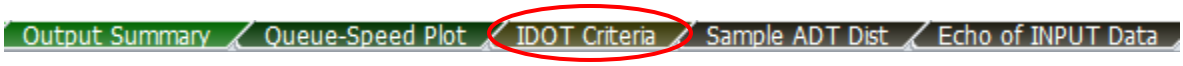


Queue-Speed Plot Worksheet Selection

This chart shows average speed of vehicles over time. When traffic slows down, the chart shows the distance that the queue reached over time.



12. Go to the IDOT Criteria worksheet to check whether the IDOT mobility criteria are satisfied (IDOT mobility criteria are provided in Appendix B).



IDOT Criteria Worksheet Selection

A	B	C	D	E	F	G
Start of Interval	End of Interval	Average speed (mph)	Delay in min. per mile of project length*	Distance severe queue reached (mi)	Distance moderate queue reached (mi)	Distance light queue reached (mi)
4:00 PM	5:00 PM	48.1	1.1	-	-	3.68
5:00 PM	6:00 PM	48.1	1.7	-	-	2.36
6:00 PM	7:00 PM	55.2	0.6	-	-	0.00

**The project length starts from the first 55-mph speed limit sign and extends to the end of the termination area*

IDOT Criteria Table

In this example, vehicles slowed down, but there was no severe or moderate queue (based on the assumed IDOT definition), so there is no value in columns E and F for the distance queue reached. The red cells in Column G indicate that light queue length exceeds 1.5 miles. The following message is displayed at the bottom of the table.

WARNING

THE CELLS HIGHLIGHTED IN RED IN COLUMNS E-G INDICATE QUEUES EXCEEDING 1.5 MILES.

You can also go to the Echo of INPUT Data worksheet to see a summary of the input data.

Echo of INPUT Data Worksheet Selection

At this point, you can save and close the file.

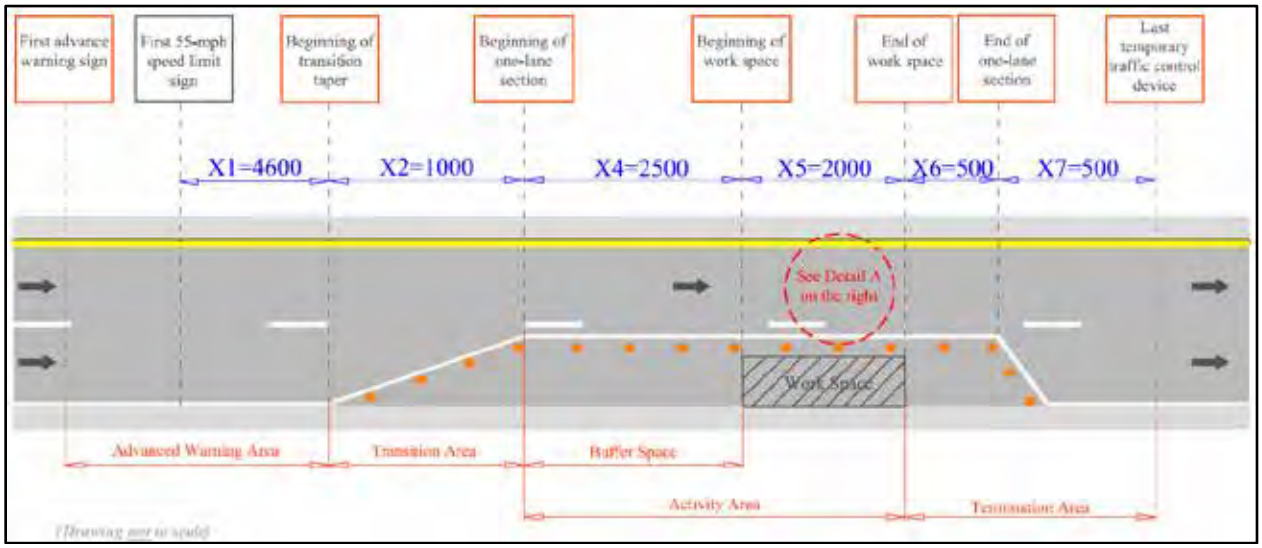
2.2 Example Problem 2

2.2.1 Getting Started

1. Follow the same steps in Section 2.1.1 to get started, except save the file as "Example2WZ.xlsm".

2.2.2 Input Data for Example Problem 2

Example Problem 2 is similar to Example Problem 1, except the traffic volume varies each 15 minutes within an hour. This requires entering the traffic demand volume for each 15-minute time interval. Additional information about the work zone is provided below.



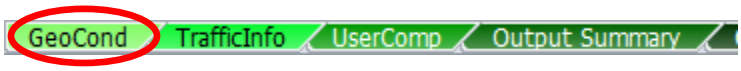
Work Zone Sketch for Example 2

Example 2 Input Data

	Interval 1	Interval 2	Interval 3	Interval 4	Interval 5	Interval 6	Interval 7	Interval 8	Interval 9	Interval 10	Interval 11	Interval 12
Start time	4:00 PM	4:15 PM	4:30 PM	4:45 PM	5:00 PM	5:15 PM	5:30 PM	5:45 PM	6:00 PM	6:15 PM	6:30 PM	6:45 PM
End time	4:15 PM	4:30 PM	4:45 PM	5:00 PM	5:15 PM	5:30 PM	5:45 PM	6:00 PM	6:15 PM	6:30 PM	6:45 PM	7:00 PM
Is there work activity?	No	No	No	No	No	No	No	No	No	No	No	No
Is there flagger?	No	No	No	No	No	No	No	No	No	No	No	No
Speed limit in the work zone (mph)	55	55	55	55	55	55	55	55	55	55	55	55
Will traffic be asked to stop?	No	No	No	No	No	No	No	No	No	No	No	No
Volume in 15 min. (veh)	350	350	350	350	400	450	400	350	300	300	300	300
Percentage of single-unit trucks	2%											
Percentage of combination trucks	21%											
Percentage of recreational vehicles	1%											
Lane width (ft)	11											
Right shoulder width (ft)	1											
Left shoulder width (ft)	2											
Terrain type	Level											
Average number of occupants in each passenger car	1.25 *(default)*											
Average number of occupants in each recreational vehicle	2.00 *(default)*											
Hourly delay cost for a single-unit truck ($/hr)	70 *(default)*											
Hourly delay cost for a combination truck ($/hr)	90 *(default)*											
Hourly delay cost for a passenger car ($/hr)	20 *(default)*											
Hourly delay cost for a recreational vehicle ($/hr)	20 *(default)*											

2.2.3 Project Information

2. Go to the GeoCond worksheet.



GeoCond Worksheet Selection

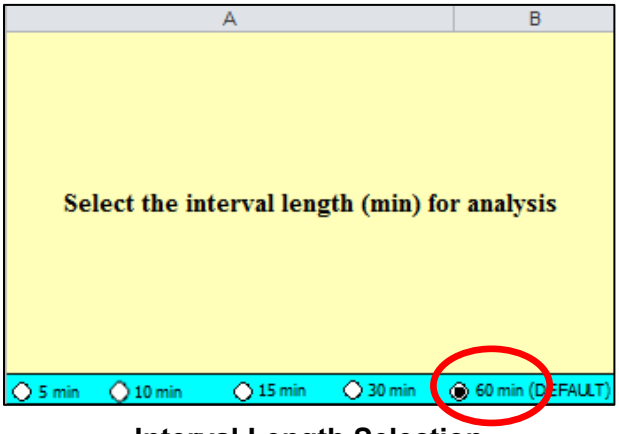
3. Write “Example 2” in cell B20 for the project name, and fill out the other information as you like.

A	B C D	E	F	G H
Project Name	Example 2		Date	9/26/2012
Project Number	237-12		Year of Analysis	2014
Site	I-57		Analyst Name	Joe Smith

Project Information

2.2.4 Work Zone Geometric Data (Step 1 of the Report)

4. If you have Peak Hour Factor (PHF) and there is volume variation within the interval, you can select 60-min interval and then based on the PHF find 15-min traffic volumes. The results of the program are the same as when 15-min interval is selected. Since the purpose of the example is to show how to handle volume variation within the interval, select “60 min” for the interval length.



Interval Length Selection

5. Enter the geometric data as shown (detailed information about the input data is provided in Appendix A).

C	D	E	F	G	H	I
Distance X1 (ft)	Distance X2 (ft)	Distance X3 (Write "0" if there is no 45-mph speed limit)	Distance X4 (ft)	Distance X5 (ft)	Distance X6 (ft)	Distance X7 (ft)
4,600	1,000	0	2,500	2,000	500	500

Geometric Input Data (Part 1)

J	K	L
Lane width Y1 (ft) *(Default is 12 ft)*	Right shoulder width Y2 (ft) *(Default is 6 ft)*	Left shoulder width Y3 (ft) *(Default is 2 ft)*
11.0	1.0	2.0

Geometric Input Data (Part 2)

Based on the input data, the following speed reductions are calculated (detailed information about the output data is provided in Appendix B):

M	N	O
Speed reduction due to lane width (mph)	Speed reduction due to right shoulder (mph)	Speed reduction due to left shoulder (mph)
1.9	3.6	0.0

Speed Reductions Due to Lane and Shoulder Widths

2.2.5 Work Zone Traffic Control Conditions (Steps 2–7 of the Report)

6. Select the intervals “4:00 PM–5:00 PM”, “5:00 PM–6:00 PM”, and “6:00 PM–7:00 PM” by choosing “Y” in column D.

B	C	D
4:00 PM	5:00 PM	Y
5:00 PM	6:00 PM	Y
6:00 PM	7:00 PM	Y

Selected Intervals

7. Click the

button. The workbook hides the unselected intervals.
8. There is no work activity and no flagger, so skip columns E–I. The speed limit is 55 mph, so verify that “55” is selected in column G. There is no speed-reduction treatment or other speed-reducing factors, so skip columns J and K. Because traffic

is not going to be stopped temporarily, make sure that “N” is selected in column L. (If traffic were asked to stop temporarily, put “Y” in column L.)

B	C	D	E	F	G
Start of Interval	End of Interval	Put "Y" if this interval is analyzed.	Put "W" if crew or construction equipment is closer than 9 ft to edge of travel lane.	Put "F" if flagger is present.	Put "45" if the speed limit is not 55 mph.
4:00 PM	5:00 PM	Y	N	N	55
5:00 PM	6:00 PM	Y	N	N	55
6:00 PM	7:00 PM	Y	N	N	55

Work Zone Condition Inputs (Part 1)

H	I	J	K	L	M
Put "C" if concrete barriers are used, and "O" for other devices. *(e.g. cones, drums)*	Put "L" for low work intensity, "M" for moderate work intensity, "H" for high work intensity.	Select the Speed Control Technique (if any) from the drop down menue. Otherwise, leave it blank.	If there is any additional speed reduction due to any other factors not considered so far, enter here. *Otherwise, leave it blank:*	Put "Y" if the traffic will be asked to stop temporarily in this interval.	For how many minutes will the traffic be stopped in this interval?
				N	
				N	
				N	

Work Zone Condition Inputs (Part 2)

The worksheet computes the following outputs in columns N–S (detailed information about input and output data is provided in Appendix A and Appendix B, respectively).

N	O	P	Q	R	S
Free flow speed (mph)	Speed reduction due to work intensity (mph)	Adjusted free-flow speed (mph)	Maximum flow rate (pcphpl)	Speed at maximum flow rate (mph)	Prevailing capacity (pcphpl)
62.0		56.5	1,657	48.1	1,657
62.0		56.5	1,657	48.1	1,657
62.0		56.5	1,657	48.1	1,657

Estimated Capacity and Corresponding Speed

2.2.6 PCE, Traffic Volume, and Percentage of Trucks (Steps 8–10 of the Report)

9. Go to the TrafficInfo worksheet.

TrafficInfo Worksheet Selection

10. The work zone is located on level terrain, so enter the HCM 2010-suggested PCE values of “1.5” and “1.2” in cells B3 and C3, respectively. There are variations in demand within some of the intervals, so select “Y” in cell D3.

B	C	D
PCE for heavy vehicles *(Default is 1.5)*	PCE for recretional vehicles *(Default is 1.2)*	Put "Y" if there is variation in traffic demand within an interval
1.5	1.2	Y

Traffic Inputs (Part 1)

11. Enter the percentage of single-unit trucks, combination trucks, and recreational vehicles in columns D–F. Enter the traffic volume for each 15-min subinterval in columns G–J.

B	C	D	E	F	G	H	I	J
Start of Interval	End of Interval	Percentage of single-unit trucks (%)	Percentage of combination trucks (%)	Percentage of recreational vehicles (%)	Expected traffic volume during the first 15-min (veh)	Expected traffic volume during the second 15-min (veh)	Expected traffic volume during the third 15-min (veh)	Expected traffic volume during the fourth 15-min (veh)
4:00 PM	5:00 PM	2.0	21.0	1.0	350	350	350	350
5:00 PM	6:00 PM	2.0	21.0	1.0	400	450	400	350
6:00 PM	7:00 PM	2.0	21.0	1.0	300	300	300	300

Traffic Inputs (Part 2)

The worksheet shows the following output (detailed information about the input and output data is provided in Appendix A and Appendix B, respectively):

K	L	M	N	O	T
Heavy vehicle adjustment factor	Adjusted demand for the first 15-min (pcphpl)	Adjusted demand for the second 15-min (pcphpl)	Adjusted demand for the third 15-min (pcphpl)	Adjusted demand for the fourth 15-min (pcphpl)	Adjusted capacity (vphpl)
0.90	1,564	1,564	1,564	1,564	1,484
0.90	1,787	2,011	1,787	1,564	1,484
0.90	1,340	1,340	1,340	1,340	1,484

Converted Capacity and Demand

2.2.7 Occupancy and Cost Figures (Steps 11–15 of the Report)

12. Go to the UserComp worksheet.

UserComp Worksheet Selection

13. Enter the values for occupancy and cost figures as shown (detailed information about the input data is provided in Appendix A).

B	C	D	E	F	G	H
Average number of occupants in a passenger car. *(Default is 1.25)*	**Average number of occupants in a recreational vehicle.** *(Default is 2.00)*	**Hourly delay cost for a single-unit truck** ($/hr) *(Default is 70 $/hr)*	**Hourly delay cost for a combination truck** ($/hr) *(Default is 90 $/hr)*	**Hourly delay cost for a recreational vehicle** ($/hr) *(Default is 20 $/hr)*	**Hourly delay cost for a passenger car** ($/hr) *(Default is 20 $/hr)*	**Speed limit outside of the work zone** (mph)
1.25	**2.00**	**$70**	**$90**	**$20**	**$20**	**65**

Cost Figure Inputs

The worksheet calculates the output values shown below (detailed information about the output data is provided in Appendix B).

B	C	D	E	F	G	H	I
Start of Interval	End of Interval	No. of study period	No. of vehicles in queue	Average spacing between vehicles in queue (ft)	Occupied length of queued vehicles stacked in a single lane* (ft)	Distance queue reached* (ft)	Average speed (mph)
4:00 PM	4:15 PM	1	0	-	0	0	52.6
4:15 PM	4:30 PM	1	0	-	0	0	52.6
4:30 PM	4:45 PM	1	0	-	0	0	52.6
4:45 PM	5:00 PM	1	11	167	1,832	1,832	52.4
5:00 PM	5:15 PM	1	29	171	4,978	4,239	48.1
5:15 PM	5:30 PM	1	108	171	18,508	11,004	48.1
5:30 PM	5:45 PM	1	137	171	23,486	13,493	48.1
5:45 PM	6:00 PM	1	116	171	19,913	11,707	48.1
6:00 PM	6:15 PM	1	46	171	7,789	5,645	48.1
6:15 PM	6:30 PM	1	0	-	0	0	53.3
6:30 PM	6:45 PM	1	0	-	0	0	54.4
6:45 PM	7:00 PM	1	0	-	0	0	54.4
						MAXIMUM DISTANCE QUEUE REACHED (ft)	
						13,493	

**: At the end of the corresponding interval or when there is no more vehicle in queue*

Queue and Speed Computations

J	K	L	M	N	O	P
Average delay per vehicle in oversaturated condition (hr)	Average delay per vehicle in undersaturated conditions (hr)	Delay experienced by all vehicles (veh-hr)	Users' Costs ($)			
			Severe Queue (SQ)	Moderate Queue (MQ)	Light Queue (LQ)	All three queues
-	0	0.2	-	-	$6.64	$6.64
-	0	0.2	-	-	$6.64	$6.64
-	0	0.2	-	-	$6.64	$6.64
0.0005	-	0.2	-	-	$6.68	$6.68
0.0030	-	1.1	-	-	$43.69	$43.69
0.0200	-	7.4	-	-	$295.03	$295.03
0.0428	-	15.9	-	-	$629.82	$629.82
0.0445	-	16.5	-	-	$655.52	$655.52
0.0250	-	9.3	-	-	$368.41	$368.41
0.0056	0	1.4	-	-	$53.75	$53.75
-	0	0.0	-	-	$1.37	$1.37
-	0	0.0	-	-	$1.37	$1.37
		SUM Delay	SUM SQ	SUM MQ	SUM LQ	SUM All
		52.3	*$0.00*	*$0.00*	*$2,075.57*	*$2,075.57*

Delay and Users' Costs Computations

2.2.8 Output Summary

14. Go to the Output Summary worksheet to see the output values shown below (detailed information about the output data is provided in Appendix B).

Output Summary Worksheet Selection

C	D	E	F	G	H	I
Start time	End time	No. of study period	Maximum distance queue reached in this study period (mi)	Minimum speed in queue in this study period (mph)	Approximate start of congestion#	Approximate end of congestion#
4:00 PM	7:00 PM	1	2.6	48.1	4:51 PM	6:24 PM
			MAX	MIN		
			2.6	48.1		

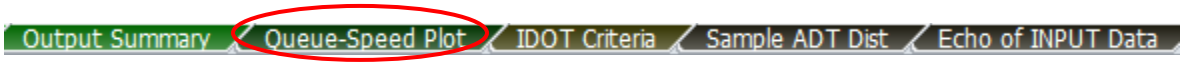
#: Uniform arrival/ departure rate is assumed within each time period.

Output Summary Part 1

J	K	L	M	N
Total delay in this study period (veh-hr)	Total users' costs ($) in this study period for			
	SQ	MQ	LQ	All
52.28	$0.00	$0.00	$2,075.57	$2,075.57
SUM	SUM	SUM	SUM	SUM
52.28	$0.00	$0.00	$2,075.57	$2,075.57

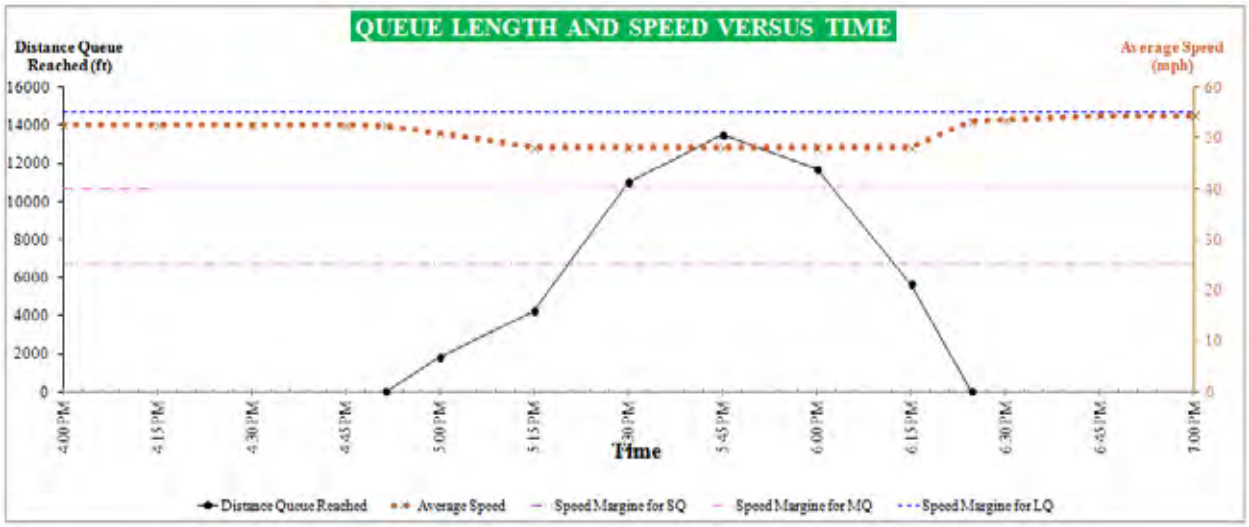
Output Summary (Part 2)

15. Go to the Queue-Speed Plot worksheet to see average speed and the distance that the queue reached.

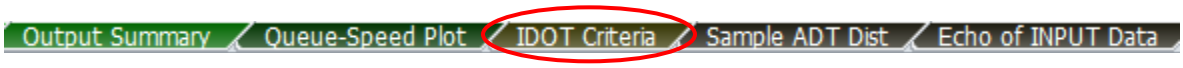


Queue-Speed Plot Worksheet Selection

This chart shows the average speed of vehicles over time. When traffic slows down, the chart shows the distance that the queue reached over time.



16. Go to the IDOT Criteria worksheet to check whether the IDOT mobility criteria are satisfied (IDOT mobility criteria are provided in Appendix B).



IDOT Criteria Worksheet Selection

A	B	C	D	E	F	G
Start of Interval	End of Interval	Average speed (mph)	Delay in min. per mile of project length*	Distance severe queue reached (mi)	Distance moderate queue reached (mi)	Distance light queue reached (mi)
4:00 PM	4:15 PM	52.6	0.0	-	-	0.00
4:15 PM	4:30 PM	52.6	0.0	-	-	0.00
4:30 PM	4:45 PM	52.6	0.0	-	-	0.00
4:45 PM	5:00 PM	52.4	0.0	-	-	0.35
5:00 PM	5:15 PM	48.1	0.1	-	-	0.80
5:15 PM	5:30 PM	48.1	0.6	-	-	2.08
5:30 PM	5:45 PM	48.1	1.2	-	-	2.56
5:45 PM	6:00 PM	48.1	1.3	-	-	2.22
6:00 PM	6:15 PM	48.1	0.7	-	-	1.07
6:15 PM	6:30 PM	53.3	0.2	-	-	0.00
6:30 PM	6:45 PM	54.4	0.0	-	-	0.00
6:45 PM	7:00 PM	54.4	0.0	-	-	0.00

**The project length starts from the first 55-mph speed limit sign and extends to the end of the termination area*

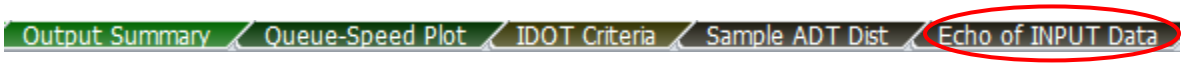
IDOT Criteria Table

In this example, vehicles slowed down, but there was no severe or moderate queue (based on the assumed IDOT definition), so there is no value in columns E and F for the distance queue reached. The red cells in Column G indicate that light queue length exceeds 1.5 miles. The following message is displayed at the bottom of the table.

WARNING

THE CELLS HIGHLIGHTED IN RED IN COLUMNS E-G INDICATE QUEUES EXCEEDING 1.5 MILES.

You can also go to the Echo of INPUT Data worksheet to see a summary of the input data.



Echo of INPUT Data Worksheet Selection

At this point, you can save and close the file.

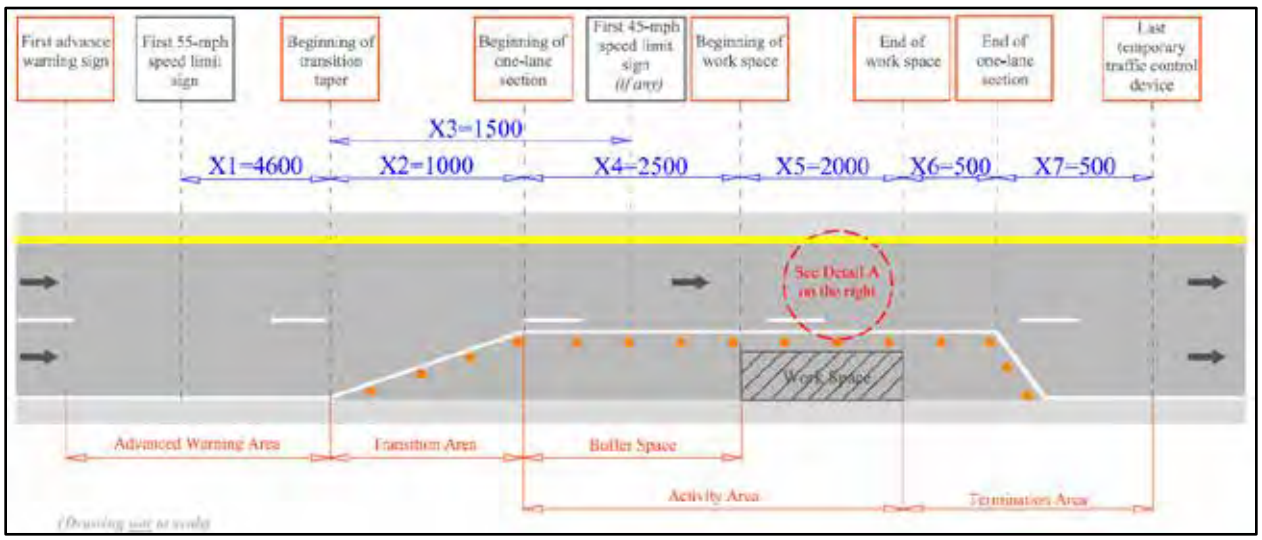
2.3 Example Problem 3

2.3.1 Getting Started

1. Follow the same steps in Section 2.1.1 to get started, except save the file as "Example3WZ.xlsm".

2.3.2 Input Data for Example Problem 3

Example Problem 3 is similar to Example Problem 1, but a flagger is present for some time period. This example is a work zone located on an interstate highway with one lane open and one lane closed. The speed limit outside of the work zone is 65 mph, but inside the work zone, the limit is 55 mph when a flagger is not present and 45 mph when there is a flagger. The lane width is reduced from 12 feet to 11 feet, and the right shoulder width is only 1 foot. Cones and drums separate the activity area from the traffic. At certain times, workers and a flagger are present in the work zone. Additional information about the work zone is below. Compute the total delay and users' costs for the given intervals.



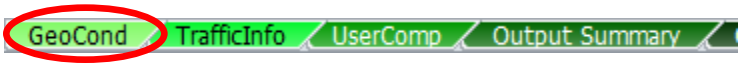
Work Zone Sketch for Example 3

Example 3 Input Data

	Interval 1	Interval 2	Interval 3	Interval 4	Interval 5	Interval 6	Interval 7	Interval 8
Start time	4:00 PM	4:30 PM	5:00 PM	5:30 PM	6:00 PM	6:30 PM	7:00 PM	7:30 PM
End time	4:30 PM	5:00 PM	5:30 PM	6:00 PM	6:30 PM	7:00 PM	7:30 PM	8:00 PM
Is there work activity?	No	Yes (low)	Yes (low)	No	No	No	No	No
Is there flagger?	No	Yes	Yes	No	No	No	No	No
Speed limit (mph)	55	45	45	55	55	55	55	55
Will traffic be asked to stop?	No	No	No	No	No	No	No	No
Volume in 30 min (veh)	700	700	800	800	600	600	400	350
Percentage of single-unit trucks	2%							
Percentage of combination trucks	21%							
Percentage of recreational vehicles	1%							
Lane width (ft)	11							
Right shoulder width (ft)	1							
Left shoulder width (ft)	2							
Terrain type	Level							
Average number of occupants in each passenger car	1.25 *(default)*							
Average number of occupants in each recreational vehicle	2.00 *(default)*							
Hourly delay cost for a single-unit truck ($/hr)	70 *(default)*							
Hourly delay cost for a combination truck ($/hr)	90 *(default)*							
Hourly delay cost for a passenger car ($/hr)	20 *(default)*							
Hourly delay cost for a recreational vehicle ($/hr)	20 *(default)*							

2.3.3 Project Information

2. Go to the GeoCond worksheet.



GeoCond Worksheet Selection

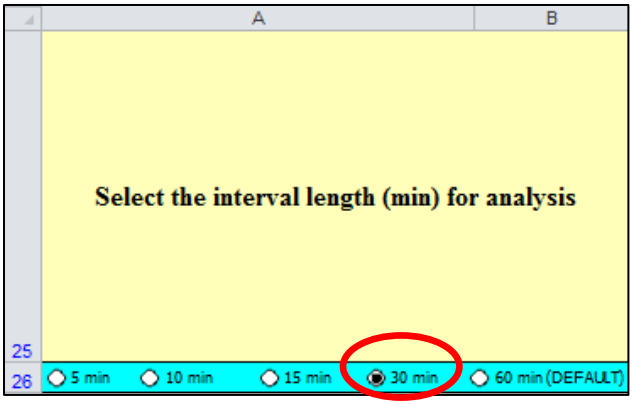
3. Write “Example 3” for the name of the project in cell B20, and fill out the rest of information as you like.

Project Name	Example 3	**Date**	9/26/2012
Project Number	237-12	**Year of Analysis**	2014
Site	I-57	**Analyst Name**	Joe Smith

Project Information

2.3.4 Work Zone Geometric Data (Step 1 of the Report)

4. Select “30 min” for the interval length.



Interval Length Selection

5. Enter the geometric data as shown (detailed information about the input data is provided in Appendix A).

Distance X1 (ft)	Distance X2 (ft)	Distance X3 (Write "0" if there is no 45-mph speed limit) (ft)	Distance X4 (ft)	Distance X5 (ft)	Distance X6 (ft)	Distance X7 (ft)
4,600	1,000	1,500	2,500	2,000	500	500

Geometric Input Data (Part 1)

J	K	L
Lane width Y1 (ft) *(Default is 12 ft)*	Right shoulder width Y2 (ft) *(Default is 6 ft)*	Left shoulder width Y3 (ft) *(Default is 2 ft)*
11.0	1.0	2.0

Geometric Input Data (Part 2)

Based on the input data, the following speed reductions are calculated (detailed information about the output data is provided in Appendix B):

M	N	O
Speed reduction due to lane width (mph)	Speed reduction due to right shoulder (mph)	Speed reduction due to left shoulder (mph)
1.9	3.6	0.0

Speed Reductions Due to Lane and Shoulder Widths

2.3.5 Work Zone Traffic Control Conditions (Steps 2–7 of the Report)

6. Select the intervals starting at 4:00 PM and ending at 8:00 PM by choosing “Y” in column D.

B	C	D
Start of Interval	End of Interval	Put "Y" if this interval is analyzed.
4:00 PM	4:30 PM	Y
4:30 PM	5:00 PM	Y
5:00 PM	5:30 PM	Y
5:30 PM	6:00 PM	Y
6:00 PM	6:30 PM	Y
6:30 PM	7:00 PM	Y
7:00 PM	7:30 PM	Y
7:30 PM	8:00 PM	Y

Selected Intervals

7. Click the CLICK TO SHOW ONLY SELECTED INTERVALS button. The workbook hides the unselected intervals.
8. For only the second and third intervals (i.e., from 4:30 PM to 5:30 PM):
   - There is work activity, so select “W” in column E.
   - There is a flagger, so select “F” in column F.
   - The speed limit is 45 mph, so select “45” in column G.
   - The activity area is separated from the traffic by cones and drums, so select “O” in column H.
   - Work intensity is low, so select “L” in column I.
9. There is no other speed-reducing factor, so skip columns J and K. Because traffic is not going to be stopped temporarily, make sure that “N” is selected in column L. (If traffic were asked to stop temporarily, put “Y” in column L.)

B	C	D	E	F	G
Start of Interval	End of Interval	Put "Y" if this interval is analyzed.	Put "W" if crew or construction equipment is closer than 9 ft to edge of travel lane.	Put "F" if flagger is present.	Put "45" if the speed limit is not 55 mph.
4:00 PM	4:30 PM	Y	N	N	55
4:30 PM	5:00 PM	Y	W	F	45
5:00 PM	5:30 PM	Y	W	F	45
5:30 PM	6:00 PM	Y	N	N	55
6:00 PM	6:30 PM	Y	N	N	55
6:30 PM	7:00 PM	Y	N	N	55
7:00 PM	7:30 PM	Y	N	N	55
7:30 PM	8:00 PM	Y	N	N	55

Work Zone Condition Inputs (Part 1)

H	I	J	K	L	M
Put "C" if concrete barriers are used, and "O" for other devices. *(e.g. cones, drums)*	Put "L" for low work intensity, "M" for moderate work intensity, "H" for high work intensity.	Select the Speed Control Technique (if any) from the drop down menue. Otherwise, leave it blank.	If there is any additional speed reduction due to any other factors not considered so far, enter here. *Otherwise, leave it blank.*	Put "Y" if the traffic will be asked to stop temporarily in this interval.	For how many minutes will the traffic be stopped in this interval?
				N	
O	L			N	
O	L			N	
				N	
				N	
				N	
				N	
				N	

Work Zone Condition Inputs (Part 2)

The worksheet computes the following outputs in columns N–S (detailed information about input and output data is provided in Appendix A and Appendix B, respectively).

N	O	P	Q	R	S
Free flow speed (mph)	Speed reduction due to work intensity (mph)	Adjusted free-flow speed (mph)	Maximum flow rate (pcphpl)	Speed at maximum flow rate (mph)	Prevailing capacity (pcphpl)
62.0		56.5	1,657	48.1	1,657
43.0	8.0	29.5	1,118	22.7	1,118
43.0	8.0	29.5	1,118	22.7	1,118
62.0		56.5	1,657	48.1	1,657
62.0		56.5	1,657	48.1	1,657
62.0		56.5	1,657	48.1	1,657
62.0		56.5	1,657	48.1	1,657
62.0		56.5	1,657	48.1	1,657

Estimated Capacity and Corresponding Speed

2.3.6 PCE, Traffic Volume, and Percentage of Trucks (Steps 8–10 of the Report)

10. Go to the TrafficInfo worksheet.

TrafficInfo Worksheet Selection

11. The work zone is located on level terrain, so enter the HCM 2010-suggested PCE values of “1.5” and “1.2” in cells B3 and C3, respectively. Because there is no variation in traffic demand within an interval, make sure “N” is selected in cell D3.

B	C	D
PCE for heavy vehicles *(Default is 1.5)*	PCE for recretional vehicles *(Default is 1.2)*	Put "Y" if there is variation in traffic demand within an interval
1.5	1.2	N

Traffic Inputs (Part 1)

12. Enter the percentage of single-unit trucks, combination trucks, and recreational vehicles in columns D–F. Enter the traffic volume for each interval in column G.

B	C	D	E	F	G
Start of Interval	End of Interval	Percentage of single-unit trucks (%)	Percentage of combination trucks (%)	Percentage of recreational vehicles (%)	Expected traffic volume during the interval (veh)
4:00 PM	4:30 PM	2.0	21.0	1.0	700
4:30 PM	5:00 PM	2.0	21.0	1.0	700
5:00 PM	5:30 PM	2.0	21.0	1.0	800
5:30 PM	6:00 PM	2.0	21.0	1.0	800
6:00 PM	6:30 PM	2.0	21.0	1.0	600
6:30 PM	7:00 PM	2.0	21.0	1.0	600
7:00 PM	7:30 PM	2.0	21.0	1.0	400
7:30 PM	8:00 PM	2.0	21.0	1.0	350

Traffic Inputs (Part 2)

The worksheet shows the following output (detailed information about the input and output data is provided in Appendix A and Appendix B, respectively):

K	L	T
Heavy vehicle adjustment factor	**Adjusted demand (pcphpl)**	**Adjusted capacity (vphpl)**
0.90	1,564	1,484
0.90	1,564	1,001
0.90	1,787	1,001
0.90	1,787	1,484
0.90	1,340	1,484
0.90	1,340	1,484
0.90	894	1,484
0.90	782	1,484

Converted Capacity and Demand

2.3.7 Occupancy and Cost Figures (Steps 11–15 of the Report)

13. Go to the UserComp worksheet.

UserComp Worksheet Selection

14. Enter the values for occupancy and cost figures as shown (detailed information about the input data is provided in Appendix A).

B	C	D	E	F	G	H
Average number of occupants in a passenger car. *(Default is 1.25)*	**Average number of occupants in a recreational vehicle.** *(Default is 2.00)*	**Hourly delay cost for a single-unit truck** ($/hr) *(Default is 70 $/hr)*	**Hourly delay cost for a combination truck** ($/hr) *(Default is 90 $/hr)*	**Hourly delay cost for a recreational vehicle** ($/hr) *(Default is 20 $/hr)*	**Hourly delay cost for a passenger car** ($/hr) *(Default is 20 $/hr)*	**Speed limit outside of the work zone** (mph)
1.25	**2.00**	**$70**	**$90**	**$20**	**$20**	**65**

Cost Figure Inputs

The worksheet calculates the output values shown below (detailed information about the output data is provided in Appendix B).

B	C	D	E	F	G	H	I
Start of Interval	End of Interval	No. of study period	No. of vehicles in queue	Average spacing between vehicles in queue (ft)	Occupied length of queued vehicles stacked in a single lane* (ft)	Distance queue reached* (ft)	Average speed (mph)
4:00 PM	4:30 PM	1	0	-	0	0	52.6
4:30 PM	5:00 PM	1	200	120	23,927	13,714	48.8
5:00 PM	5:30 PM	1	499	106	52,727	28,114	22.7
5:30 PM	6:00 PM	1	558	146	81,527	42,514	31.5
6:00 PM	6:30 PM	1	416	183	76,246	39,873	42.9
6:30 PM	7:00 PM	1	274	190	51,997	27,749	48.1
7:00 PM	7:30 PM	1	0	-	0	0	49.9
7:30 PM	8:00 PM	1	0	-	0	0	56.4
						MAXIMUM DISTANCE QUEUE REACHED (ft)	
						42,514	

**: At the end of the corresponding interval or when there is no more vehicle in queue*

Queue and Speed Computations

J	K	L	M	N	O	P
Average delay per vehicle in oversaturated condition (hr)	Average delay per vehicle in undersaturated conditions (hr)	Delay experienced by all vehicles (veh-hr)	Users' Costs ($)			
			Severe Queue (SQ)	Moderate Queue (MQ)	Light Queue (LQ)	All three queues
-	0	0.3	-	-	$13.29	$13.29
0.0746	-	37.3	-	-	$1,482.48	$1,482.48
0.2667	-	133.5	-	$5,298.10	-	$5,298.10
0.2740	-	203.2	-	$8,067.88	-	$8,067.88
0.2143	-	159.0	-	-	$6,311.13	$6,311.13
0.1404	-	104.1	-	-	$4,133.62	$4,133.62
0.0530	0	35.0	-	-	$1,389.20	$1,389.20
-	0	0.0	-	-	$0.00	$0.00
		SUM Delay	SUM SQ	SUM MQ	SUM LQ	SUM All
		672.4	*$0.00*	*$13,365.98*	*$13,329.71*	*$26,695.69*

Delay and Users' Costs Computations

Two cells in column I of the Queue and Speed Computations chart are highlighted in pink because the average speed is between 20 and 35 mph (when the speed limit is 45 mph) or between 25 and 40 mph (when the speed limit is 55 mph). The following message is displayed at the bottom of the table:

MODERATE QUEUE!

AVERAGE SPEED IS BETWEEN 20-35 MPH (SPEED LIMIT=45 MPH) OR 25-40 MPH (SPEED LIMIT=55 MPH).

2.3.8 Output Summary

15. Go to the Output Summary worksheet to see the output values shown below (detailed information about the output data is provided in Appendix B).

Output Summary Worksheet Selection

C	D	E	F	G	H	I
Start time	End time	No. of study period	Maximum distance queue reached in this study period (mi)	Minimum speed in queue in this study period (mph)	Approximate start of congestion#	Approximate end of congestion#
4:00 PM	8:00 PM	1	8.1	22.7	4:30 PM	7:26 PM
			MAX	MIN		
			8.1	22.7		

#: Uniform arrival/ departure rate is assumed within each time period.

Output Summary (Part 1)

J	K	L	M	N
Total delay in this study period (veh-hr)	Total users' costs ($) in this study period for			
	SQ	MQ	LQ	All
672.4	$0.00	$13,365.98	$13,329.71	$26,695.69
SUM	SUM	SUM	SUM	SUM
672.44	$0.00	$13,365.98	$13,329.71	$26,695.69

Output Summary (Part 2)

The following message explains why the cell in column G is highlighted:

MODERATE QUEUE!

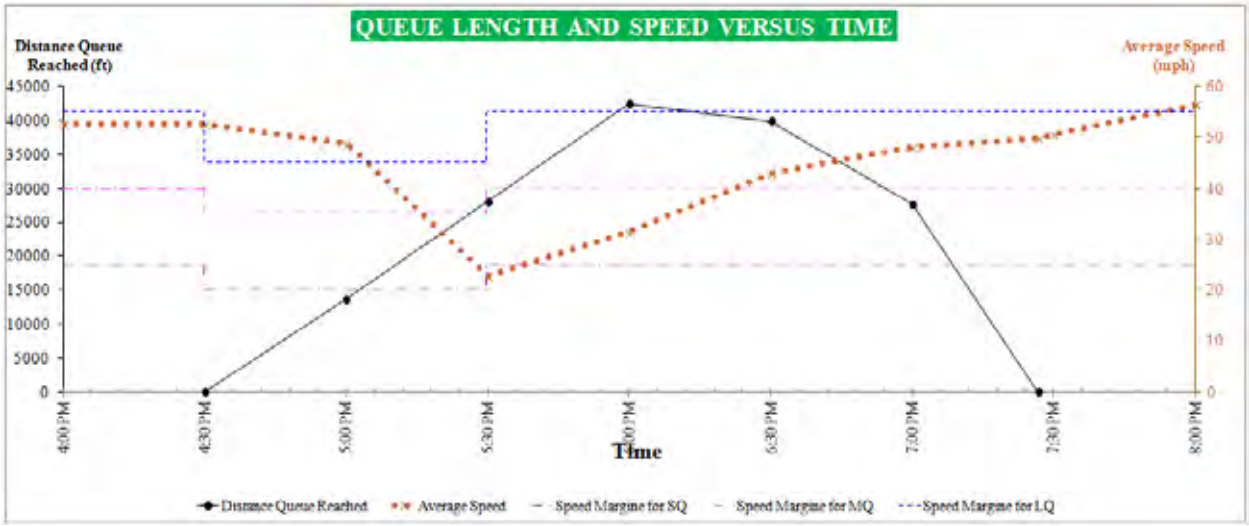
AVERAGE SPEED IS BETWEEN 20-35 MPH (SPEED LIMIT=45 MPH) OR 25-40 MPH (SPEED LIMIT=55 MPH).

16. Go to the Queue-Speed Plot worksheet to see average speed and the distance that the queue reached.

Output Summary | Queue-Speed Plot | IDOT Criteria | Sample ADT Dist | Echo of INPUT Data

Queue-Speed Plot Worksheet Selection

This chart shows the average speed of vehicles over time. When traffic slows down, the chart shows the distance that the queue reached over time.



17. Go to the IDOT Criteria worksheet to check whether the IDOT mobility criteria are satisfied (IDOT mobility criteria are provided in Appendix B).

Output Summary | Queue-Speed Plot | IDOT Criteria | Sample ADT Dist | Echo of INPUT Data

IDOT Criteria Worksheet Selection

A	B	C	D	E	F	G
Start of Interval	End of Interval	Average speed (mph)	Delay in min. per mile of project length*	Distance severe queue reached (mi)	Distance moderate queue reached (mi)	Distance light queue reached (mi)
4:00 PM	4:30 PM	52.6	0.0	-	-	0.00
4:30 PM	5:00 PM	48.8	2.1	-	-	2.60
5:00 PM	5:30 PM	22.7	7.6	-	5.32	-
5:30 PM	6:00 PM	33.5	7.8	-	8.05	-
6:00 PM	6:30 PM	42.9	6.1	-	-	7.55
6:30 PM	7:00 PM	48.1	4.0	-	-	5.26
7:00 PM	7:30 PM	49.9	1.5	-	-	0.00
7:30 PM	8:00 PM	56.4	0.0	-	-	0.00

**The project length starts from the first 55-mph speed limit sign and extends to the end of the termination area*

IDOT Criteria Table

Two cells in column C, starting at 5:00 PM and ending at 6:00 PM are highlighted in pink because the average speed is between 20 and 35 mph (when the speed limit is

45 mph) or between 25 and 40 mph (when the speed limit is 55 mph). The following message at the bottom of the table is shown:

MODERATE QUEUE

AVERAGE SPEED IS BETWEEN 20-35 MPH (SPEED LIMIT=45 MPH) OR 25-40 MPH (SPEED LIMIT=55 MPH).

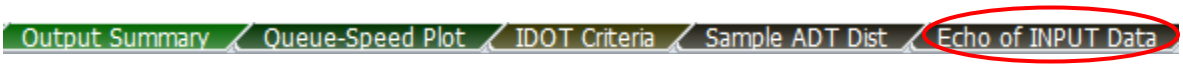
Three cells in column D are highlighted in red because the delay per mile of project length exceeds the IDOT threshold (i.e., 5 minutes). In this example, vehicles slowed down, but there was no severe queue (based on the assumed IDOT definition), so there is no value in column E for the distance that severe queue reached. The red cells in Columns F and G indicate queues exceeding 1.5 miles. This message is displayed at the bottom of the table:

WARNING

THE CELLS IN COLUMN D HIGHLIGHTED IN RED INDICATE DELAYS EXCEEDING 5 MIN PER MILE OF PROJECT LENGTH.

THE CELLS IN COLUMNS E-G HIGHLIGHTED IN RED INDICATE QUEUES EXCEEDING 1.5 MILES.

You can also go to the Echo of INPUT Data worksheet to see a summary of the input data.



Echo of INPUT Data Worksheet Selection

At this point, you can save and close the file.

2.3.9 Example Problem 3.1

Example Problem 3.1 is the same as Example Problem 3; however, the flagger shows the "Stop" paddle for 3 minutes during the interval starting at 4:30 PM.

2.3.9.1 Getting Started

1. Follow the same steps in Section 2.1.1 to get started, except save the file as "Example1.1WZ.xlsm".

2.3.9.2 Project Information

2. Write "Example 3.1" for the name of the project in cell B20, and fill out the rest of information as you like.

A	B	C	D	E	F	G	H
Project Name	Example 3.1				Date	9/26/2012	
Project Number	237-12				Year of Analysis	2014	
Site	I-57				Analyst Name	Joe Smith	

Project Information

2.3.9.3 Work Zone Geometric Data (Step 1 of the Report)

3. It is the same as used in Section 2.3.4.

2.3.9.4 Work Zone Traffic Control Conditions (Steps 2–7 of the Report)

4. Enter the input data as explained in Section 2.3.5. Then select "Y" from the drop-down menu in column L for the interval starting at 4:30 PM and ending at 5:00 PM. For the same time interval, enter "3" as the stoppage time in column M. Make sure that "N" has been chosen in column L for the other time intervals.

B	C	D	E	F	G
Start of Interval	End of Interval	Put "Y" if this interval is analyzed.	Put "W" if crew or construction equipment is closer than 9 ft to edge of travel lane.	Put "F" if flagger is present.	Put "45" if the speed limit is not 55 mph.
4:00 PM	4:30 PM	Y	N	N	55
4:30 PM	5:00 PM	Y	W	F	45
5:00 PM	5:30 PM	Y	W	F	45
5:30 PM	6:00 PM	Y	N	N	55
6:00 PM	6:30 PM	Y	N	N	55
6:30 PM	7:00 PM	Y	N	N	55
7:00 PM	7:30 PM	Y	N	N	55
7:30 PM	8:00 PM	Y	N	N	55

Work Zone Condition Inputs (Part 1)

H	I	J	K	L	M
Put "C" if concrete barriers are used, and "O" for other devices. (e.g. cones, drums)	Put "L" for low work intensity, "M" for moderate work intensity, "H" for high work intensity.	Select the Speed Control Technique (if any) from the drop down menus. Otherwise, leave it blank.	If there is any additional speed reduction due to any other factors not considered so far, enter here. Otherwise, leave it blank.	Put "Y" if the traffic will be asked to stop temporarily in this interval.	For how many minutes will the traffic be stopped in this interval?
				N	
o				Y	3
o				N	
				N	
				N	
				N	
				N	
				N	

Work Zone Condition Inputs (Part 2)

The following caution message explains why the cell in column M is highlighted:

CAUTION!

THE HIGHLIGHTED ORANGE CELLS INDICATE TEMPORARY TRAFFIC STOPPAGE IN THAT INTERVAL.

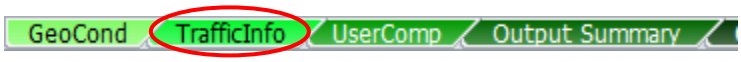
Then the worksheet computes the following outputs in column N-S (detailed information about input and output data is provided in Appendix A and Appendix B, respectively):

N	O	P	Q	R	S
Free flow speed (mph)	Speed reduction due to work intensity (mph)	Adjusted free-flow speed (mph)	Maximum flow rate (pcphpl)	Speed at maximum flow rate (mph)	Prevailing capacity (pcphpl)
62.0		56.5	1,657	48.1	1,657
43.0	8.0	29.5	1,118	22.7	1,006
43.0	8.0	29.5	1,118	22.7	1,118
62.0		56.5	1,657	48.1	1,657
62.0		56.5	1,657	48.1	1,657
62.0		56.5	1,657	48.1	1,657
62.0		56.5	1,657	48.1	1,657
62.0		56.5	1,657	48.1	1,657

Estimated Capacity and Corresponding Speed

2.3.9.5 PCE, Traffic Volume, and Percentage of Trucks (Steps 8–10 of the Report)

5. Go to the TrafficInfo worksheet.



TrafficInfo Worksheet Selection

All the inputs are the same as those in Section 2.3.6; however, the outputs are different because of the 3-minute stoppage time (detailed information about the input and output data is provided in Appendix A and Appendix B, respectively).

K	L	T
Heavy vehicle adjustment factor	**Adjusted demand (pcphpl)**	**Adjusted capacity (vphpl)**
0.90	1,564	1,484
0.90	1,564	901
0.90	1,787	1,001
0.90	1,787	1,484
0.90	1,340	1,484
0.90	1,340	1,484
0.90	894	1,484
0.90	782	1,484

Converted Capacity and Demand

2.3.9.6 Occupancy and Cost Figures (Steps 11–15 of the Report)

6. Go to the UserComp worksheet.

UserComp Worksheet Selection

7. Use the same occupancy and cost figures that you entered in Section 2.3.7 (detailed information about the input data is provided in Appendix A).

B	C	D	E	F	G	H
Average number of occupants in a passenger car. *(Default is 1.25)*	**Average number of occupants in a recreational vehicle.** *(Default is 2.00)*	**Hourly delay cost for a single-unit truck** ($/hr) *(Default is 70 $/hr)*	**Hourly delay cost for a combination truck** ($/hr) *(Default is 90 $/hr)*	**Hourly delay cost for a recreational vehicle** ($/hr) *(Default is 20 $/hr)*	**Hourly delay cost for a passenger car** ($/hr) *(Default is 20 $/hr)*	**Speed limit outside of the work zone** (mph)
1.25	**2.00**	**$70**	**$90**	**$20**	**$20**	**65**

Cost Figure Inputs

The worksheet calculates the output values shown below (detailed information about the output data is provided in Appendix B).

B	C	D	E	F	G	H	I
Start of Interval	**End of Interval**	**No. of study period**	**No. of vehicles in queue**	**Average spacing between vehicles in queue** (ft)	**Occupied length of queued vehicles stacked in a single lane*** (ft)	**Distance queue reached*** (ft)	**Average speed** (mph)
4:00 PM	4:30 PM	1	0	-	0	0	52.6
4:30 PM	5:00 PM	1	250	115	28,800	16,150	47.9
5:00 PM	5:30 PM	1	549	105	57,600	30,550	22.0
5:30 PM	6:00 PM	1	608	142	86,400	44,950	35.0
6:00 PM	6:30 PM	1	466	182	84,982	44,241	42.4
6:30 PM	7:00 PM	1	324	187	60,733	32,117	48.1
7:00 PM	7:30 PM	1	0	-	0	0	48.1
7:30 PM	8:00 PM	1	0	-	0	0	56.3
						MAXIMUM DISTANCE QUEUE REACHED (ft)	
						44,950	

**: At the end of the corresponding interval or when there is no more vehicle in queue*

Queue and Speed Computations

J	K	L	M	N	O	P
Average delay per vehicle in oversaturated condition (hr)	Average delay per vehicle in undersaturated conditions (hr)	Delay experienced by all vehicles (veh-hr)	Users' Costs ($)			
			Severe Queue (SQ)	Moderate Queue (MQ)	Light Queue (LQ)	All three queues
-	0	0.3	-	-	$13.29	$13.29
0.1064	-	47.9	-	-	$1,901.87	$1,901.87
0.3113	-	155.8	-	$6,183.85	-	$6,183.85
0.2755	-	204.3	-	$8,112.52	-	$8,112.52
0.2386	-	177.0	-	-	$7,025.29	$7,025.29
0.1617	-	119.9	-	-	$4,760.72	$4,760.72
0.0648	0	48.1	-	-	$1,909.41	$1,909.41
0.0006	0	0.0	-	-	$0.57	$0.57
		SUM Delay	SUM SQ	SUM MQ	SUM LQ	SUM All
		753.3	*$0.00*	*$14,296.37*	*$15,611.15*	*$29,907.51*

Delay and Users' Costs Computations

Two cells in column I for the third and fourth intervals are highlighted in pink because the average speed is between 20 and 35 mph (when the speed limit is 45 mph) or between 25 and 45 mph (when the speed limit is 55 mph). The following message is displayed:

MODERATE QUEUE!

AVERAGE SPEED IS BETWEEN 20-35 MPH (SPEED LIMIT=45 MPH) OR 25-40 MPH (SPEED LIMIT=55 MPH).

2.3.9.7 Output Summary

8. Go to the Output Summary worksheet to see the output values shown below (detailed information about the output data is provided in Appendix B).

Output Summary Worksheet Selection

C	D	E	F	G	H	I
Start time	End time	No. of study period	Maximum distance queue reached in this study period (mi)	Minimum speed in queue in this study period (mph)	Approximate start of congestion#	Approximate end of congestion#
4:00 PM	8:00 PM	1	8.5	22.0	4:30 PM	7:31 PM
			MAX	MIN		
			8.5	22.0		

#: Uniform arrival/ departure rate is assumed within each time period.

Output Summary (Part 1)

J	K	L	M	N
Total delay in this study period (veh-hr)	Total users' costs ($) in this study period for			
	SQ	MQ	LQ	All
753.3	$0.00	$14,296.37	$15,611.15	$29,907.51
SUM	SUM	SUM	SUM	SUM
753.34	$0.00	$14,296.37	$15,611.15	$29,907.51

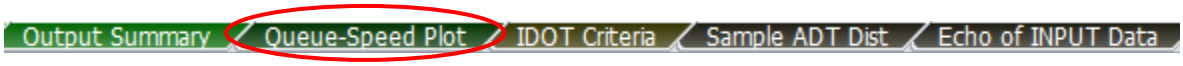
Output Summary (Part 2)

The following message at the bottom of the table explains why the cell in column G is highlighted:

MODERATE QUEUE!

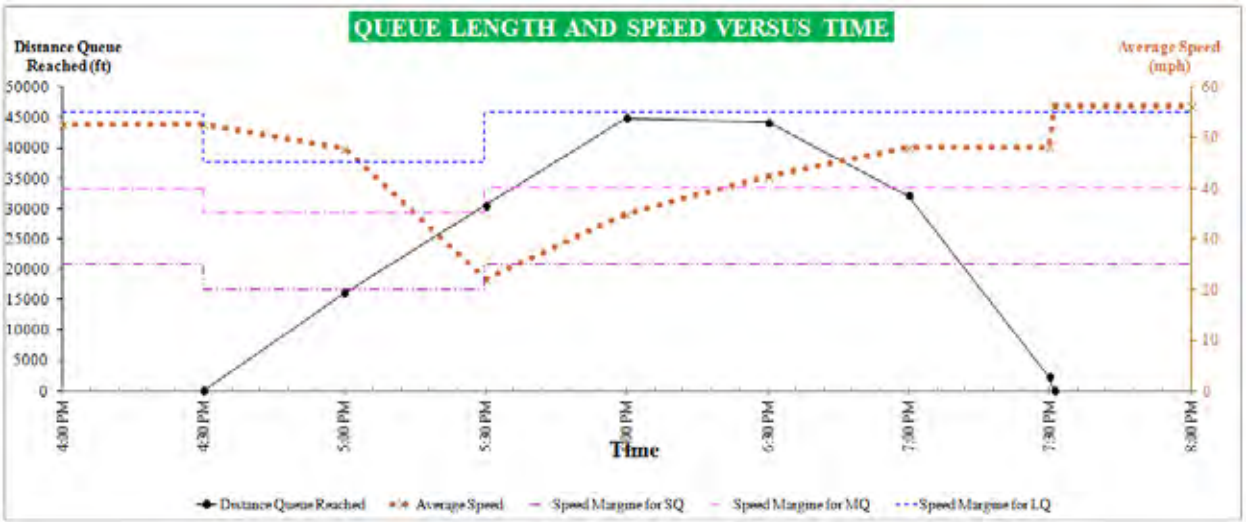
AVERAGE SPEED IS BETWEEN 20-35 MPH (SPEED LIMIT=45 MPH) OR 25-40 MPH (SPEED LIMIT=55 MPH).

9. Go to the Queue-Speed Plot worksheet to see average speed and the distance that the queue reached.

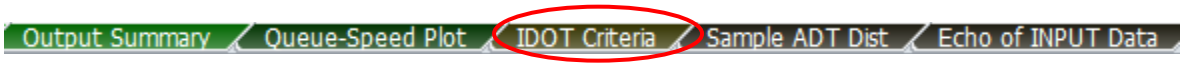


Queue-Speed Plot Worksheet Selection

This chart shows average speed of vehicles over time. When traffic slows down, the chart shows the distance that the queue reached over time.



10. Go to the IDOT Criteria worksheet to check whether the IDOT mobility criteria are satisfied (IDOT mobility criteria are provided in Appendix B).



IDOT Criteria Worksheet Selection

A	B	C	D	E	F	G
Start of Interval	End of Interval	Average speed (mph)	Delay in min. per mile of project length*	Distance severe queue reached (mi)	Distance moderate queue reached (mi)	Distance light queue reached (mi)
4:00 PM	4:30 PM	52.6	0.0	-	-	0.00
4:30 PM	5:00 PM	47.9	3.0	-	-	3.06
5:00 PM	5:30 PM	22.0	8.9	-	5.79	-
5:30 PM	6:00 PM	35.0	7.9	-	8.51	-
6:00 PM	6:30 PM	42.4	6.8	-	-	8.38
6:30 PM	7:00 PM	48.1	4.6	-	-	6.08
7:00 PM	7:30 PM	48.1	1.9	-	-	0.00
7:30 PM	8:00 PM	56.3	0.0	-	-	0.00

**The project length starts from the first 55-mph speed limit sign and extends to the end of the termination area*

IDOT Criteria Table

Two cells in column C, starting at 5:00 PM and ending at 6:00 PM, are highlighted in pink because the average speed is between 20 and 35 mph (when the speed limit is 45 mph) or between 25 and 40 mph (when the speed limit is 55 mph). Three cells in column D are highlighted in red because the delay per mile of project length exceeds 5 minutes. In this example, vehicles slowed down, but there was no severe queue (based on the assumed IDOT definition), so there is no value in column E for the distance that severe queue reached. The red cells in Columns F and G indicate queues exceeding 1.5 miles. The following messages are displayed at the bottom of the table:

WARNING

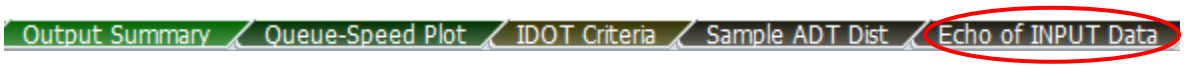
THE CELLS IN COLUMN D HIGHLIGHTED IN RED INDICATE DELAYS EXCEEDING 5 MIN PER MILE OF PROJECT LENGTH.

THE CELLS IN COLUMNS E-G HIGHLIGHTED IN RED INDICATE QUEUES EXCEEDING 1.5 MILES.

MODERATE QUEUE

AVERAGE SPEED IS BETWEEN 20-35 MPH (SPEED LIMIT=45 MPH) OR 25-40 MPH (SPEED LIMIT=55 MPH).

You can also go to the Echo of INPUT Data worksheet to see a summary of the input data.



Echo of INPUT Data Worksheet Selection

At this point, you can save and close the file.

2.4 Example Problem 4

2.4.1 Getting Started

1. Follow the same steps in Section 2.1.1 to get started, except save the file as "Example4WZ.xlsm".

2.4.2 Input Data for Example Problem 4

Example Problem 4 is the same as Example Problem 3, except there is Police patrol car present in the work zone when there is flagger (i.e., from 4:30 PM to 5:30 PM). Otherwise, the remaining input data are the same as in Section 2.3.2. Compute the total delay and users' costs.

2.4.3 Project Information

2. Go to the GeoCond worksheet.

GeoCond Worksheet Selection

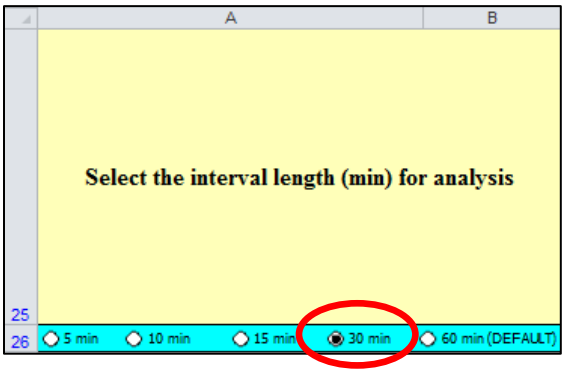
3. Write "Example 4" for the name of the project in cell B20, and fill out the rest of information as you like.

A	B	D	E	F	G	H
Project Name	Example 4			Date	9/26/2012	
Project Number	237-12			Year of Analysis	2014	
Site	I-57			Analyst Name	Joe Smith	

Project Information

2.4.4 Work Zone Geometric Data (Step 1 of the Report)

4. Select "30 min" for the interval length.



Interval Length Selection

5. Enter the geometric data as shown (detailed information about the input data is provided in Appendix A).

C	D	E	F	G	H	I
Distance X1 (ft)	Distance X2 (ft)	Distance X3 (Write "0" if there is no 45-mph speed limit) (ft)	Distance X4 (ft)	Distance X5 (ft)	Distance X6 (ft)	Distance X7 (ft)
4,600	1,000	1,500	2,500	2,000	500	500

Geometric Input Data (Part 1)

J	K	L
Lane width Y1 (ft) *(Default is 12 ft)*	Right shoulder width Y2 (ft) *(Default is 6 ft)*	Left shoulder width Y3 (ft) *(Default is 2 ft)*
11.0	1.0	2.0

Geometric Input Data (Part 2)

Based on the input data, the following speed reductions are calculated (detailed information about the output data is provided in Appendix B):

M	N	O
Speed reduction due to lane width (mph)	Speed reduction due to right shoulder (mph)	Speed reduction due to left shoulder (mph)
1.9	3.6	0.0

Speed Reductions Due to Lane and Shoulder Widths

2.4.5 Work Zone Traffic Control Conditions (Steps 2–7 of the Report)

6. Select the intervals starting at 4:00 PM and ending at 8:00 PM by choosing “Y” in column D.

B	C	D
Start of Interval	End of Interval	Put "Y" if this interval is analyzed.
4:00 PM	4:30 PM	Y
4:30 PM	5:00 PM	Y
5:00 PM	5:30 PM	Y
5:30 PM	6:00 PM	Y
6:00 PM	6:30 PM	Y
6:30 PM	7:00 PM	Y
7:00 PM	7:30 PM	Y
7:30 PM	8:00 PM	Y

Selected Intervals

7. Click the CLICK TO SHOW ONLY SELECTED INTERVALS button. The workbook hides the unselected intervals.
8. For only the second and third intervals (i.e., from 4:30 PM to 5:30 PM):
   - There is work activity, so select “W” in column E.
   - There is a flagger, so select “F” in column F.
   - The speed limit is 45 mph, so select “45” in column G.
   - The activity area is separated from the traffic by cones and drums, so select “O” in column H.
   - Work intensity is low, so select “L” in column I.
   - There is a Police patrol car in the work zone, so select “Police Presence” from the drop-down menu in column J.
9. There is no other speed-reducing factor, so skip column K. Because traffic is not going to be stopped temporarily, make sure that “N” is selected in column L. (If traffic were asked to stop temporarily, put “Y” in column L.)

B	C	D	E	F	G
Start of Interval	End of Interval	Put "Y" if this interval is analyzed.	Put "W" if crew or construction equipment is closer than 9 ft to edge of travel lane.	Put "F" if flagger is present.	Put "45" if the speed limit is not 55 mph.
4:00 PM	4:30 PM	Y	N	N	55
4:30 PM	5:00 PM	Y	W	F	45
5:00 PM	5:30 PM	Y	W	F	45
5:30 PM	6:00 PM	Y	N	N	55
6:00 PM	6:30 PM	Y	N	N	55
6:30 PM	7:00 PM	Y	N	N	55
7:00 PM	7:30 PM	Y	N	N	55
7:30 PM	8:00 PM	Y	N	N	55

Work Zone Condition Inputs (Part 1)

H	I	J	K	L	M
Put "C" if concrete barriers are used, and "O" for other devices. *(e.g. cones, drums)*	Put "L" for low work intensity, "M" for moderate work intensity, "H" for high work intensity.	Select the Speed Control Technique (if any) from the drop down menue. Otherwise, leave it blank.	If there is any additional speed reduction due to any other factors not considered so far, enter here. *Otherwise, leave it blank.*	Put "Y" if the traffic will be asked to stop temporarily in this interval.	For how many minutes will the traffic be stopped in this interval?
				N	
O	L	Police Presence		N	
O	L	Police Presence		N	
				N	
				N	
				N	
				N	
				N	

Work Zone Condition Inputs (Part 2)

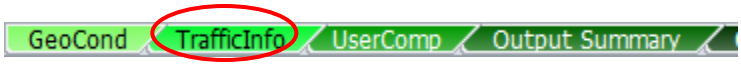
The worksheet computes the following outputs in columns N–S (detailed information about input and output data is provided in Appendix A and Appendix B, respectively).

N	O	P	Q	R	S
Free flow speed (mph)	Speed reduction due to work intensity (mph)	Adjusted free-flow speed (mph)	Maximum flow rate (pcphpl)	Speed at maximum flow rate (mph)	Prevailing capacity (pcphpl)
62.0		56.5	1,657	48.1	1,657
43.0	8.0	25.0	1,022	18.9	1,022
43.0	8.0	25.0	1,022	18.9	1,022
62.0		56.5	1,657	48.1	1,657
62.0		56.5	1,657	48.1	1,657
62.0		56.5	1,657	48.1	1,657
62.0		56.5	1,657	48.1	1,657
62.0		56.5	1,657	48.1	1,657

Estimated Capacity and Corresponding Speed

2.4.6 PCE, Traffic Volume and Percent Trucks (Steps 8–10 of the Report)

10. Go to the TrafficInfo worksheet.



TrafficInfo Worksheet Selection

11. The work zone is located on level terrain, so enter the HCM 2010-suggested PCE values of “1.5” and “1.2” in cells B3 and C3, respectively. Because there is no variation in traffic demand within an interval, make sure “N” is selected in cell D3.

B	C	D
PCE for heavy vehicles *(Default is 1.5)*	PCE for recretional vehicles *(Default is 1.2)*	Put "Y" if there is variation in traffic demand within an interval
1.5	1.2	N

Traffic Inputs (Part 1)

12. Enter the percentage of single-unit trucks, combination trucks, and recreational vehicles in columns D–F. Enter the traffic volume for each interval in column G.

B	C	D	E	F	G
Start of Interval	End of Interval	Percentage of single-unit trucks (%)	Percentage of combination trucks (%)	Percentage of recreational vehicles (%)	Expected traffic volume during the interval (veh)
4:00 PM	4:30 PM	2.0	21.0	1.0	700
4:30 PM	5:00 PM	2.0	21.0	1.0	700
5:00 PM	5:30 PM	2.0	21.0	1.0	800
5:30 PM	6:00 PM	2.0	21.0	1.0	800
6:00 PM	6:30 PM	2.0	21.0	1.0	600
6:30 PM	7:00 PM	2.0	21.0	1.0	600
7:00 PM	7:30 PM	2.0	21.0	1.0	400
7:30 PM	8:00 PM	2.0	21.0	1.0	350

Traffic Inputs (Part 2)

The worksheet shows the following outputs (detailed information about the input and output data is provided in Appendix A and Appendix B, respectively):

K	L	T
Heavy vehicle adjustment factor	Adjusted demand (pcphpl)	Adjusted capacity (vphpl)
0.90	1,564	1,484
0.90	1,564	915
0.90	1,787	915
0.90	1,787	1,484
0.90	1,340	1,484
0.90	1,340	1,484
0.90	894	1,484
0.90	782	1,484

Converted Capacity and Demand

2.4.7 Occupancy and Cost Figures (Steps 11–15 of the Report)

13. Go to the UserComp worksheet.

UserComp Worksheet Selection

14. Enter the values for occupancy and cost figures as shown (detailed information about the input data is provided in Appendix A).

B	C	D	E	F	G	H
Average number of occupants in a passenger car. *(Default is 1.25)*	**Average number of occupants in a recreational vehicle.** *(Default is 2.00)*	**Hourly delay cost for a single-unit truck** ($/hr) *(Default is 70 $/hr)*	**Hourly delay cost for a combination truck** ($/hr) *(Default is 90 $/hr)*	**Hourly delay cost for a recreational vehicle** ($/hr) *(Default is 20 $/hr)*	**Hourly delay cost for a passenger car** ($/hr) *(Default is 20 $/hr)*	**Speed limit outside of the work zone** (mph)
1.25	**2.00**	**$70**	**$90**	**$20**	**$20**	**65**

Cost Figure Inputs

The worksheet computes the following outputs (detailed information about the output data is provided in Appendix B):

B	C	D	E	F	G	H	I
Start of Interval	End of Interval	No. of study period	No. of vehicles in queue	Average spacing between vehicles in queue (ft)	Occupied length of queued vehicles stacked in a single lane* (ft)	Distance queue reached* (ft)	Average speed (mph)
4:00 PM	4:30 PM	1	0	-	0	0	52.6
4:30 PM	5:00 PM	1	242	109	26,419	14,960	47.6
5:00 PM	5:30 PM	1	585	94	55,219	29,360	18.9
5:30 PM	6:00 PM	1	643	131	84,019	43,760	27.9
6:00 PM	6:30 PM	1	501	169	84,738	44,119	41.5
6:30 PM	7:00 PM	1	359	168	60,489	31,995	48.1
7:00 PM	7:30 PM	1	18	115	2,035	2,035	48.1
7:30 PM	8:00 PM	1	0	-	0	0	56.3
						MAXIMUM DISTANCE QUEUE REACHED (ft)	
						44,119	

**: At the end of the corresponding interval or when there is no more vehicle in queue*

Queue and Speed Computations

J	K	L	M	N	O	P
Average delay per vehicle in oversaturated condition (hr)	Average delay per vehicle in undersaturated conditions (hr)	Delay experienced by all vehicles (veh-hr)	Users' Costs ($)			
			Severe Queue (SQ)	Moderate Queue (MQ)	Light Queue (LQ)	All three queues
-	0	0.3	-	-	$13.29	$13.29
0.1051	-	48.1	-	-	$1,910.16	$1,910.16
0.3588	-	164.2	$6,518.98	-	-	$6,518.98
0.3332	-	247.2	-	$9,811.86	-	$9,811.86
0.2531	-	187.8	-	-	$7,454.73	$7,454.73
0.1729	-	128.2	-	-	$5,090.41	$5,090.41
0.0703	-	52.1	-	-	$2,069.06	$2,069.06
0.0005	0	0.0	-	-	$0.45	$0.45
		SUM Delay	SUM SQ	SUM MQ	SUM LQ	SUM All
		827.9	*$6,518.98*	*$9,811.86*	*$16,538.10*	*$32,868.95*

Delay and Users' Costs Computations

The average speed in column I for the third interval is highlighted in burgundy because it dropped below 20 mph. Also, the average speed in column I for the fourth interval is highlighted in pink because it is between 25 and 40 mph. The following messages are displayed the bottom of the table:

SEVERE QUEUE!

AVERAGE SPEED DROPPED BELOW 20 MPH (SPEED LIMIT=45 MPH) OR BELOW 25 MPH (SPEED LIMIT=55 MPH).

MODERATE QUEUE!

AVERAGE SPEED IS BETWEEN 20-35 MPH (SPEED LIMIT=45 MPH) OR 25-40 MPH (SPEED LIMIT=55 MPH).

2.4.8 Output Summary

15. Go to the Output Summary worksheet to see the output values shown below (detailed information about the output data is provided in Appendix B).

Output Summary Worksheet Selection

C	D	E	F	G	H	I
Start time	End time	No. of study period	Maximum distance queue reached in this study period (mi)	Minimum speed in queue in this study period (mph)	Approximate start of congestion#	Approximate end of congestion#
4:00 PM	8:00 PM	1	8.4	18.9	4:30 PM	7:30 PM
			MAX	MIN		
			8.4	18.9		

#: Uniform arrival/ departure rate is assumed within each time period.

Output Summary (Part 1)

H	I	J	K	L	M	N
Approximate start of congestion#	Approximate end of congestion#	Total delay in this study period (veh-hr)	Total users' costs ($) in this study period for			
			SQ	MQ	LQ	All
4:30 PM	7:30 PM	827.9	$6,518.98	$9,811.86	$16,538.10	$32,868.95
		SUM	SUM	SUM	SUM	SUM
		827.93	$6,518.98	$9,811.86	$16,538.10	$32,868.95

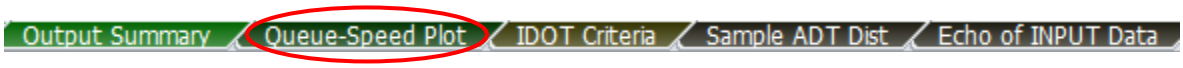
Output Summary (Part 2)

The cell in column G is highlighted in burgundy because the average speed dropped below 20 mph. The following message is displayed below the table:

SEVERE QUEUE!

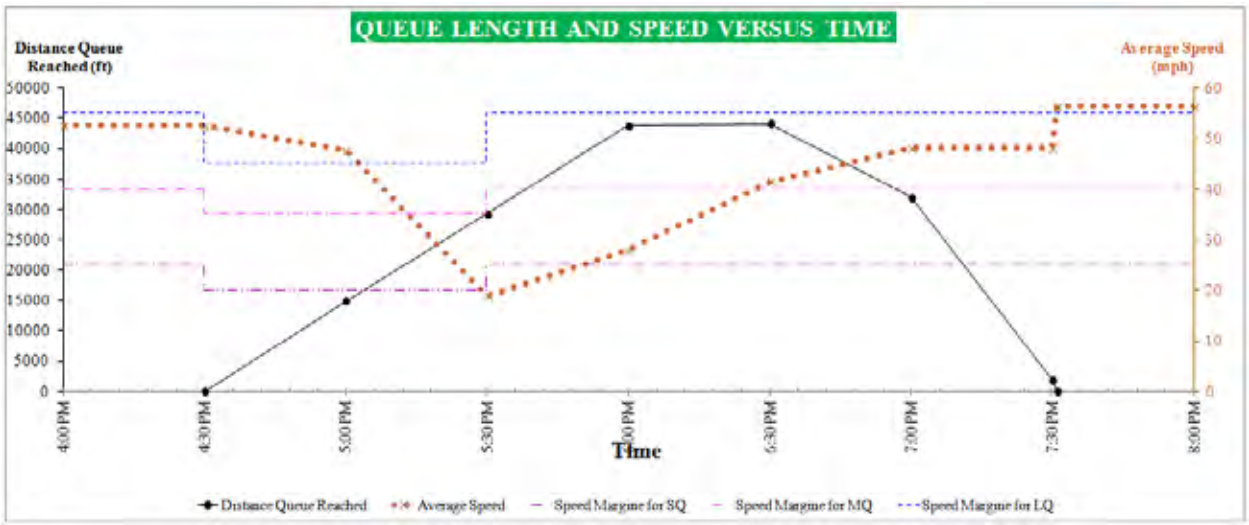
AVERAGE SPEED DROPPED BELOW 20 MPH *(SPEED LIMIT=45 MPH)* OR BELOW 25 MPH *(SPEED LIMIT=55 MPH).*

16. Go to the Queue-Speed Plot worksheet to see average speed and the distance that the queue reached.

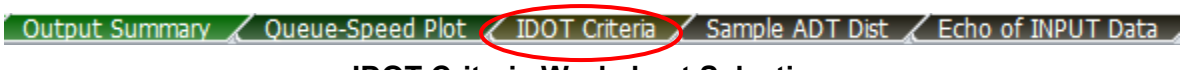


Queue-Speed Plot Worksheet Selection

This chart shows the average speed of vehicles over time. When traffic slows down, the chart shows the distance that the queue reached over time.



17. Go to the IDOT Criteria worksheet to check whether the IDOT mobility criteria are satisfied (IDOT mobility criteria are provided in Appendix B).



IDOT Criteria Worksheet Selection

A	B	C	D	E	F	G
Start of Interval	End of Interval	Average speed (mph)	Delay in min. per mile of project length*	Distance severe queue reached (mi)	Distance moderate queue reached (mi)	Distance light queue reached (mi)
4:00 PM	4:30 PM	52.6	0.0	-	-	0.00
4:30 PM	5:00 PM	47.6	3.0	-	-	2.83
5:00 PM	5:30 PM	18.9	10.2	5.56	-	-
5:30 PM	6:00 PM	27.9	9.5	-	8.29	-
6:00 PM	6:30 PM	41.5	7.2	-	-	8.36
6:30 PM	7:00 PM	48.1	4.9	-	-	6.06
7:00 PM	7:30 PM	48.1	2.0	-	-	0.39
7:30 PM	8:00 PM	56.3	0.0	-	-	0.00

**The project length starts from the first 55-mph speed limit sign and extends to the end of the termination area*

IDOT Criteria Table

One cell in column C, starting at 5:00 PM, is highlighted in burgundy because the average speed fell below 20 mph (when the speed limit is 45 mph). Also, the cell starting at 5:30 PM is pink because the average speed is between 25 and 40 mph (when the speed limit is 55 mph). Three cells in column D are in red because delay per mile of project length exceeds 5 minutes and the red cells in columns E-G indicate queues exceeding 1.5 miles. The following messages are displayed below the table:

WARNING

THE CELLS IN COLUMN D HIGHLIGHTED IN RED INDICATE DELAYS EXCEEDING 5 MIN PER MILE OF PROJECT LENGTH.

THE CELLS IN COLUMNS E-G HIGHLIGHTED IN RED INDICATE QUEUES EXCEEDING 1.5 MILES.

SEVERE QUEUE

AVERAGE SPEED DROPPED BELOW 20 MPH (SPEED LIMIT=45 MPH) OR BELOW 25 MPH (SPEED LIMIT=55 MPH).

MODERATE QUEUE

AVERAGE SPEED IS BETWEEN 20-35 MPH (SPEED LIMIT=45 MPH) OR 25-40 MPH (SPEED LIMIT=55 MPH).

You can also go to the Echo of INPUT Data worksheet to see a summary of the input data.

Echo of INPUT Data Worksheet Selection

At this point, you can save and close the file.

2.5 Example Problem 5

2.5.1 Getting Started

1. Follow the same steps in Section 2.1.1 to get started, except save the file as "Example5WZ.xlsm".

2.5.2 Input Data for Example Problem 5

Example Problem 5 is the same as Example Problem 3, except that when the flagger is present (i.e., from 4:30 PM to 5:30 PM), there is moderate work intensity. Because of the equipment being used for the work (joint repair), the cones are moved a little toward the travel lane, so the lane width is reduced to 10 feet during when the flagger is present (i.e., from 4:30 PM to 5:30 PM). Otherwise, the remaining input data are the same as in Section 2.3.2. Compute the total delay and users' costs.

2.5.3 Project Information

2. Go to the GeoCond worksheet.

GeoCond Worksheet Selection

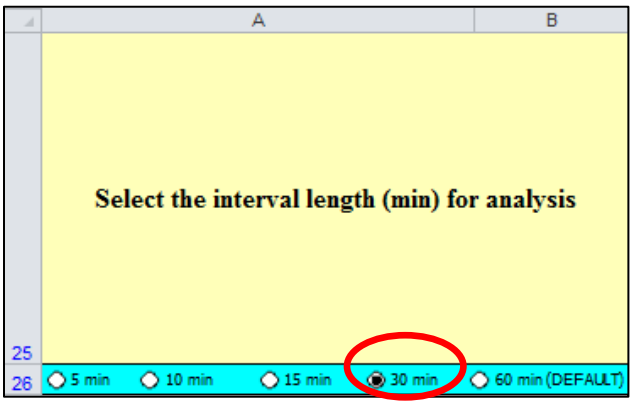
3. Write "Example 5" for the name of the project in cell B20 and fill out the rest of information as you like.

Project Name	Example 5	Date	9/26/2012
Project Number	237-12	Year of Analysis	2014
Site	I-57	Analyst Name	Joe Smith

Project Information

2.5.4 Work Zone Geometric Data (Step 1 of the Report)

4. Select "30 min" for the interval length.



Interval Length Selection

5. Enter the geometric data as shown (detailed information about the input data is provided in Appendix A).

C	D	E	F	G	H	I
Distance X1 (ft)	Distance X2 (ft)	Distance X3 (Write "0" if there is no 45-mph speed limit) (ft)	Distance X4 (ft)	Distance X5 (ft)	Distance X6 (ft)	Distance X7 (ft)
4,600	1,000	1,500	2,500	2,000	500	500

Geometric Input Data (Part 1)

J	K	L
Lane width Y1 (ft) *(Default is 12 ft)*	Right shoulder width Y2 (ft) *(Default is 6 ft)*	Left shoulder width Y3 (ft) *(Default is 2 ft)*
11.0	1.0	2.0

Geometric Input Data (Part 2)

Based on the input data, the following speed reductions are calculated (detailed information about the output data is provided in Appendix B):

M	N	O
Speed reduction due to lane width (mph)	Speed reduction due to right shoulder (mph)	Speed reduction due to left shoulder (mph)
1.9	3.6	0.0

Speed Reductions Due to Lane and Shoulder Widths

2.5.5 Work Zone Traffic Control Conditions (Steps 2–7 of the Report)

6. Select the intervals starting at 4:00 PM and ending at 8:00 PM by choosing “Y” in column D.

B	C	D
Start of Interval	End of Interval	Put "Y" if this interval is analyzed.
4:00 PM	4:30 PM	Y
4:30 PM	5:00 PM	Y
5:00 PM	5:30 PM	Y
5:30 PM	6:00 PM	Y
6:00 PM	6:30 PM	Y
6:30 PM	7:00 PM	Y
7:00 PM	7:30 PM	Y
7:30 PM	8:00 PM	Y

Selected Intervals

7. Click the CLICK TO SHOW ONLY SELECTED INTERVALS button. The workbook hides the unselected intervals.
8. For only the second and third intervals (i.e., from 4:30 PM to 5:30 PM):
   - There is work activity, so select “W” in column E.
   - There is a flagger, so select “F” in column F.
   - The speed limit is 45 mph, so select “45” in column G.
   - The activity area is separated from the traffic by cones and drums, so select “O” in column H.
   - Work intensity is moderate, so select “M” in column I.
   - According to Table D.1 in Appendix D, the estimated speed reduction required for an 11-foot lane is 1.9 mph and for a 10-foot lane is 6.6 mph. Because the lane width is entered as “11 ft” in step 1, a 1.9-mph speed reduction is already accounted for. To account for the additional speed reduction for the 10-foot lane, enter 4.7 (i.e., 6.6 mph – 1.9 mph = 4.7 mph) in column K.
9. There is no speed reduction treatment, so skip column J. Because traffic is not going to be stopped temporarily, make sure that “N” is selected in column L. (If traffic were asked to stop temporarily, put “Y” in column L.)

B	C	D	E	F	G
Start of Interval	End of Interval	Put "Y" if this interval is analyzed.	Put "W" if crew or construction equipment is closer than 9 ft to edge of travel lane.	Put "F" if flagger is present.	Put "45" if the speed limit is not 55 mph.
4:00 PM	4:30 PM	Y	N	N	55
4:30 PM	5:00 PM	Y	W	F	45
5:00 PM	5:30 PM	Y	W	F	45
5:30 PM	6:00 PM	Y	N	N	55
6:00 PM	6:30 PM	Y	N	N	55
6:30 PM	7:00 PM	Y	N	N	55
7:00 PM	7:30 PM	Y	N	N	55
7:30 PM	8:00 PM	Y	N	N	55

Work Zone Condition Inputs (Part 1)

H	I	J	K	L	M
Put "C" if concrete barriers are used, and "O" for other devices. *(e.g. cones, drums)*	Put "L" for low work intensity, "M" for moderate work intensity, "H" for high work intensity.	Select the Speed Control Technique (if any) from the drop down menue. Otherwise, leave it blank.	If there is any additional speed reduction due to any other factors not considered so far, enter here. *Otherwise, leave it blank.*	Put "Y" if the traffic will be asked to stop temporarily in this interval.	For how many minutes will the traffic be stopped in this interval?
				N	
O	M		4.7	N	
O	M		4.7	N	
				N	
				N	
				N	
				N	
				N	

Work Zone Condition Inputs (Part 2)

The worksheet computes the following outputs in columns N–S (detailed information about input and output data is provided in Appendix A and Appendix B, respectively).

N	O	P	Q	R	S
Free flow speed (mph)	Speed reduction due to work intensity (mph)	Adjusted free-flow speed (mph)	Maximum flow rate (pcphpl)	Speed at maximum flow rate (mph)	Prevailing capacity (pcphpl)
62.0		56.5	1,657	48.1	1,657
43.0	12.0	20.8	933	15.3	933
43.0	12.0	20.8	933	15.3	933
62.0		56.5	1,657	48.1	1,657
62.0		56.5	1,657	48.1	1,657
62.0		56.5	1,657	48.1	1,657
62.0		56.5	1,657	48.1	1,657
62.0		56.5	1,657	48.1	1,657

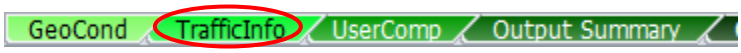
Estimated Capacity and Corresponding Speed

Column P (adjusted free-flow speed) is highlighted in orange for the second and third intervals. The reason is that the adjusted free-flow speed for those intervals is less than 25 mph. The calculations for those two intervals are based on extrapolation and may be used with caution. The following caution message is displayed in the worksheet:

CAUTION!
THE HIGHLIGHTED ORANGE CELLS ARE BASED ON EXTRAPOLATION AND MAY BE USED WITH CAUTION.

2.5.6 PCE, Traffic Volume, and Percentage of Trucks (Steps 8–10 of the Report)

10. Go to the TrafficInfo worksheet.



TrafficInfo Worksheet Selection

11. The work zone is located on level terrain, so enter the HCM 2010-suggested PCE values of “1.5” and “1.2” in cells B3 and C3, respectively. Because there is no variation in traffic demand within an interval, make sure “N” is selected in cell D3.

B	C	D
PCE for heavy vehicles *(Default is 1.5)*	PCE for recretional vehicles *(Default is 1.2)*	Put "Y" if there is variation in traffic demand within an interval
1.5	1.2	N

Traffic Inputs (Part 1)

12. Enter the percentage of single-unit trucks, combination trucks, and recreational vehicles in columns D through F. Enter the traffic volume for each interval in column G.

B	C	D	E	F	G
Start of Interval	End of Interval	Percentage of single-unit trucks (%)	Percentage of combination trucks (%)	Percentage of recreational vehicles (%)	Expected traffic volume during the interval (veh)
4:00 PM	4:30 PM	2.0	21.0	1.0	700
4:30 PM	5:00 PM	2.0	21.0	1.0	700
5:00 PM	5:30 PM	2.0	21.0	1.0	800
5:30 PM	6:00 PM	2.0	21.0	1.0	800
6:00 PM	6:30 PM	2.0	21.0	1.0	600
6:30 PM	7:00 PM	2.0	21.0	1.0	600
7:00 PM	7:30 PM	2.0	21.0	1.0	400
7:30 PM	8:00 PM	2.0	21.0	1.0	350

Traffic Inputs (Part 2)

The worksheet provides the following outputs (detailed information about the input and output data is provided in Appendix A and Appendix B, respectively):

K	L	T
Heavy vehicle adjustment factor	**Adjusted demand (pcphpl)**	**Adjusted capacity (vphpl)**
0.90	1,564	1,484
0.90	1,564	835
0.90	1,787	835
0.90	1,787	1,484
0.90	1,340	1,484
0.90	1,340	1,484
0.90	894	1,484
0.90	782	1,484

Converted Capacity and Demand

2.5.7 Occupancy and Cost Figures (Steps 11–15 of the Report)

13. Go to the UserComp worksheet.

UserComp Worksheet Selection

14. Enter the values for occupancy and cost figures as shown (detailed information about the input data is provided in Appendix A).

B	C	D	E	F	G	H
Average number of occupants in a passenger car. *(Default is 1.25)*	**Average number of occupants in a recreational vehicle.** *(Default is 2.00)*	**Hourly delay cost for a single-unit truck** ($/hr) *(Default is 70 $/hr)*	**Hourly delay cost for a combination truck** ($/hr) *(Default is 90 $/hr)*	**Hourly delay cost for a recreational vehicle** ($/hr) *(Default is 20 $/hr)*	**Hourly delay cost for a passenger car** ($/hr) *(Default is 20 $/hr)*	**Speed limit outside of the work zone** (mph)
1.25	**2.00**	**$70**	**$90**	**$20**	**$20**	**65**

Cost Figure Inputs

The worksheet computes the following outputs (detailed information about the output data is provided in Appendix B):

B	C	D	E	F	G	H	I
Start of Interval	End of Interval	No. of study period	No. of vehicles in queue	Average spacing between vehicles in queue (ft)	Occupied length of queued vehicles stacked in a single lane* (ft)	Distance queue reached* (ft)	Average speed (mph)
4:00 PM	4:30 PM	1	0	-	0	0	52.6
4:30 PM	5:00 PM	1	282	97	27,353	15,427	46.3
5:00 PM	5:30 PM	1	665	84	56,153	29,827	15.3
5:30 PM	6:00 PM	1	723	118	84,953	44,227	24.5
6:00 PM	6:30 PM	1	581	154	89,410	46,455	40.0
6:30 PM	7:00 PM	1	439	148	65,161	34,331	48.1
7:00 PM	7:30 PM	1	97	69	6,707	5,104	48.1
7:30 PM	8:00 PM	1	0	-	0	0	55.9
						MAXIMUM DISTANCE QUEUE REACHED (ft)	
						46,455	

**: At the end of the corresponding interval or when there is no more vehicle in queue*

Queue and Speed Computations

J	K	L	M	N	O	P
Average delay per vehicle in oversaturated condition (hr)	Average delay per vehicle in undersaturated conditions (hr)	Delay experienced by all vehicles (veh-hr)	Users' Costs ($)			
			Severe Queue (SQ)	Moderate Queue (MQ)	Light Queue (LQ)	All three queues
-	0	0.3	-	-	$13.29	$13.29
0.1408	-	58.8	-	-	$2,335.74	$2,335.74
0.4679	-	195.4	$7,758.95	-	-	$7,758.95
0.3955	-	293.4	$11,647.45	-	-	$11,647.45
0.2893	-	214.6	-	$8,519.96	-	$8,519.96
0.2013	-	149.3	-	-	$5,928.61	$5,928.61
0.0939	-	69.6	-	-	$2,763.89	$2,763.89
0.0091	0	0.7	-	-	$26.88	$26.88
		SUM Delay	SUM SQ	SUM MQ	SUM LQ	SUM All
		982.2	*$19,406.40*	*$8,519.96*	*$11,068.42*	*$38,994.78*

Delay and Users' Costs Computations

The cells in column I are highlighted in burgundy for the third and fourth intervals. The reason is that the average speed for these two intervals dropped below the severe queue margin (i.e., 20 mph for a speed limit of 45 mph and 25 mph for a speed limit of 55 mph). The average speed for the fifth interval is in pink because it is between 25 and 40 mph, indicating there is a moderate queue. The following messages are displayed at the bottom of the table:

SEVERE QUEUE!

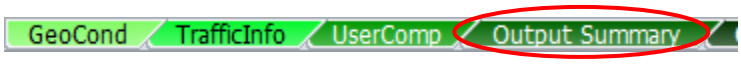
AVERAGE SPEED DROPPED BELOW 20 MPH (SPEED LIMIT=45 MPH) OR BELOW 25 MPH (SPEED LIMIT=55 MPH).

MODERATE QUEUE!

AVERAGE SPEED IS BETWEEN 20-35 MPH (SPEED LIMIT=45 MPH) OR 25-40 MPH (SPEED LIMIT=55 MPH).

2.5.8 Output Summary

15. Go to the Output Summary worksheet to see the output values shown below (detailed information about the output data is provided in Appendix B).



Output Summary Worksheet Selection

C	D	E	F	G	H	I
Start time	End time	No. of study period	Maximum distance queue reached in this study period (mi)	Minimum speed in queue in this study period (mph)	Approximate start of congestion#	Approximate end of congestion#
4:00 PM	8:00 PM	1	8.8	15.3	4:30 PM	7:33 PM
			MAX	MIN		
			8.8	15.3		

#: Uniform arrival/ departure rate is assumed within each time period.

Output Summary (Part 1)

J	K	L	M	N
Total delay in this study period (veh-hr)	Total users' costs ($) in this study period for			
	SQ	MQ	LQ	All
982.2	$19,406.40	$8,519.96	$11,068.42	$38,994.78
SUM	SUM	SUM	SUM	SUM
982.24	$19,406.40	$8,519.96	$11,068.42	$38,994.78

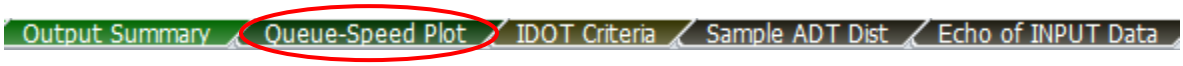
Output Summary (Part 2)

The cell in column G is highlighted in burgundy because the average speed drops below 20 mph. The following message is displayed at the bottom of the table:

SEVERE QUEUE!

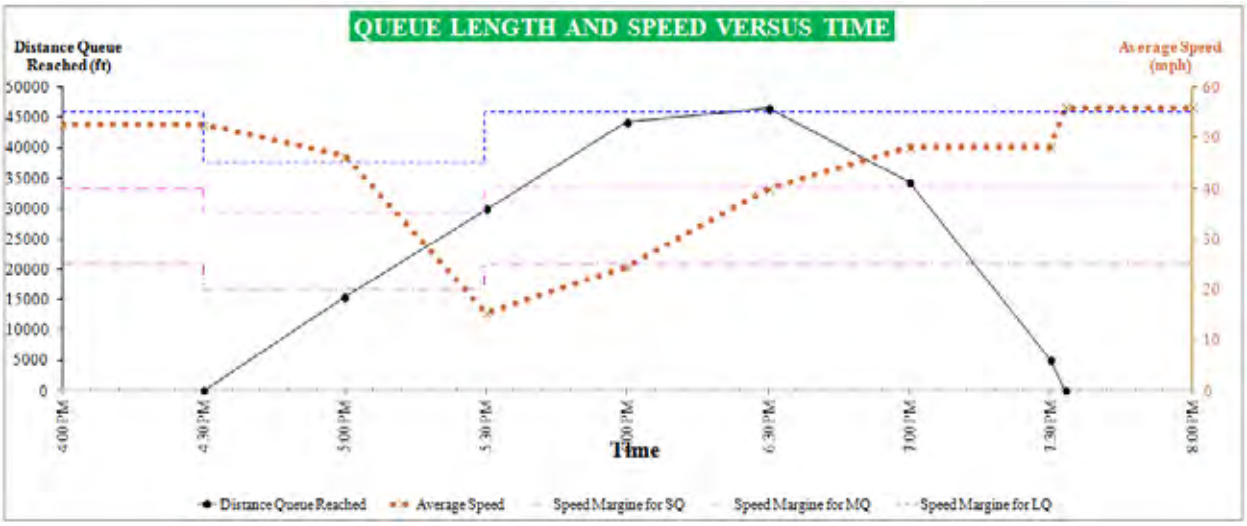
AVERAGE SPEED DROPPED BELOW 20 MPH *(SPEED LIMIT=45 MPH)* OR BELOW 25 MPH *(SPEED LIMIT=55 MPH).*

16. Go to the Queue-Speed Plot worksheet to see average speed and the distance that the queue reached.

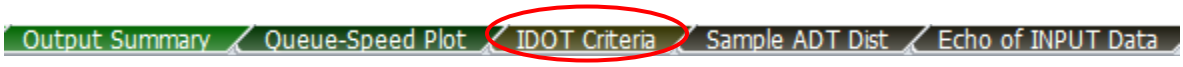


Queue-Speed Plot Worksheet Selection

This chart shows the average speed of vehicles over time. When traffic slows down, the chart shows the distance that the queue reached over time.



17. Go to the IDOT criteria worksheet to check whether the IDOT mobility criteria are satisfied (IDOT mobility criteria are provided in Appendix B).



IDOT Criteria Worksheet Selection

A	B	C	D	E	F	G
Start of Interval	End of Interval	Average speed (mph)	Delay in min. per mile of project length*	Distance severe queue reached (mi)	Distance moderate queue reached (mi)	Distance light queue reached (mi)
4:00 PM	4:30 PM	52.6	0.0	-	-	0.00
4:30 PM	5:00 PM	46.3	4.0	-	-	2.92
5:00 PM	5:30 PM	15.3	13.4	5.65	-	-
5:30 PM	6:00 PM	24.5	11.3	8.38	-	-
6:00 PM	6:30 PM	40.0	8.3	-	8.80	-
6:30 PM	7:00 PM	48.1	5.7	-	-	0.00
7:00 PM	7:30 PM	48.1	2.7	-	-	0.00
7:30 PM	8:00 PM	55.9	0.3	-	-	0.00

**The project length starts from the first 55-mph speed limit sign and extends to the end of the termination area*

IDOT Criteria Table

The third and fourth cells in column C are highlighted in burgundy because the average speed during these intervals dropped below 20 mph (when the speed limit is 45 mph) or 25 mph (when the speed limit is 55 mph). Also, the fifth cell is pink because the average speed is between 25 and 40 mph, indicating a moderate queue for a speed limit of 55 mph. The red cells in column D indicate the intervals during which the delay per mile of project length exceeds 5 minute; the red cells in columns E-G indicate queues exceeding 1.5 miles. The following messages are displayed at the bottom of the table.

WARNING

THE CELLS IN COLUMN D HIGHLIGHTED IN RED INDICATE DELAYS EXCEEDING 5 MIN PER MILE OF PROJECT LENGTH.

THE CELLS IN COLUMNS E-G HIGHLIGHTED IN RED INDICATE QUEUES EXCEEDING 1.5 MILES.

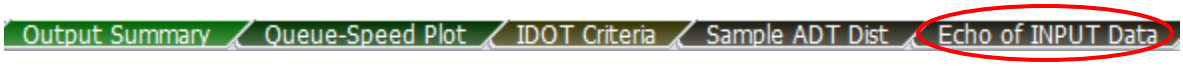
SEVERE QUEUE

AVERAGE SPEED DROPPED BELOW 20 MPH (SPEED LIMIT=45 MPH) OR BELOW 25 MPH (SPEED LIMIT=55 MPH).

MODERATE QUEUE

AVERAGE SPEED IS BETWEEN 20-35 MPH (SPEED LIMIT=45 MPH) OR 25-40 MPH (SPEED LIMIT=55 MPH).

You can also go to Echo of INPUT Data worksheet to see the summary of the input data.

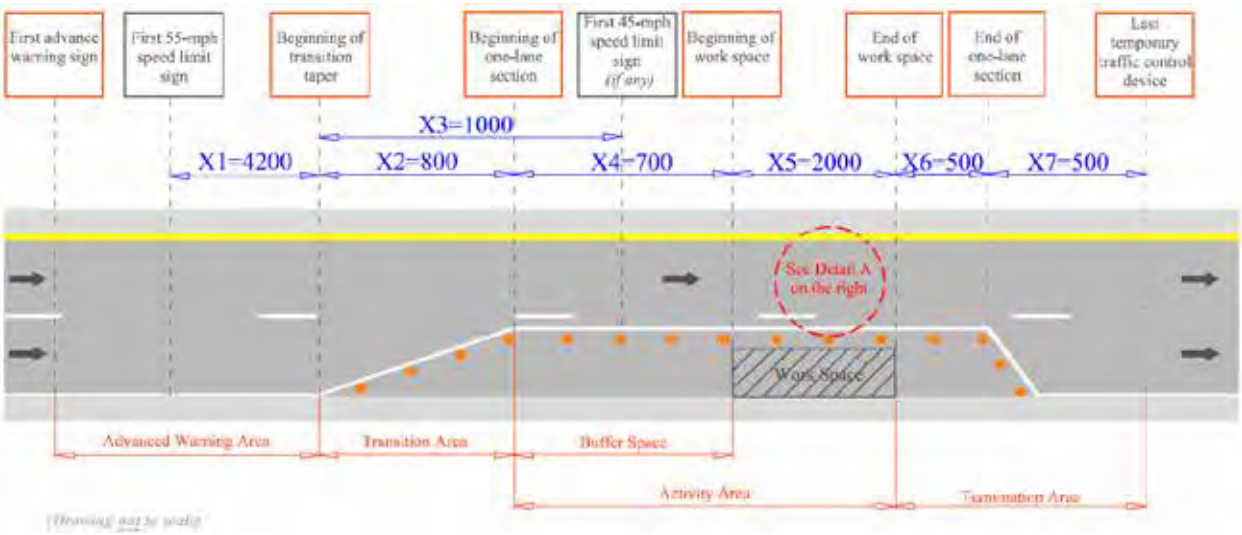


Echo of INPUT Data Worksheet Selection

At this point, you can save and close the file.

Example Problem 6: In-Class Exercise

This example uses part of the field traffic data collected by IDOT District 9 on I-57 southbound. This highway has two lanes on the SB, but one of the lanes will be closed during construction activities. The speed limit outside the work zone is 65 mph, but inside it is 45 mph. Cones and drums separate the activity area from the traffic. During the analysis period, workers and a flagger are present in the work zone. The study period runs from 7:00 AM to 7:00 PM (daylight). Additional information about the work zone is shown below. Compute the total delay and users' costs for the given intervals.



Work Zone Sketch for Example Problem 6

Example Problem 6 Input Data

	Interval 1	Interval 2	Interval 3	Interval 4	Interval 5	Interval 6	Interval 7	Interval 8	Interval 9	Interval 10	Interval 11	Interval 12
Start time	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM
End time	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM
Is there work activity?	Yes (Low)											
Is there a flagger?	Yes											
Speed limit (mph)	45											
Will traffic be asked to stop?	No											
Volume in 60 min. (veh)	1,103	989	945	979	982	929	994	965	1,182	1083	996	807
Percentage of single-unit trucks	3	3	5	4	4	3	5	4	3	4	5	3
Percentage of combination trucks	13	16	24	18	21	21	23	23	25	25	28	35
Percentage of recreational vehicles	0	0	0	0	0	0	0	0	0	0	0	0
Lane width (ft)	12											
Right shoulder width (ft)	6											
Left shoulder width (ft)	2											
Terrain type	Level											
Average number of occupants in each passenger car	1.25											
Average number of occupants in each recreational vehicle	2											
Hourly delay cost for a single-unit truck ($/hr)	70											
Hourly delay cost for a combination truck ($/hr)	90											
Hourly delay cost for a passenger car ($/hr)	20											
Hourly delay cost for a recreational vehicle ($/hr)	20											

Once all the input data are entered, the program should return the following tables in the Output Summary worksheet:

C	D	E	F	G	H	I
Start time	End time	No. of study period	Maximum distance queue reached in this study period (mi)	Minimum speed in queue in this study period (mph)	Approximate start of congestion#	Approximate end of congestion#
7:00 AM	7:00 PM	1	1.5	27.4	2:32 PM	6:09 PM
			MAX	MIN		
			1.5	27.4		

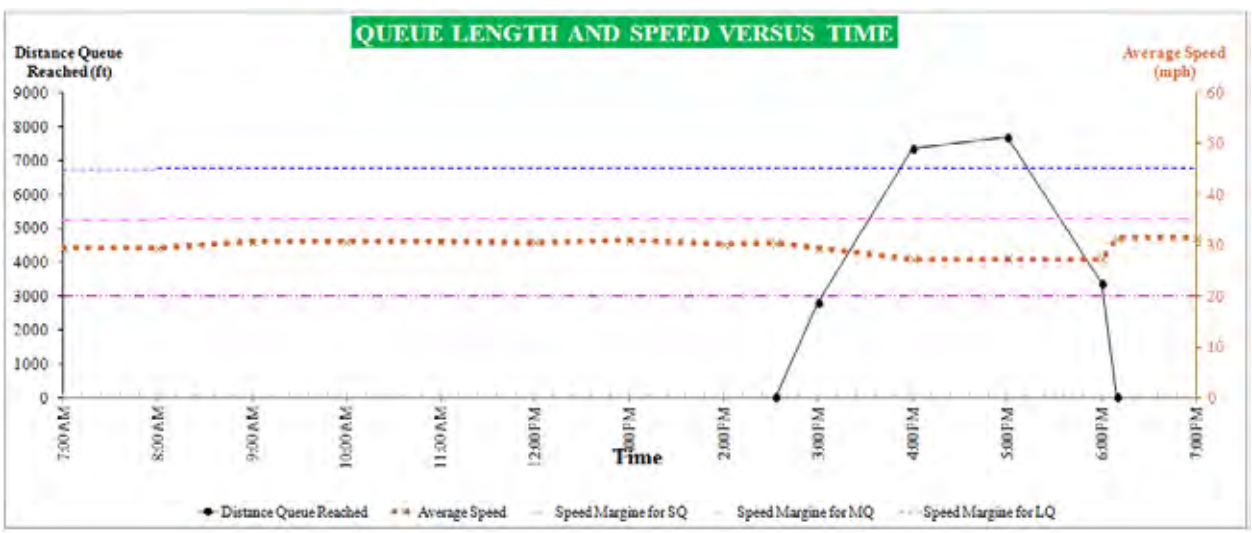
#: Uniform arrival/ departure rate is assumed within each time period.

Output Summary (Part 1)

J	K	L	M	N
Total delay in this study period (veh-hr)	Total users' costs ($) in this study period for			
	SQ	MQ	LQ	All
224.09	$0.00	$9,599.74	$0.00	$9,599.74
SUM	SUM	SUM	SUM	SUM
224.09	$0.00	$9,599.74	$0.00	$9,599.74

Output Summary (Part 2)

Also, this chart is developed in the Queue-Speed Plot worksheet.



CHAPTER 3 WORKSHOPS

The research team held three training workshops for IDOT engineers in northern, southern, and central Illinois. The following table shows location, date, and number of participants in each workshop:

Workshop Information

Location	Date	No. of Participants	District
Collinsville	9-26-2012	15	8, 9
Schaumburg	11-27-2012	30	1, 2, 3
Springfield	1-24-2013	12	4, 5, 6, 7

The workshops began with a brief review of traffic flow, followed by a presentation of the concept of the WorkZoneQ algorithm. Next, program features and how to interpret the results were explained through the examples provided in this manual.

The program was updated after each workshop based on feedback from the participants. For instance, the method for entering geometric data was changed based on comments from construction engineers in the first workshop. Likewise, file size and program speed were improved to accommodate users with low-speed computers. Some of the engineers' needs that were identified in feedback were beyond the scope of the study and will be presented in the next chapter as proposed future expansions.

CHAPTER 4 RECOMMENDATIONS

The current WorkZoneQ was developed using the data collected from freeway work zones where one of the two lanes in a single direction is closed (2-to-1 work zones). Based on IDOT engineer needs, it is recommended that the program be expanded to estimate capacity for the following cases:

- Freeway work zones with different lane configurations; for instance, crossover, 2-to-2 (means two lanes open outside and two lanes open inside the work zone), 3-to-3, 3-to-2 (means three lanes open outside the work zone reduced to two lanes open inside the work zone), 3-to-1, etc.
- Different facilities: arterials, two-lane highways, and multilane highways (non-freeway)

The program may be extended to include these scenarios using models available in the literature; however, field data collection is recommended for the conditions for which existing knowledge is limited. The effect of diversion and/or trip rescheduling may be considered as other expansions for the program.

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APPENDIX A DESCRIPTION OF THE INPUT DATA

This section provides in-depth explanation of the input data that users are required to enter when using WorkZoneQ.

A.1 Input Data for the GeoCond Worksheet

The GeoCond worksheet consists of three parts. The first part is project information: project name, project number, analyst name, date, site, and year of analysis. These inputs do not have any effect on the calculations.

The second part is step 1, in which users must enter the input data into the following option buttons and cells:

Interval Length: The interval length is the duration for which

- The traffic demand and traffic composition are known and are assumed to be uniform over time.
- Work zone geometry such as lane width, shoulder width, etc. does not change.
- Work zone characteristics such as speed limit, presence of a flagger, work intensity, etc. do not change.

Users can select interval lengths of 5, 10, 15, 30, or 60 minutes (60 minutes is the default value). To select a particular interval length, users click the corresponding option button. For instance, if the user selects the interval length as 10 minutes, he/she should click the option button next to “10 min”. At that point, the workbook updates all the input and output tables accordingly.

NOTES ON INTERVAL LENGTH SELECTION

Interval length depends on the type of data available. If hourly traffic volumes are available, for instance, the user chooses the interval length of 60 minutes. If traffic volumes for each 5 minutes are available, then the user chooses the interval length of 5 minutes.

When data are collected over shorter intervals (e.g., traffic volume data for 5-min intervals), the data may be aggregated to 15-minute intervals. However, in that case, some slight imprecision is introduced compared with the use of shorter (i.e., 5-minute) intervals.

On the other hand, when data for smaller intervals are not available (e.g., only the hourly traffic volumes are available), it is *not* appropriate to divide the data (i.e., traffic volume) into shorter intervals (e.g., 15 minutes).

Distance X1 (Cell C33): The input for cell C33 is “Distance X1”, which is the distance in feet from the first 55-mph speed limit sign to the beginning of the transition taper. Figure D.4 in Appendix D presents a schematic view for a work zone.

Distance X2 (Cell D33): The input for cell D33 is “Distance X2”, which is the distance in feet from the beginning of the transition taper to the beginning of the one-lane section. Figure D.4 in Appendix D presents a schematic view for a work zone.

Distance X3 (Cell E33): The input for cell E33 is Distance X3, which is the distance in feet from the beginning of the transition taper to the first 45-mph speed limit sign. If the speed limit throughout the work zone is 55 mph and there is no 45-mph speed limit sign, Distance X3 should be entered as "0". Figure D.4 in Appendix D presents a schematic view for a work zone.

Distance X4 (Cell F33): The input for cell F33 is Distance X4, which is the distance in feet from the beginning of the one-lane section to the beginning of the work space. Figure D.4 in Appendix D presents a schematic view for a work zone.

Distance X5 (Cell G33): The input for cell G33 is Distance X5, which is the length of the work space. Figure D.4 in Appendix D presents a schematic view for a work zone.

Distance X6 (Cell H33): The input for cell H33 is Distance X6, which is the distance in feet from the end of the work space to the end of the one-lane section. Figure D.4 in Appendix D presents a schematic view for a work zone.

Distance X7 (Cell I33): The input for cell I33 is Distance X7, which is the distance in feet from the end of the one-lane section to the end of the termination area. The end of termination area coincides with the last temporary traffic control device. Figure D.4 in Appendix D presents a schematic view for a work zone.

Distance Y1 (Cell J33): The input for cell J33 is Distance Y1, which is the lane width in feet. According to HCM 2010, it is defined as "the arithmetic mean of the lane widths of a roadway in one direction, expressed in feet." The default value is 12 feet. The lane width must be between 8 and 16 feet.

Distance Y2 (Cell K33): The input for cell K33 is Distance Y2, which is the left shoulder width in feet from the left edge of the travel lane to the median. The default value is 2 feet, and the left shoulder width must be less than or equal to 16 feet.

Distance Y3 (Cell L33): The input for cell L33 is Distance Y3, which is the right shoulder width in feet from the right edge of the travel lane to the edge of the traffic control devices. The traffic control devices can be cones, concrete barriers, or other means. The default value is 6 feet, and the right shoulder width must be less than or equal to 16 feet.

The second part of the GeoCond worksheet is steps 2–7, which consist of 12 input columns, starting with column B and ending with column M. Each row of steps 2–7 belongs to a particular interval to be analyzed. Descriptions of the input columns are as follows:

Start Time (Column B): Column B shows the start time of the particular time interval in question. When the interval length is specified by the user, the start times shown in column B of steps 2–7 are updated automatically by the workbook. Users are not allowed to modify the cells in column B of steps 2–7.

End Time (Column C): Column C shows the end time of the particular time interval in question. When the interval length is specified by the user, the end times shown in column C of steps 2–7 are updated automatically. Users are not allowed to modify the cells in column C of steps 2–7.

Column D: Each cell in column D has a drop-down list that returns either "N" or "Y". By using the dropdown lists, users specify the intervals to be analyzed. The default entry for column D is "N". For all intervals to be analyzed, users should select "Y" from the drop-down lists of the

corresponding cells in column D. For instance, if the interval length is 60 minutes, and a user wants to analyze the interval from 2:00 PM to 3:00 PM, he/she should select “Y” from the dropdown list of the cell in column D that is in the same row as the desired interval (i.e., cell D53). In steps 2–7, data for column D should be entered first . If users do not specify the intervals to be analyzed, the workbook does not display the input cells in columns E–K.

Column E: Each cell in column E has a drop-down list that returns either “N” or “W”. Users select from the drop-down lists the interval during which the crew will be working. The default entry for column E is “N”, which assumes no work activity. For all intervals with work activity, users should select “W” from the drop-down lists in the corresponding cells in column E.

Column F: Each cell in column F has a drop-down list that returns either “N” or “F”. From the drop-down lists, users select the intervals during which a flagger will be present in the work zone. The default entry for column F is “N”, which assumes no flagger. For all intervals with a flagger, users should select “F” from the drop-down lists in the corresponding cells in column F.

Column G: The input in column G is the work zone speed limit. Each cell in column G has a drop-down list that returns either “45” or “55”. In the drop-down lists, users specify the work zone speed limit in mph for the intervals to be analyzed. The default entry for column G is “55”, which assumes a speed limit of 55 mph. If the speed limit for a particular interval is 45 mph, users should select “45” from the drop-down list in the corresponding cell in column G.

Column H: The input for column H is the type of device used to separate the activity area from the traffic. Each cell in column H has a drop-down list that returns either “C” or “O”. Column H requires input data only for the intervals with work activity. From the drop-down lists, users specify whether the work zone has concrete barriers or other devices (cones, drums, etc.) to separate the activity area from the traffic. The default entry for column H is “C”, which assumes concrete barriers separate the activity area from the traffic. If other devices such as cones and drums separate the traffic from the activity area, users should select “O” from the drop-down list in the corresponding cell in column H. For intervals with no work activity, users are not allowed to enter data in column H.

Column I: The input for column I is the work intensity. Each cell in column I has a drop-down list that returns either “L”, “M”, or “H”. Similar to column H, column I also requires input data only for the intervals with work activity. In the drop-down lists, users specify the level of work intensity for the intervals to be analyzed. The default entry for column I is “M”, which assumes moderate work intensity. If work intensity is high during a particular interval, users should select “H” from the drop-down list of the corresponding cell in column I. Likewise, if work intensity is low during a particular interval, users should select “L” from the drop-down list of the corresponding cell in column I. For the intervals with no work activity, users are not allowed to enter data in column I. Users can refer to Section 7.2.1.2 of Benekohal, Ramezani, and Avrenli (2010) for detailed definitions of low, moderate, and high work intensity. Summary of work intensity values are provided in Appendix D of the current report.

Column J: Sometimes, there may be additional speed reduction treatment in the work zone, such as police presence, speed photo enforcement, changeable message signs, etc. If there is an additional speed reduction treatment in the work zone during a particular interval, users select the treatment from the drop-down menu in the corresponding cell of column J. The estimated mean speed reductions due to the selected treatment will be taken from Table D.4 in Appendix D. If no additional speed reduction treatments are used, column J should be left blank.

Column K: If there are other speed-reducing factors not considered so far, users enter the estimated speed reduction due to those factors in column K. Such factors can be inclement

weather conditions, temporarily reduced lane/shoulder width, etc. If there are no such other factors, column K should be left blank.

Column L: Each cell in column L has a drop-down list that returns either “N” or “Y”. Column L requires input data for a particular interval only if the traffic is to be stopped temporarily during that interval. The default entry for column L is “N”, which assumes that the traffic is not to be stopped temporarily. If the traffic is to be stopped temporarily during a particular time interval, users should select “Y” from the drop-down list in the corresponding cell in column L.

Column M: For the intervals during which the traffic is to be stopped temporarily, users should enter the duration in minutes into the corresponding cells in column M. The duration entered in a particular cell in column M should be less than or equal to the interval length. For instance, if the interval length is 5 minutes, then the maximum allowable input for a particular cell in column E is 5 minutes. The program assumes that stoppage happens in the beginning of the interval and speed changes instantaneously.

If the traffic is not to be stopped temporarily in a particular interval, users must not enter data into the corresponding cell in column L.

A.2 Input Data for the TrafficInfo Worksheet

The worksheet consists of two parts. The first part is related primarily to the passenger car equivalent (PCE), volume variation within intervals, and an average daily traffic (ADT) column if the interval length selected in ”GeoCond” worksheet is 60 minutes.

PCE for Heavy Vehicles (Cell B3): The input for cell B3 is the PCE for heavy vehicles, which is defined in HCM 2010 as the “the number of passenger cars that are displaced by a single heavy vehicle of a particular type under prevailing roadway, traffic, and control conditions.” HCM 2010 suggests a PCE of 1.5 for level terrain, 2.5 for rolling terrain, and 4.5 for mountainous terrain. Cell B3 has a drop-down list that returns 1.5, 2.5, or 4.5. The default value is 1.5. If the PCE is computed for a specific condition and differs from the values provided in the drop-down list, users are allowed to enter the computed value in cell B3. The maximum allowable entry is 7.0, as suggested by HCM 2010. The minimum allowable entry is 1.0.

PCE for Recreational Vehicles (Cell C3): The input for cell C3 is the passenger car equivalent (PCE) for recreational vehicles, which is defined in HCM 2010 as the “the number of passenger cars that are displaced by a single recreational vehicle of a particular type under prevailing roadway, traffic, and control conditions.” HCM 2010 suggests a PCE of 1.2 for level terrain, 2.0 for rolling terrain, and 4.0 for mountainous terrain. Cell C3 has a drop-down list that returns 1.2, 2.0, or 4.0. The default value is 1.2. If the PCE is computed for a specific condition and differs from the values provided in the drop-down list, users are allowed to enter the computed value in cell C3. The maximum allowable entry is 6.0 as suggested by the HCM 2010. The minimum allowable entry is 1.0.

Cell D3: This input cell becomes available if the interval length selected in step 1 of the GeoCond worksheet is either 30 or 60 minutes. Then, users indicate whether there is volume variation within the interval using the dropdown menu in cell D3. The choice is either “N” or “Y”. The default value is “N”, which means that the traffic volume within each interval is uniform, which requires users to enter the traffic volume for the whole interval. When “Y” is selected, the worksheet allows users to enter the traffic demand separately for each 15-minute interval.

Cell E3: The input cell becomes available when the interval length selected in the GeoCond worksheet is 60 minutes and ADT data exist rather than hourly volumes. Users should enter "NA" in the cell when hourly volume data are available. When hourly volume data are not available, the percentages provided in the sample ADT distributions (Table A.1) can be used to estimate the distribution of ADT over 24 hours. The percentages are for a suburban interstate highway near a mid-size city. Direction 1 has a distinct peak in the morning, while direction 2 has a peak in the afternoon. Users select direction 1 or 2 to estimate hourly volumes for the project.

Cell F3: For this cell, users must determine the direction of analysis when ADT is entered in Cell E3. There are two choices: direction 1 or 2. Once a direction is selected in cell F3, the corresponding ADT distribution is used to estimate arriving volume.

The following table and figure show the distribution of ADT for directions 1 and 2. These ADT data are based on the data collected from a two-lane freeway and may be used for highways with similar traffic distribution. Moreover, as illustrated in Figure A.1, the percentage of ADT in the morning (7:30 AM) is the highest for direction 1. The same situation exists in the evening (4:30 PM) for direction 2. Therefore, it is recommended to use direction 1 when the highest volume happens in morning and to use direction 2 when the peak hour is in the evening.

Table A.1. ADT Distributions for Direction 1 and 2

	Direction 1	***Direction 2***
Mid Time	**% ADT**	**% ADT**
12:30 AM	0.5%	0.7%
1:30 AM	0.3%	0.4%
2:30 AM	0.3%	0.3%
3:30 AM	0.4%	0.4%
4:30 AM	1.0%	0.8%
5:30 AM	3.0%	2.5%
6:30 AM	7.8%	4.6%
7:30 AM	10.6%	5.4%
8:30 AM	7.7%	4.6%
9:30 AM	5.9%	4.3%
10:30 AM	5.6%	4.6%
11:30 AM	5.7%	5.3%
12:30 PM	5.5%	5.5%
1:30 PM	5.4%	5.7%
2:30 PM	6.2%	6.8%
3:30 PM	6.8%	9.8%
4:30 PM	7.7%	10.6%
5:30 PM	6.4%	9.5%
6:30 PM	3.9%	5.7%
7:30 PM	2.6%	3.9%
8:30 PM	2.3%	3.2%
9:30 PM	1.8%	2.3%
10:30 PM	1.4%	1.7%
11:30 PM	1.1%	1.2%
Sum	**1.00**	**1.00**

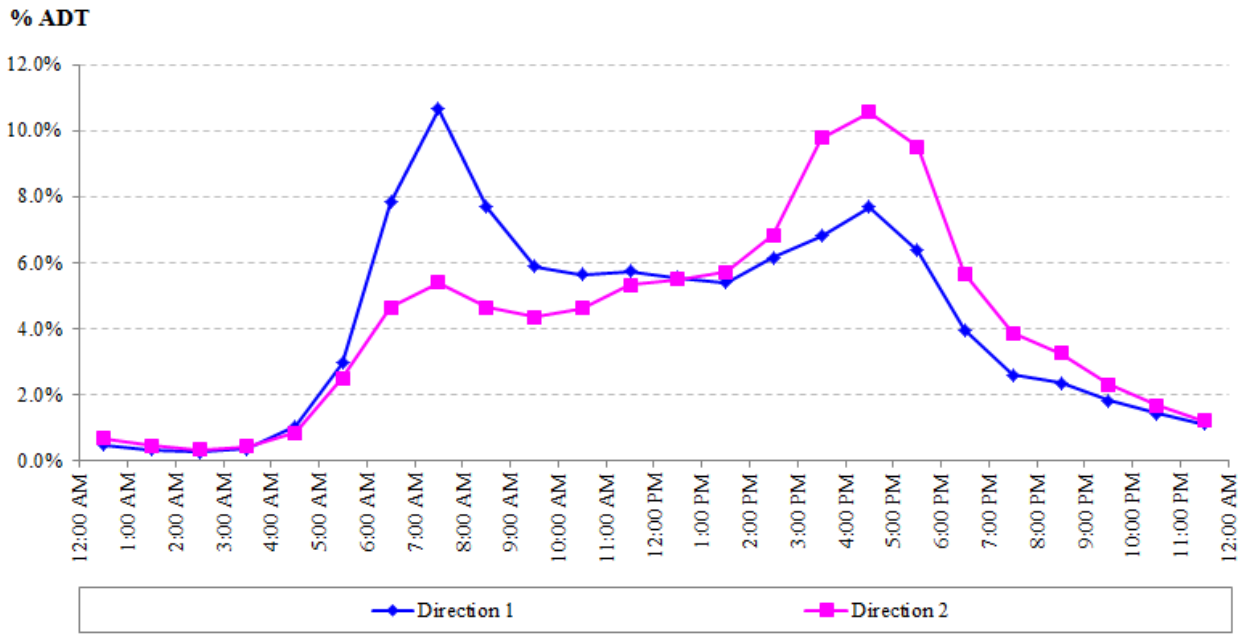

Figure A.1. ADT distribution for a suburban interstate highway with two lanes per direction.

The second part of the TrafficInfo worksheet is steps 9–10, which involve up to nine input columns as follows:

Start Time (Column B): Column B of step 7 is the same as column B of steps 2–6. Users are not allowed to modify the cells in column B of step 7.

End Time (Column C): Column C of step 7 is the same as column C of steps 2–6. Users are not allowed to modify the cells in column C of step 6.

Percentage of Single-Unit Trucks (Column D): The input for column D is the percentage of single-unit trucks. Single-unit trucks have more than four tires touching the pavement (HCM 2010), so the percentage of single-unit trucks excludes vans and pickup trucks. Users are not allowed to enter data into column D for the intervals that are not selected for analysis in steps 2–6.

Percentage of Combination Trucks (Column E): The input for column E is the percentage of combination trucks. According to AASHTO (2011), combination trucks consist of "a single-unit truck with a full trailer, a truck tractor with a semitrailer, or a truck tractor with a semitrailer and one or more full trailers." Users are not allowed to enter data into column E for the intervals that are not selected for analysis in steps 2–6.

Percentage of Recreational Vehicles (Column F): The input for column F is the percentage of recreational vehicles. According to AASHTO (2011), recreational vehicles consist of "motor homes, cars with camper trailers, cars with boat trailers, motor homes with boat trailers, and

motor homes pulling cars." Users are not allowed to enter data into column F for the intervals that are not selected for analysis in steps 2–6.

Expected Traffic Volume (Column G): If the interval length (see Section A.1 for the definition of interval length) is greater than or equal to 30 minutes and option "Y" is selected in cell D3, the input for column G is the expected traffic volume (vehicles) for the first 15-minute interval. Otherwise, the input for column G is the expected traffic volume (vehicles) for the corresponding interval. Users are not allowed to enter data into column G for the intervals that are not selected for analysis in steps 2–6.

Expected Traffic Volume for the Second 15-min (Column H): If the interval length (see Section A.1 for the definition of interval length) is greater than or equal to 30 minute and option "Y" is selected in cell D3, the input for column H is the expected traffic volume in (veh) for the second 15-minute interval. Otherwise, column H is hidden and is not used in calculations. Users are not allowed to enter data into column H for the intervals that are not selected for analysis in steps 2–6.

Expected Traffic Volume for the Third 15-min (Column I): If the interval length (see Section A.1 for the definition of interval length) is equal to 60 minutes and option "Y" is selected in cell D3, the input for column I is the expected traffic volume in (veh) for the third 15-minute interval. Otherwise, column I is hidden and is not used in calculations. Users are not allowed to enter data into column I for the intervals that are not selected for analysis in steps 2–6.

Expected Traffic Volume for the Fourth 15-min (Column J): If the interval length (see Section A.1 for the definition of interval length) is equal to 60 minutes and option "Y" is selected in cell D23, the input for column J is the expected traffic volume in (veh) for the fourth 15-minute interval. Otherwise, column J is hidden and is not used in calculations. Users are not allowed to enter data into column J for the intervals that are not selected for analysis in steps 2–6.

A.3 Input Data for the UserComp Worksheet

This worksheet has nine input cells, described as follows:

Average Number of Occupants in Each Passenger Car (Cell B4): The input for cell B4 is the average number of occupants in each passenger car. The default is 1.25 passengers/car. The minimum and the maximum allowable entries are 1 and 5 passengers/car, respectively.

Average Number of Occupants in Each Recreational Vehicle (Cell C4): The input for cell C4 is the average number of occupants in each recreational vehicle. The default is 2.00 passengers/recreational vehicle. The minimum and the maximum allowable entries are 1 and 5 passengers/recreational vehicle, respectively.

Hourly Delay Cost for a Single-Unit Truck (Cell D4): The input for cell D4 is the average hourly delay cost for a single-unit truck in $/hour. The default is $70/hour. The minimum and the maximum allowable entries are $20 and $200/hour, respectively.

Hourly Delay Cost for a Combination Truck (Cell E4): The input for cell E4 is the average hourly delay cost for a combination truck in $/hour. The default is $90/hour. The minimum and the maximum allowable entries are $20 and $200/hour, respectively.

Hourly Delay Cost for a Recreational Vehicle (Cell F4): The input for cell F4 is the average hourly delay cost for a recreational vehicle in $/hour. The default is $20/hour. The minimum and the maximum allowable entries are $10 and $100/hour, respectively.

Hourly Delay Cost for a Passenger Car (Cell G4): The input for cell G4 is the average hourly delay cost for a passenger car in $/hour. The default is $20/hour. The minimum and the maximum allowable entries are $10 and $100/hour, respectively.

Speed Limit Outside of the Work Zone (Cell H4): The input for cell H4 is the speed limit (mph) outside of the work zone. The choices are 55, 65, 70, 75 mph.

In addition to the aforementioned input cells, the UserComp worksheet has two more input columns in the Results section. Those input columns are defined as follows:

Start Time (Column B): Column B of the Results section is the same as column B of steps 2–6. Users are not allowed to modify the cells in column B of step 7.

End Time (Column C): Column C of the Results section is the same as column C of steps 2–6. Users are not allowed to modify the cells in column C of step 7.

APPENDIX B DESCRIPTION OF THE OUTPUT DATA

This section offers an in-depth explanation of the output that the workbook returns. The following subsections involve detailed description of the output obtained from each worksheet. The output data described in the following subsections are obtained only if users enter the required input data properly. Wrong or missing input data lead to error messages that are described in the Troubleshooting section, Appendix C.

B.1 Output Data from the GeoCond Worksheet

The outputs for step 1 are as follows:

Speed Reduction Due to Lane Width (Cell M33): The output in cell M33 is the estimated speed reduction in mph due to lane width. It is computed based on Table B.1.

Speed Reduction Due to Right Shoulder Width (Cell N33): The output in cell N33 is the estimated speed reduction in mph due to right shoulder width. It is computed based on Table B.1.

Speed Reduction Due to Left Shoulder Width (Cell O33): The output in cell O33 is the estimated speed reduction in mph due to left shoulder width. It is computed based on Table B.1.

The other part of the GeoCond worksheet consists of steps 2–7. In that part, users obtain the output data from six output columns. Each row corresponds to a particular interval. The workbook returns no output for the intervals not selected for analysis. The six output columns are described as follows:

Free-Flow Speed (Column N): The output in column N is the free-flow speed in mph. The free-flow speed is computed without considering the speed-reducing effects such as narrower-than-ideal lane width, work intensity, etc. If the work zone speed limit is 55 mph, column N returns a free-flow speed of 62 mph. If the work zone speed limit is 45 mph and there is no flagger, column N returns a free-flow speed of 55 mph. If the work zone speed limit is 45 mph and there is a flagger, column N returns a free-flow speed of 43 mph.

Speed Reduction Due to Work Intensity (Column O): The output in column O is the estimated speed reduction in mph due to work intensity. It is computed based on Table D.4 in Appendix D for short-term work zones and Table D.5 for long-term work zones.

Adjusted Free-Flow Speed (Column P): The output in column P is the adjusted free-flow speed in mph. The adjusted free-flow speed is computed based on Equation 1 in Appendix D. Unlike the free-flow speed shown in column N, the adjusted free-flow speed is computed by considering the speed-reducing effects of work intensity, less-than-ideal lane/shoulder width, additional speed reduction treatments (if they exist), and other factors.

Maximum Flow Rate (Column Q): The output in column Q is the estimated maximum flow rate in passenger cars per hour per lane (pcphpl) that can be maintained in the work zone under the prevailing conditions. The maximum flow rate is computed based on the four-regime speed-flow curves shown in Figures D.1–D.3 in Appendix D.

Speed at Maximum Flow Rate (Column R): The output in column R is the estimated operating speed (mph) corresponding to the maximum flow rate for that work zone. The operating speed at the maximum flow rate is computed based on the four-regime speed-flow curves shown in Figures D.1–D.3 in Appendix D.

Prevailing Capacity (Column S): Prevailing capacity is different from the maximum flow rate when traffic is asked to stop temporarily, as determined in input columns L and M. In this case, it is computed based on Equation 2 in Appendix D.

B.2 Output Data from the TrafficInfo Worksheet

The outputs of the TrafficInfo worksheet are as follows:

Heavy Vehicle Adjustment Factor (Column K): The output in column K is the heavy vehicle adjustment factor. It is computed based on Equation 3 in Appendix D.

Adjusted Demand (Column L): The output in column L is the adjusted demand in passenger cars per hour per lane (pcphpl). It is computed based on Equation 6 in Appendix D. If the interval length (see Section A.1 for the definition of interval length) is greater than or equal to 30 minutes and option "Y" is selected in cell D3, the output in column L is the adjusted demand in (pcphpl) for the first 15-minute interval. Otherwise, the output in column L is the adjusted demand in (pcphpl) for the corresponding interval.

Adjusted Demand for the Second 15-min (Column M): If the interval length (see Section A.1 for the definition of interval length) is greater than or equal to 30 minutes and option "Y" is selected in cell D3, the output in column M is the adjusted demand in (pcphpl) for the second 15-minute interval. Otherwise, column M is hidden and does not return any output.

Adjusted Demand for the Third 15-min (Column N): If the interval length (see Section A.1 for the definition of interval length) is equal to 60 minutes and option "Y" is selected in cell D3, the output in column N is the adjusted demand in (pcphpl) for the third 15-minute interval. Otherwise, column N is hidden and does not return any output.

Adjusted Demand for the Fourth 15-min (Column O): If the interval length (see Section A.1 for the definition of interval length) is equal to 60 minutes and option "Y" is selected in cell D3, the output in column O is the adjusted demand in (pcphpl) for the fourth 15-minute interval. Otherwise, column O is hidden and does not return any output.

Adjusted Capacity (Column T): The output in column T is the adjusted capacity in vehicles per hour per lane (vphpl). It is computed based on Equation 4 in Appendix D.

B.3 Output Data from the UserComp Worksheet

The UserComp worksheet returns output in 13 columns under the Results section. Detailed definitions of the 13 output columns are as follows:

No. of Study Period (Column D): The output in column D is the number of the study period analyzed. In the workbook, a study period consists of consecutive intervals selected for analysis. The workbook combines all consecutive intervals into a study period. For further information on the definition of study period, please refer to Chapter 2 of the user guide.

No. of Vehicles in Queue (Column E): For a given interval, the output in column E is the number of vehicles in the queue at the end of the interval. It is computed based on Equation 7 in Appendix D.

Average Spacing Between Vehicles in Queue (Column F): For a given interval, the output in column F is the spacing in feet between vehicles in the queue. It is computed based on Equation 8. If there is no queue at the end of a particular interval, column F returns "—" for that interval.

Occupied Length of Queued Vehicles Stacked in a Single Lane (Column G): For a given interval, the output in column G is the occupied length in feet if the queued vehicles are stacked in a single lane at the end of the interval. It is computed based on Equation 9 in Appendix D.

Distance Queue Reached (Column H): For a given interval, the output in column H is the length in feet that the queue reached at the end of the interval. Depending on the work zone geometry, it is computed based on either Equation 11 or 12 in Appendix D.

Average Speed (Column I): The output in column I is the average speed in mph. When the entire interval is undersaturated, the average speed for a given adjusted demand is found from the four-regime speed-flow curves shown in Figures D.1–D.3 in Appendix D. When the entire interval is oversaturated (there is a queue in the work zone during the interval), the average speed is assumed to be equal to the speed at the maximum flow rate. When the interval is partially oversaturated, the average speed is computed as the weighted average of the speeds in that interval. The weight for each traffic condition (undersaturated or oversaturated) is the number of vehicles that experience that particular condition in the middle of the time interval during which the particular condition exists.

Average Delay per Vehicles in Oversaturated Conditions (Column J): For a given interval, the output in column J is the average delay in hours per vehicle in oversaturated conditions. Depending on the speed limit in the vicinity of the work space, it is computed based on either Equation 16 or 17. Oversaturated conditions are defined as the total traffic demand being greater than the work zone capacity. For a given interval, if undersaturated conditions exist throughout the entire interval, column K returns "—" for that interval.

Average Delay per Vehicles in Undersaturated Conditions (Column K): For a given interval, the output in column K is the average delay in hours per vehicle in undersaturated conditions. It is computed based on Equation 17. For a given interval, if oversaturated conditions exist throughout the entire interval, column K returns "—" for that interval.

Delay Experienced by All Vehicles (Column L): For a given interval, the output in column L is the total delay in vehicle-hour. It is computed based on Equation 20.

Users' Costs for Severe Queue (Column M): For a given interval, the output in column M is total users' costs when there is a severe queue. A severe queue is defined as when the average speed of vehicles in the queue is below 20 mph for a speed limit of 45 mph, or is below 25 mph for a speed limit of 55 mph. Users' costs are computed based on Equation 21.

Users' Costs for Moderate Queue (Column N): For a given interval, the output in column N is total users' costs when there is a moderate queue. A moderate queue is defined as when the average speed of vehicles in the queue is 20 to 35 mph for a speed limit of 45 mph, or 25 to 40 mph for a speed limit of 55 mph. Users' costs are computed based on Equation 21.

Users' Costs for Light Queue (Column O): For a given interval, the output in column O is total users' costs when there is a light queue. A light queue is defined as when the average speed of vehicle in the queue is 35 to 45 mph for a speed limit of 45 mph, or 40 to 55 mph for a speed limit of 55 mph. Users' costs are computed based on Equation 21.

Users' Costs for All Three Queues (Column P): For a given interval, the output in column P is total users' costs in US$ for all types of queues. It is computed based on Equation 21.

In addition to the aforementioned output columns, the Results of Users' Costs section has six additional output cells, described as follows:

Maximum Distance Queue Reached (Cell H299): The input in cell H299 is the maximum back of queue reached, in feet, among all analyzed intervals. In other words, it is the maximum value in the entire column H.

Sum Delay (Cell L299): The output in cell L299 is the sum of the total delays in vehicle hours for all intervals. It is the summation of all total delay values in column L.

Sum SQ (Cell M299): The output in cell M299 is the sum of the users' costs in US$ when there is severe queue condition. It is the summation of all users' costs values in column M.

Sum MQ (Cell N299): The output in cell N299 is the sum of the users' costs in US$ when there is moderate queue condition. It is the summation of all users' costs values in column N.

Sum LQ (Cell O299): The output in cell O299 is the sum of the users' costs in US$ when there is light queue condition. It is the summation of all users' costs values in column O.

Sum All (Cell P299): The output in cell P299 is the sum of the users' costs in US$ for all three types of queue. It is the summation of all users' costs values in column P.

B.4 Output Data from the Output Summary Worksheet

The Output Summary worksheet does not require any input data. In the Output Summary worksheet, some output data are tabulated for each study period rather than for each interval. A study period is the combination of consecutive intervals analyzed. A detailed definition of study period is provided in Chapter 2.

There are ten output columns in the Output Summary worksheet, and they are described as follows:

Start Time (Column C): Column C provides the start time of each study period.

End Time (Column D): Column D provides the end time of each study period.

No. of Study Period (Column E): Column E returns the number of each study period. To check which time interval belongs to which study period, users can refer to column D of the Results section in the UserComp worksheet.

Maximum Distance Queue Reached (Column F): Column F returns the maximum distance that the queue reached, in feet, for each study period.

Minimum Speed in Queue (Column G): Column G returns the minimum speed for each study period when demand exceeds capacity.

Start of Congestion (Column H): If there is congestion in a particular study period, column H returns the estimated time when the congestion starts in that period. The start of congestion is assumed to be the time from which total demand exceeds work zone capacity. It is assumed that the traffic arrival/departure rate is uniform within each interval. If there is no congestion in a particular study period, column H returns "—" for that study period.

End of Congestion (Column I): If there is congestion in a particular study period, column I returns the estimated time when the congestion ends in that period. The end of congestion is assumed to be the time at which there are no more vehicles left in the queue. It is assumed that the traffic arrival/departure rate is uniform within each interval.

If there is no congestion in a particular study period, column I returns "—" for that study period. Likewise, if there is congestion in a particular study period but the queue does not clear before the end of the study period, column I returns "—" for that study period.

Total Delay for the Study Period (Column J): Column J returns the total delay in vehicle-hours for each study period.

Total Users' Costs in Severe Queue Conditions for the Study Period (Column K): Column K returns the total users' costs in US$ for each study period when there is a severe queue, based on the IDOT definition in Section B.6 of this appendix.

Total Users' Costs in Moderate Queue Conditions for the Study Period (Column L): Column L returns the total users' costs in US$ for each study period when there is a moderate queue, based on the IDOT definition in Section B.6 of this appendix.

Total Users' Costs in Light Queue Conditions for the Study Period (Column M): Column M returns the total users' costs in US$ for each study period when there is a light queue, based on the IDOT definition in Section B.6 of this appendix.

Total Users' Costs for the Study Period (Column N): Column N returns the total users' costs in US$ for each study period for all three types of queue. Definitions of the three types of queue are provided in Section B.6 of this appendix.

B.5 Output from the Queue-Speed Plot Worksheet

The only output of this worksheet is a chart displaying the distance that the queue reached and the average speed for each interval.

B.6 Output Data from the IDOT Criteria Worksheet

This worksheet includes the variables for checking the IDOT mobility criteria. According to the Work Zone Safety and Mobility Rule (October 12, 2007), the following mobility criteria should be satisfied:

1. "Delays caused by work zones should not exceed more than five (5) minutes per mile of project length with a maximum of thirty (30) minutes above the normal recurring traffic delay"; and

2. “Queues caused by work zones should be no more than 1.5 miles beyond pre-existing queues.”

To verify the criteria, the following outputs are reported:

Average Speed (Column C): This is the same as the average speed computed in Column I of the UserComp worksheet. Based on this computed average speed, three levels of queue conditions are defined, and each level is denoted by a particular color as displayed in Table B.1.

Table B.1. Definitions of Queue Levels

Queue level	Speed limit of 45 mph		Speed limit of 55 mph	
	Definition	Color code	Definition	Color code
Light queue	35 ≤ Speed < 45	Blue	40 ≤ Speed < 55	Blue
Moderate queue	20 ≤ Speed < 35	Pink	25 ≤ Speed < 40	Pink
Severe queue	Speed < 20	Burgundy	Speed < 25	Burgundy

Delay in Minutes per Mile of Project Length (Column D): This is computed as the average delay divided by project length. The distance from the first 55-mph speed limit sign to the last temporary traffic control device is considered the project length. This length is computed based on the input data provided in step 1 of the GeoCond worksheet. When the computed value exceeds 5 minutes, the cell is highlighted in red, indicating that this IDOT mobility criterion is not satisfied.

Distance Severe Queue Reached (Column E): For a given interval, the output in column E is the length that the severe queue reached at the end of the interval. When it exceeds 1.5 miles, the cell is highlighted in red, indicating that this IDOT mobility criterion is not satisfied.

Distance Moderate Queue Reached (Column F): For a given interval, the output in column F is the length that the moderate queue reached at the end of the interval. When it exceeds 1.5 miles, the cell is highlighted in red, indicating that this IDOT mobility criterion is not satisfied.

Distance Light Queue Reached (Column G): For a given interval, the output in column G is the length that the light queue reached at the end of the interval. When it exceeds 1.5 miles, the cell is highlighted in red, indicating that this IDOT mobility criterion is not satisfied.

APPENDIX C TROUBLESHOOTING

This appendix describes some possible errors that users might make when entering data into the workbook.

C.1 Troubleshooting for GeoCond Worksheet

Step 1: In step 1, if users do not fill out any of the input cells from C33–J33, the worksheet displays the error message shown in red in the figure below (an exception to this requirement is that if the work zone speed limit is 55 mph during all intervals, users must not input any data in cell F33).

When the worksheet displays this error message, users must enter the missing data to be able to proceed to steps 2–7. Otherwise, the workbook will not be able to perform the users' costs calculations.

Select the interval length (min) for analysis	Distance a (ft)	Distance b (ft)	Distance c (ft)	Distance d (ft)	Distance e (ft)	Lane width f (ft) (Default is 12 ft)	Right shoulder width g (ft) (Default is 6 ft)	Left shoulder width h (ft) (Default is 2 ft)
	3.500		3.500	2.000	3.000	11.0	1.0	2.0

ERROR! INPUT FOR STEP 1 NOT COMPLETE! INPUT ALL DATA INTO CELLS C26 THROUGH J26.

Steps 2–7: Error in Speed Limit: In this step, if users specify the speed limit as 55 mph for a particular interval in column G, and if they also specify flagger presence by selecting "F" for the same interval in column F, the worksheet returns "*ERROR!" in column N, and the following error message is displayed at the bottom of the table:

*ERROR!
WZ SPEED LIMIT IN COLUMN G CAN'T BE 55 MPH WHEN FLAGGER IS SPECIFIED IN COLUMN F.

This error occurs because when there is a flagger in the work zone, the speed limit is always 45 mph; thus, it should not be entered as 55 mph for any intervals with a flagger.

F	G	H	I	J	K	L	M	N
Put "F" if flagger is present.	Put "45" if the speed limit is not 55 mph.	Put "C" if concrete barriers are used, and "O" for other devices. *(e.g. cones, barrels).*	Put "L" for low work intensity, "M" for moderate work intensity, "H" for high work intensity.	If there is any additional speed reduction due to treatments given in Table 6 of the manual, enter here. *Otherwise, leave it blank.*	If there is any additional speed reduction due to any other factors not considered so far, enter here. *Otherwise, leave it blank.*	Put "Y" if the traffic will be asked to stop temporarily in this interval.	For how many minutes will the traffic be stopped in this interval?	Free flow speed (mph)
N	55					N		62.0
F	45	O	L	4.5		N		43.0
F	55	O	L	4.5		N		ERROR!
N	55					N		62.0

Steps 2–7: Error in Stoppage Time: In this step, if users select "Y" in column L for a particular interval, they must enter the duration for which the traffic is to be temporarily stopped for the same interval in column M. If users do not enter that duration for that interval in column M, the workbook returns an error message for that interval in column S. The error message reads "ERROR! Columns M and L don't match! Enter the duration that traffic is stopped in column M." To fix the error, users must enter in column M the duration for which the traffic is to be stopped for that interval.

L	M	N	O	P	Q	R	S
Put "Y" if the traffic will be asked to stop temporarily in this interval.	For how many minutes will the traffic be stopped in this interval?	Free flow speed (mph)	Speed reduction due to work intensity (mph)	Adjusted free-flow speed (mph)	Maximum flow rate (pcphpl)	Speed at maximum flow rate (mph)	Prevailing capacity (pcphpl)
N		62.0		56.5	1,657	48.1	1,657
N		43.0	8.0	25.0	1,022	18.9	1,022
Y		43.0	8.0	25.0	1,022	18.9	ERROR! Columns M and L don't match! Enter the duration that the traffic is stopped in column M
N		62.0		56.5	1,657	48.1	1,657

C.2 Troubleshooting for Traffic Info Worksheet

Step 8: An error users might make in this step is to enter an unrealistic PCE value in cell B3 and/or C3. According to the *Highway Capacity Manual* (HCM 2010; Transportation Research Board 2010), the maximum PCE value is 7.0 and 6.0 for heavy vehicles and recreational vehicles, respectively. If the PCE value entered in cell B3 exceeds 7.0 and/or if the PCE value entered in cell C3 exceeds 6.0, an error message appears, as shown in the following figure. To fix this error, users should avoid entering PCE values greater than 7.0 in cell B3 and greater than 6.0 in cell C3.

B	C	D
PCE for heavy vehicles (Default is 1.5)	PCE for recretional vehicles (Default is 1.2)	Put "Y" if there is variation in traffic demand within an interval
8.0	7.0	N

ERROR! THE PCE VALUES YOU ENTERED INTO B3 & C3 CAN'T EXCEED THE HCM VALUES OF 7.0 & 6.0, RESPECTIVELY!

Likewise, the minimum value of the PCE entered in cells B3 and C3 cannot be less than 1.0. If the PCE value entered either in cell B3 or C3 is less than 1.0, the worksheet displays the error message shown in the following figure:

B	C	D
PCE for heavy vehicles (Default is 1.5)	PCE for recretional vehicles (Default is 1.2)	Put "Y" if there is variation in traffic demand within an interval
0.5	0.5	N

ERROR! THE PCE VALUES YOU ENTERED INTO B3 & C3 CAN'T BE LESS THAN 1.0!

Steps 9–10: In this step, if there are missing data for the intervals to be analyzed, the workbook produces error messages. For instance, if users do not enter the percentage of single-unit trucks in column D and/or the percentage of combination trucks in column E for a particular interval, the worksheet returns an error message for that interval in column K. The error message reads, “ERROR! Enter data in columns D and/or E.” Likewise, if users do not enter the percentage of recreational vehicles for a particular interval, the workbook shows an error message for that interval in column K. The error message reads “ERROR! Enter data in column F.” Moreover, if users do not enter the expected traffic volume in column G for a particular interval, the workbook shows an error message for that interval in column L. The error message reads “ERROR! Enter data in column G.”

D	E	F	G	K	L	P	T
Percentage of single-unit trucks (%) *(Default is 5%)*	**Percentage of combination trucks (%)** *(Default is 5%)*	**Percentage of recreational vehicles (%)** *(Default is 0%)*	**Expected traffic volume during the interval (veh)**	**Heavy vehicle adjustment factor**	**Adjusted demand (pcphphl)**	**Average speed (mph)**	**Adjusted capacity (vphpl)**
	5.0%	0.0%	1,200	ERROR! Enter data in columns D and/ or E!	#VALUE!	#VALUE!	#VALUE!
5.0%		0.0%	1,400	ERROR! Enter data in columns D and/ or E!	#VALUE!	#VALUE!	#VALUE!
5.0%	5.0%		1,300	ERROR! Enter data in column F!	#VALUE!	#VALUE!	#VALUE!
5.0%	5.0%	0.0%		0.95	ERROR! Enter data in column G	#VALUE!	#VALUE!
5.0%	5.0%	0.0%	1,100	0.95	1,155	#VALUE!	#VALUE!

APPENDIX D STEP-BY-STEP APPROACH

The software algorithm is an updated version of the methodology proposed by Benekohal, Ramezani, and Avrenli (2010). The primary difference is that step 11 has been modified. In particular, shockwave theory is used to estimate queue and delay when there is more than one queue in the work zone. However, in this appendix, the simplified version of the modified algorithm is presented for when there is only one queue. More details on the algorithm are provided in Appendix E.

It should be noted that in this appendix when the word “queue” is used, it refers to any vehicle going slower than the speed limit in a work zone.

Given the input data, the algorithm first estimates the work zone capacity under the prevailing geometric and traffic control conditions. The capacity estimation is achieved with the four-regime speed-flow curves suggested by Benekohal, Ramezani, and Avrenli (2010). Once the traffic demand and composition have been entered, the workbook estimates the queue length, delay, and users’ costs for each interval of analysis.

The step-by-step approach consists of the following steps:

1. Find the speed reductions due to less-than-ideal lane width (R_{LW}) and lateral clearance (R_{LC}) from Table D.1.

Table D.1. Adjustment Due to Lane Width and Lateral Clearance

Adjustment for lane width				
Lane width (ft)	Reduction in speed (mph)			
12 ft or more	0.0			
11	1.9			
10	6.6			
9	15.0*			
8	25.0*			
Adjustment for left shoulder				
Left shoulder (ft) width	Reduction in speed (mph)			
2 ft or more	0			
1	1			
0	2			
Adjustment for right shoulder				
Right shoulder width (ft)	Reduction in speed (mph)			
	No of Lanes in one direction (without work zone)			
	2	3	4	>= 5
6 ft or more	0	0.0	0.0	0.0
5	0.6	0.4	0.2	0.1
4	1.2	0.8	0.4	0.2
3	1.8	1.2	0.6	0.3
2	2.4	1.6	0.8	0.4
1	3.6	2.0	1.0	0.5
0	3.9	2.4	1.2	0.6

**Based on the authors' best estimate.*

2. Determine the level of work intensity for short-term work zones from Table D.2 and for long-term work zones from Table D.3. In this appendix, “long-term work zone” is a work zone where the activity area is separated from the traffic by concrete barriers, and “short-term work zone” is where the activity area is separated from the traffic by using other devices, such as cones, drums, or similar means.

Table D.2. Work Intensity Table for Short-Term* Work Zones

Lateral distance between the work activity area and the edge of the open lane (ft)	(# of workers) + (# of large construction equipment) in the work activity area														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
9	LO	LO	LO	LO	LO	LO	MO	MO	MO	MO	MO	MO	MO	MO	MO
8	LO	LO	LO	LO	LO	MO	MO	MO	MO	MO	MO	MO	MO	MO	MO
7	LO	LO	LO	LO	MO	MO	MO	MO	MO	MO	MO	MO	MO	MO	MO
6	LO	LO	LO	LO	MO	MO	MO	MO	MO	MO	MO	MO	MO	MO	MO
5	LO	LO	LO	MO	MO	MO	MO	MO	MO	MO	MO	MO	MO	HI	HI
4	LO	LO	MO	MO	MO	MO	MO	MO	MO	MO	HI	HI	HI	HI	HI
3	LO	LO	MO	MO	MO	MO	MO	HI	HI	HI	HI	HI	HI	HI	HI
2	LO	MO	MO	MO	MO	HI	HI	HI	HI	HI	HI	HI	HI	HI	HI
1	MO	MO	HI	HI	HI	HI	HI	HI	HI	HI	HI	HI	HI	HI	HI

LO = Low work intensity MO = Moderate work intensity HI = High work intensity

**In this report, a short-term work zone refers to a work zone where the activity area is separated from the traffic by means of cones, drums, etc.*

Table D.3. Work Intensity Table for Long-Term* Work Zones

Lateral distance between the work activity area and the edge of the concrete barrier closer to the activity area (ft)	(# of workers) + (# of large construction equipment) in the work activity area														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
9	LO	LO	LO	LO	LO	LO	LO	LO	MO	MO	MO	MO	MO	MO	MO
8	LO	LO	LO	LO	LO	LO	LO	MO	MO	MO	MO	MO	MO	MO	MO
7	LO	LO	LO	LO	LO	LO	MO	MO	MO	MO	MO	MO	MO	MO	MO
6	LO	LO	LO	LO	LO	MO	MO	MO	MO	MO	MO	MO	MO	MO	MO
5	LO	LO	LO	LO	MO	MO	MO	MO	MO	MO	MO	MO	MO	MO	MO
4	LO	LO	LO	MO	MO	MO	MO	MO	MO	MO	MO	MO	HI	HI	HI
3	LO	LO	MO	MO	MO	MO	MO	MO	MO	HI	HI	HI	HI	HI	HI
2	LO	MO	MO	MO	MO	MO	HI	HI	HI	HI	HI	HI	HI	HI	HI
1	MO	MO	MO	HI	HI	HI	HI	HI	HI	HI	HI	HI	HI	HI	HI

LO = Low work intensity MO = Moderate work intensity HI = High work intensity

**In this report, a long-term work zone refers to a work zone where the activity area is separated from the traffic by means of concrete barriers.*

3. Find the speed reduction corresponding to the work intensity determined in step 2. Use Table D.4 for short-term work zones and Table D.5 for long-term work zones.

Table D.4. Speed Reduction Due to Work Intensity in Short-Term* Work Zones

Work Intensity	Estimated Speed Reduction Range (mph)	Suggested Speed Reduction (mph)
LOW	6.04 – 10.80	8.00
MODERATE	10.81 – 14.40	12.00
HIGH	14.41 – 19.16	16.00

**In this report, a short-term work zone refers to a work zone where the activity area is separated from the traffic by means of cones, drums, etc.*

Table D.5. Speed Reduction Due to Work Intensity in Long-Term* Work Zones

Work Intensity	Estimated Speed Reduction Range (mph)	Suggested Speed Reduction (mph)
LOW	0.01 – 2.65	2
MODERATE	2.66 – 3.80	3
HIGH	3.81 – 5.93	5

**In this report, a long-term work zone refers to a work zone where the | activity area is separated from the traffic by means of concrete barriers.*

4. Find the speed reduction (mph) due to any treatment by using Table D.6.

Table D.6. Speed Reduction Reported in the Literature

Speed Control Technique	Observed Range of Speed Reduction (mph)	Typical Speed Reduction (mph)
Changeable Message Signs[1]	1.4 – 4.7	3.0
Drone Radar[2]	1.2 – 9.8	2.5
Police Presence[3]	4.3 – 5.0	4.5
Speed Photo Enforcement[3]	3.4 – 7.8	5.0
MUTCD Flagging[4]	3.0 – 12.0*	7.0*
Innovative Flagging[4,**]	4.0 –16.0*	10.0*
Changeable Message Signs with Radar[5]	4.0 – 8.0	5.0
Speed Monitoring Display[5]	4.0 – 5.0	4.0

**When a flagger is present, the authors recommend use of the speed-flow curves for a speed limit of 45 mph and a flagger in the work zone rather than the suggested speed reduction shown in the table.*

***Innovative flagging is the combination of the flagging procedure described in MUTCD with the flagger using the other hand to motion the traffic to slow, and then to point to an adjacent speed limit sign (Garber and Srinivasan 1998).*

[1] Benekohal et al. (1992)
[2] Benekohal et al. (1993)
[3] Benekohal et al. (2008)
[4] Richards et al. (1985)
[5] Mattox et al. (2007)

5. Compute the adjusted free-flow speed by Equation 1:

$$AFFS = FFS - R_{WI} - R_{LW} - R_{LC} - R_T - R_o \qquad (1)$$

Where

AFFS = Adjusted free-flow speed (mph)

FFS = Free-flow speed (when there are no field data, FFS = 62 mph for a site with a speed limit of 55 mph, FFS = 55 mph for a site with a speed limit of 45 mph and without a flagger, and FFS = 43 mph for a site with a speed limit of 45 mph and a flagger)

R_{LW} = Speed reduction due to lane width (mph)

R_{LC} = Speed reduction due to lateral clearance (mph)

R_{WI} = Speed reduction due to work intensity (mph)

R_T = Speed reduction due to treatment (mph)

R_o = Speed reduction due to all other factors that may reduce speed (mph), including those that may cause a flow breakdown

6. Find the speed-flow curve corresponding to the adjusted free-flow speed and read the maximum flow rate (C_{Max}) from the speed-flow curve. Use Figure D.1 for a site with speed limit of 45 mph and a flagger, Figure D.2 for a speed limit of 45 mph without a flagger, and Figure D.3 for a speed limit of 55 mph and flagger.

NOTE

The speed-flow curves were developed using daytime data. Very limited studies are available about nighttime work zone capacity. One Canadian study (Al-Kaisy and Hall, 2000) showed a capacity reduction of up to 8% at night work zones. This seems low based on the authors' personal experiences of driving in work zones at night. A study in Germany (HCM 2010) found that nighttime capacity reduction was up to 25% on four-lane freeways (the study sites did not have work zones).

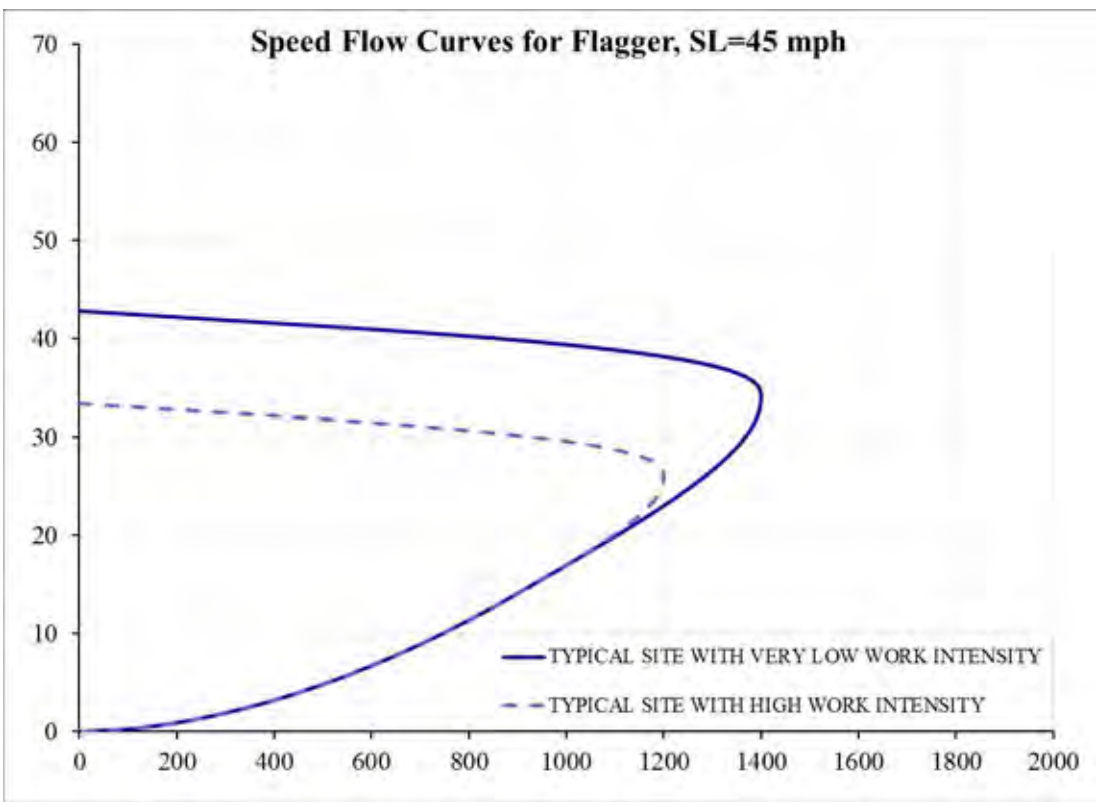

Figure D.1. Speed-flow curve for a site with a speed limit of 45 mph and a flagger.

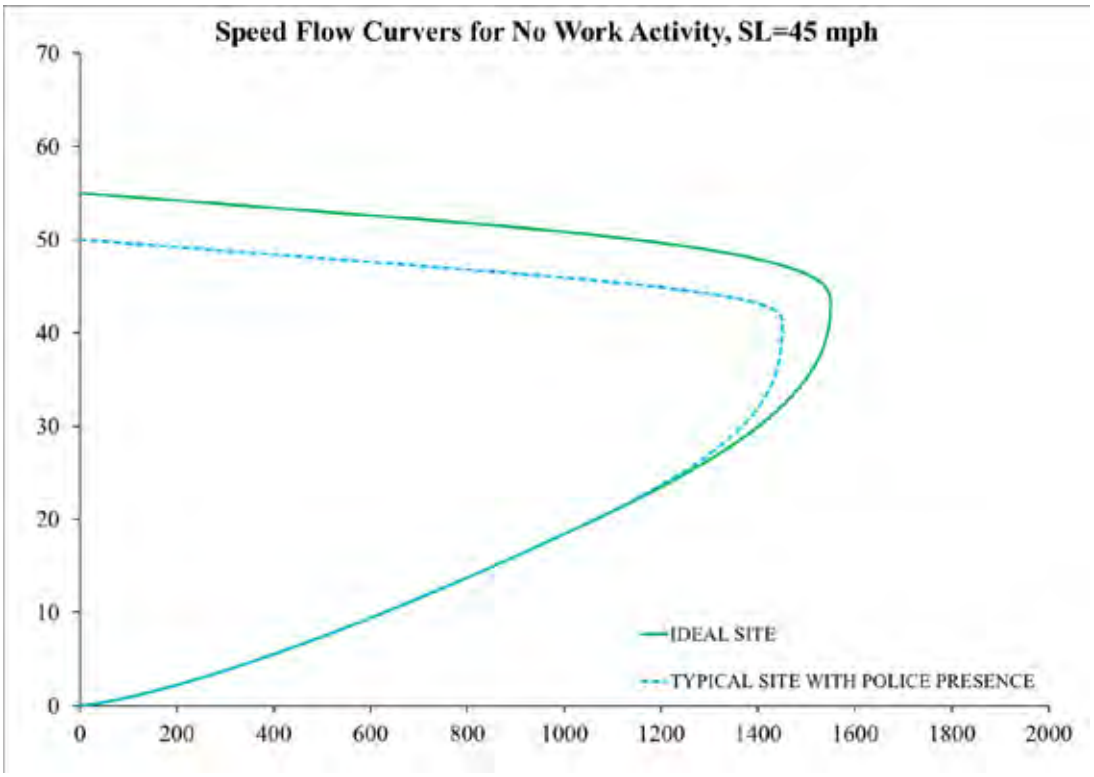

Figure D.2. Speed-flow curve for a site with a speed limit of 45 mph and no flagger.

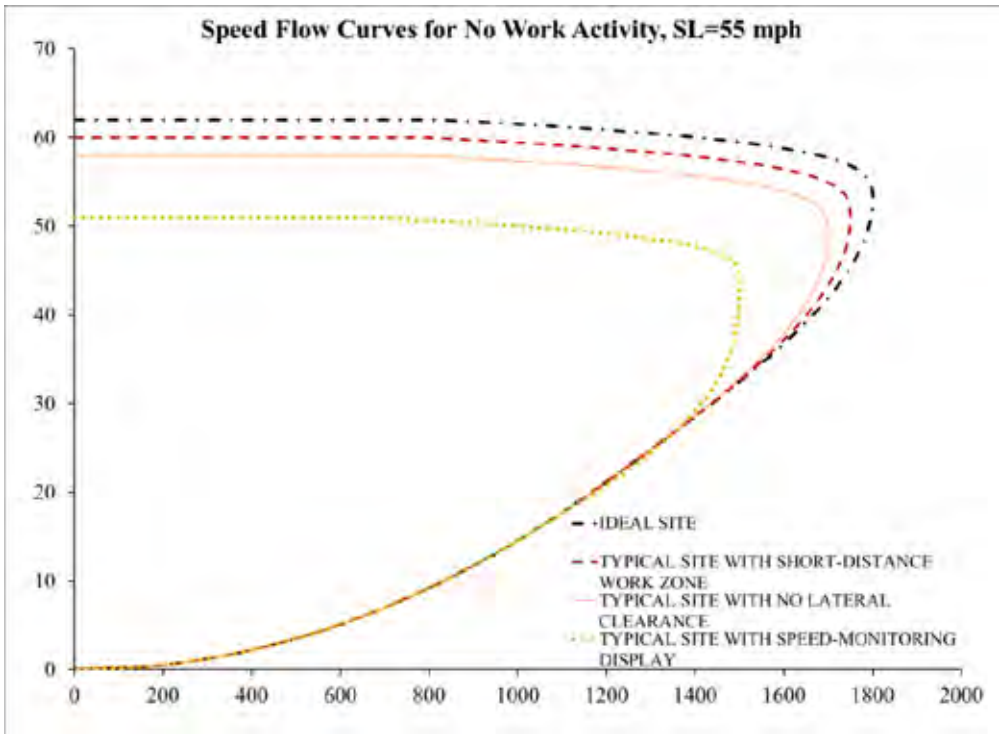

Figure D.3. Speed-flow curve for a site with a speed limit of 55 mph.

7. Find the capacity corresponding to the traffic condition in the work zone by using Equation 2:

$$\text{Capacity} = \begin{cases} C_{\text{Max}} * \dfrac{t}{60} & \text{if traffic is under normal condition} \\ \dfrac{(t - t_1) * C_{Max}}{60}, & \text{When traffic is asked to stop} \end{cases} \quad (2)$$

Where

t = Duration of the interval in minutes

Capacity = Capacity (pcpl) for an interval of length t in the prevailing conditions

C_{Max} = Maximum flow rate (pcphpl)

t_1 = Duration of time in minutes during which traffic is asked to stop temporarily

8. Compute the heavy vehicle adjustment factor as below:

$$f_{\text{HV}} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)} \quad (3)$$

Where

f_{HV} = Heavy vehicle adjustment factor

P_T = Total percentage of trucks (entered as decimal)

E_T = Passenger car equivalence factor for heavy vehicles determined by using Table D.7 when no grade is long enough or steep enough to cause a significant speed reduction on trucks (when no one grade of 3% or greater is longer than 0.25 mi or where no one grade of less than 3% is longer than 0.5 mi); otherwise, PCE should be obtained from HCM 2010

P_R = Percentage of recreational vehicles (entered as decimal)

E_R = Passenger car equivalence factor for recreational vehicles determined by using Table D.7 when no grade is long enough or steep enough to cause a significant speed reduction on trucks (when no one grade of 3% or greater is longer than 0.25 mi or where no one grade of less than 3% is longer than 0.5 mi); otherwise, PCE should be obtained from the HCM 2010

Table D.7. Passenger Car Equivalents

	Type of Terrain		
Passenger Car Equivalence	**Level**	**Rolling**	**Mountainous**
Trucks and Buses	1.5	2.5	4.5
Recreational Vehicles	1.2	2.0	4.0

9. Calculate the adjusted capacity:

$$C_{adj} = \text{Capacity} * f_{HV} \quad (4)$$

Where

C_{adj} = Adjusted capacity (vpl)
Capacity = Capacity (pcpl) for an interval of length t in the prevailing conditions
f_{HV} = Heavy vehicle adjustment factor

10. Find the traffic demand as follows:

$$D_i = n_{i-1} + V_i \quad (5)$$

Where

D_i = Traffic demand for the ith interval (vehicles)
n_{i-1} = The number of vehicles in the queue at the end of the $(i-1)^{th}$ interval (vehicles)
V_i = Volume arriving during the ith interval (vehicles)

Determine the operating speed (U_o). If demand (D_i) is greater than the departure rate ($C_{adj} * N_{op}$), then read the operating speed at the maximum flow rate from the speed-flow curve of the site. Otherwise, read the speed from the corresponding speed-flow curve by entering the passenger car equivalent hourly volume obtained by the Equation 6, on the horizontal axis.

$$V_{PCE} = \frac{Vi}{f_{HV} * N_{op}} \quad (6)$$

Where

V_{PCE} = Passenger car equivalent volume (pcpl)
V_i = Volume arriving during the ith interval (vehicles)
f_{HV} = Heavy vehicle adjustment factor
N_{op} = Number of open lanes in the activity area

11. If arriving volume (V_i) is less than or equal to the departure rate ($C_{adj} * N_{op}$) and the number of the vehicles in the queue at the end of the previous interval is zero ($n_{i-1} = 0$), then d_{qi} = 0, $n_i = 0$, $n_{ci} = 0$, and skip steps 11 and 12. Otherwise, estimate the number of vehicles in the queue at the end of the hour as follows:

$$n_i = \max(0,\ D_i - C_{adj} * N_{op}) \quad (7)$$

Where

n_i = Number of vehicles in the queue at the end of the ith interval
n_{i-1} = Number of vehicles in the queue at the end of the $(i-1)^{th}$ interval
D_i = Total demand in the $(i)^{th}$ interval (vehicles)
C_{adj} = Adjusted capacity of the work zone in vpl
N_{op} = Number of open lanes in the activity area
d_{qi} = Average queuing delay during the ith interval
n_{ci} = Number of queued vehicles in the closed lane at the end of the hour

Compute shockwave speed as follows:

$$S_{Si} = \frac{Q_{qi} - V_i}{\frac{Q_{qi}}{U_{qi}} - \frac{V_i}{U_{Vi}}} * 5280/3600 \quad (8)$$

Where

S_{Si} = Shockwave speed in feet/second during the interval i
Q_{qi} = Within-queue flow rate (vph), which is assumed to be equal to capacity
U_{qi} = Within-queue speed (mph), which is assumed to be equal to speed at capacity
V_i = Arriving volume (vph)
U_i = Speed of arriving volume, which is assumed to be the speed limit outside of the work zone

Compute the stacked length of queue at the end of the interval:

$$Q_{si} = Q_{s(i-1)} + S_{Si} * T \quad (9)$$

Q_{si} = The length of queue at the end of the interval i (feet)
$Q_{s(i-1)}$ = The length of queue at the end of the interval i – 1 (feet)
S_{Si} = Shockwave speed during the interval i (feet/second)
T = The length of interval in seconds

If $n_i > 0$, compute l (average spacing between vehicles):

$$l = \frac{Q_{si}}{ni} \quad (10)$$

Where

l = Average spacing between vehicles (feet)

Determine the distance (see Figure D.4) from the beginning of the transition taper to the beginning of the work space (C = X2 + X4) in miles.

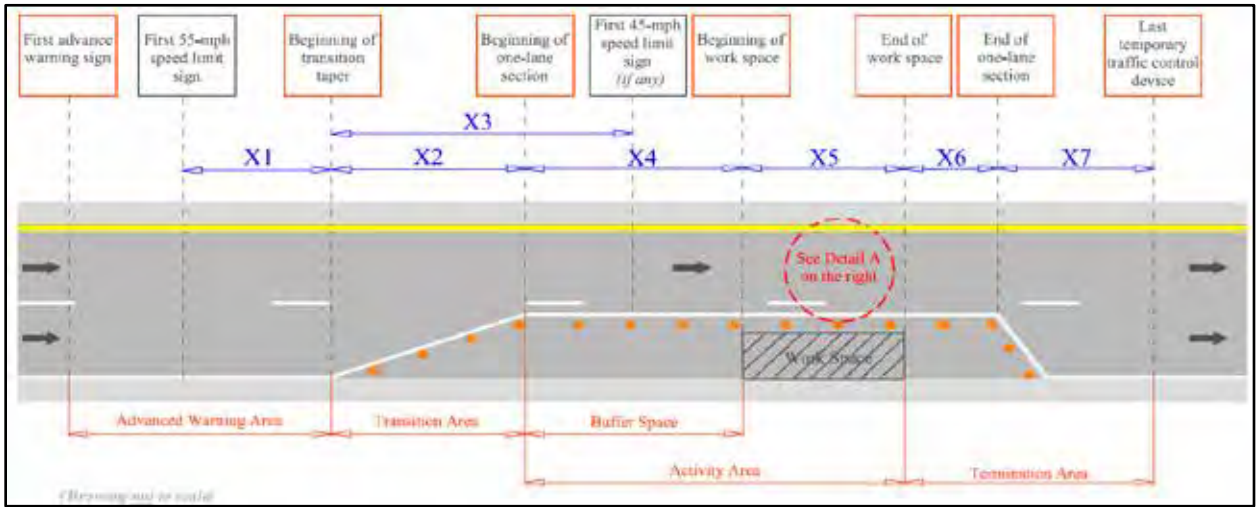

Figure D.4. Work zone sketch.

If $C \geq Q_{si} / N_{op}$, the queue does not extend upstream of the transition area, and the number of queued vehicles in the closed lane is zero ($n_{ci} = 0$). Also, the queue length (miles) at the end of this interval, Q_i, is computed by Equation 11 as follows:

$$Q_i = Q_{si} / N_{op} \tag{11}$$

Where

Q_i = Queue length at the end of the ith interval (miles)

Q_{si} = Stacked queue length at the end of the ith interval (miles)

N_{op} = Number of open lanes in the activity area

If $C < Q_{si} / N_{op}$, the queue will extend upstream of the beginning of the transition area. The queue length (mile) at the end of this interval, Q_i, is found as follows:

$$Q_i = C + (Q_{si} - C*N_{op}) / N_{nr} \tag{12}$$

Where

Q_i = Queue length at the end of the ith interval (miles)

C = The distance from the beginning of the transition taper to the beginning of the work space (mile)

Q_{si} = Stacked queue length at the end of the ith interval (miles)

N_{op} = Number of open lanes in the activity area

N_{nr} = Number of open lanes upstream of the beginning of the transition area

Also, the number of queued vehicles in the closed lane is estimated by Equation 13:

$$n_{ci} = \frac{Q_i - C}{l} * 5280 \qquad (13)$$

Where

n_{ci} = The number of queued vehicles in the closed lane at the end of the ith interval

Q_i = Queue length at the end of the ith interval (miles)

C = The distance from the beginning of the transition taper to the beginning of the work space (mile)

l = The spacing between the vehicles in the queue (feet)

Determine the average queue length during the ith interval ($\overline{Q}_i$) by using Equation 14:

$$\overline{Q}_i = \frac{(Q_i + Q_{i-1})}{2} \qquad (14)$$

Where

$\overline{Q}_i$ = Average queue length during the ith interval (miles)

Q_i = Queue length at the end of the ith interval (miles)

Q_{i-1} = Queue length at the end of the $(i - 1)^{th}$ interval (miles)

Determine the average number of queued vehicles in the closed lane:

$$\overline{n}_{ci} = \frac{(n_{ci} + n_{c(i-1)})}{2} \qquad (15)$$

Where

$\overline{n}_{ci}$ = The average number of vehicles in the queue and in the closed lane during the ith interval

n_{ci} = The number of queued vehicles in the closed lane at the end of the ith interval

$n_{c(i-1)}$ = The number of queued vehicles in the closed lane at the end of the $(I - 1)^{th}$ interval

12. Determine the distances B, C, D, defined as follows:

B = The distance (miles) from the first 55-mph speed limit sign to the beginning of the transition taper (B=X1).

C = The distance (miles) from the beginning of the taper to the beginning of the work space (C=X4+X2).

D = The distance (miles) from the 45-mph speed limit sign to the beginning of the work space (D=X4+X2-X3).

Estimate the delay in moving queue:

If the speed limit in the vicinity of the work space is 45 mph, then d_{qi} is determined by Equation 16:

$$d_{qi} = \begin{cases} \frac{\bar{Q}_i}{U_q} + \bar{n}_{ci}\bar{\gamma} - \frac{\bar{Q}_i}{45} & \text{if } \bar{Q}_i \leq D \\ \frac{\bar{Q}_i}{U_q} + \bar{n}_{ci}\bar{\gamma} - \frac{D}{45} - \frac{(\bar{Q}_i - D)}{55} & \text{if } D < \bar{Q}_i \leq B + C \\ \frac{\bar{Q}_i}{U_q} + \bar{n}_{ci}\bar{\gamma} - \frac{D}{45} - \frac{B + C - D}{55} - \frac{(\bar{Q}_i - B - C)}{65} & \text{if } B + C \leq \bar{Q}_i \end{cases} \quad (16)$$

If the speed limit in the vicinity of the work space is 55 mph, then d_{qi} is determined by Equation 17:

$$d_{qi} = \begin{cases} \frac{\bar{Q}_i}{U_q} + \bar{n}_{ci}\bar{\gamma} - \frac{\bar{Q}_i}{55} & \text{if } \bar{Q}_i \leq B + C \\ \frac{\bar{Q}_i}{U_q} + \bar{n}_{ci}\bar{\gamma} - \frac{B + C - D}{55} - \frac{(\bar{Q}_i - B - C)}{65} & \text{if } B + C < \bar{Q}_i \end{cases} \quad (17)$$

Where

d_{qi} = Average delay per vehicle during the ith hour due to queuing (hours/vehicle)

$\bar{Q}_i$ = Average queue length during the ith hour (miles)

U_q = Average speed of the traffic in the queue (mph)

$\bar{n}_{ci}$ = Average number of vehicles (obtained by Equation 15) in the queue and in the closed lane

$\bar{\gamma}$ = The additional time required for a vehicle to move from the closed lane to the open lane in the same queue position. Whenever $\bar{n}_{ci}$ is zero, $\bar{\gamma}$ = 0. Otherwise, it is suggested to use $\frac{60}{C_{adj} * t}$ for $\bar{\gamma}$ where C_{adj} is the adjusted capacity of the work zone in vpl, and t is the duration of the interval.

13. If demand is more than departure rate ($D_i > C_{adj} * N_{op}$), then d_{ui} = 0, and skip step 13. Otherwise, use Equation 18 to estimate the average delay for each vehicle due to an operating speed less than the speed limit in the work zone:

$$d_{ui} = \begin{cases} \left(\frac{E}{U_o} - \frac{E}{SL}\right) & \text{if } U_o < SL \\ 0 & \text{Otherwise} \end{cases} \quad (18)$$

Where

d_{ui} = Delay per vehicles in an undersaturated condition during the ith interval (hours/vehicle) due to an operating speed less than the speed limit

E = The distance (miles) from the end of the buffer space to the end of the activity area (E=X5)

U_0 = The operating speed (mph)

SL = Speed limit in the vicinity of the work space

14. Estimate the proportion of the hour in an oversaturated condition, β, using Equation 19 as follows:

$$\beta = \frac{n_{i-1}}{\left(C_{adj} * \frac{t}{60}\right) * N_{OP} - V_i} \tag{19}$$

Where

n_{i-1} = The number of vehicles in the queue at the end of the (i – 1)th hour

C_{adj} = Adjusted capacity of the work zone (vehicles per lane)

T = Duration of the interval (minutes)

V_i = Arriving volume during the ith interval (vehicles per lane)

N_{op} = Number of lanes open in the activity area

Estimate average delay by Equation 20 as follows:

$$d_i = \begin{Bmatrix} \beta * d_{qi} + (1-\beta) * d_{ui} & \text{if } 0 < \beta < 1 \\ d_{qi} + d_{ui} & \text{Otherwise} \end{Bmatrix} \tag{20}$$

Where

d_i = Average delay experienced by users during the ith interval

d_{qi} = Average delay per vehicle under queuing condition during the ith interval

d_{ui} = Delay experienced by each vehicle in undersaturated conditions during the ith interval due to an operating speed less than the speed limit.

Estimate the total delay during the ith interval by Equation 21 as follows:

$$D_{ti} = V_i * d_i \tag{21}$$

Where

D_{ti} = Total delay during the ith interval (hours)

V_i = Arriving volume during the ith interval (vehicles)

d_i = Average delay experienced by drivers during the ith interval (hours/vehicle)

Compute the users' costs for the ith hour using Equation 22:

$$UC_i = D_{ti} * (P_{SUTi} * C_{SUTi} + P_{MUTi} * C_{MUTi} + PC_i * C_C * N_{OCC}) \tag{22}$$

Where

UC_i = Total users' costs during the ith interval ($)

D_{ti} = Total delay during the ith interval (hours)

C_{SUTi} = Hourly delay cost for single-unit trucks ($/hour); the default value is 70$/hour in 2009

C_{MUTi} = Hourly delay cost for combination trucks ($/hour); the default value is 90$/hour in 2009

C_C = Hourly delay cost for each passenger in a car ($/hour/passenger); the default value is 20$/hour in 2009

N_{OCC} = Average rate of occupancy (passengers/car); the default value is 1.25 passengers/car in 2009

P_{SUTi} = Percentage of single-unit trucks during the ith interval (entered as decimal)

P_{MUTi} = Percentage of combination trucks during the ith interval (entered as decimal)

P_{Ci} = Percentage of passenger cars during the ith interval, obtained using Equation 23:

$$P_{Ci} = 1 - P_{SUTi} - P_{MUTi} \tag{23}$$

15. Perform steps 1 through 14 for each interval of the study and compute total users' costs for the entire period of the study as follows:

$$UC = \sum_{i=1}^{t} UC_i \tag{24}$$

Where

UC = Total users' costs across all study intervals

UC_i = Total users' costs for the ith interval of the study

t = Total number of study intervals in one day (an interval length can be less than an hour)

Equation 24 should be computed for all intervals in one day. Then it should be multiplied by the number of days with the same traffic and work zone conditions to find the total users' costs for those days.

It is worth mentioning that there may be more than one traffic/work zone condition during the time the roadway is under construction. For each of the traffic/work zone conditions, a separate computation should be made, and the users' costs should be tallied for all of the conditions.

APPENDIX E CALCULATION DETAILS

Appendix D explains the WorkZoneQ algorithm through a step-by-step procedure; this appendix provides more details for the calculations.

E.1 Shockwave Speed

The queue length calculation that was used in the software is different from the one proposed in Phase 1 of this project. The algorithm proposed in Phase 1 might be suitable for when the capacity is practically fixed and there is no further capacity reduction or increase during the analysis. To incorporate the effect of capacity and arrival variations, an algorithm based on shockwave theory was implemented in WorkZoneQ . It keeps track of the shockwaves that are produced due to capacity or arrival rate changes during traffic congestion.

The following figure shows queue propagation when arriving volume exceeds capacity:

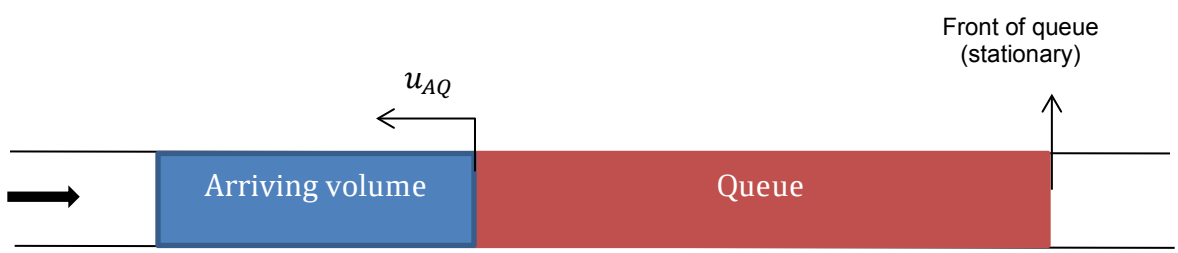

Figure E.1. Queue propagation when demand exceeds capacity.

Shockwave theory computes the rate of queue growth as follows:

$$u_{AQ} = \frac{F_Q - F_A}{D_Q - D_A} \tag{25}$$

Where

u_{AQ} = The shockwave speed between the arriving volume and queue

F_A and F_Q = Flow rates of arriving volume and queue state, respectively

D_A and D_Q = Densities of arriving volume and queue state, respectively

Because there is no density data directly collected from field, density is estimated by flow rate divided by speed. Then the estimated shockwave speed is calculated as follows:

$$u_{AQ} = \frac{F_Q - F_A}{\frac{F_Q}{S_Q} - \frac{F_A}{S_A}} \tag{26}$$

Where

S_A and S_Q = The speeds for arriving volume and queue state, respectively

S_Q and F_Q = Correspond to the peak point of the developed speed-flow curve and are determined by the program as explained in Appendix D

F_A = the arriving volume count, which is entered by WorkZoneQ users

Usually, the speed of the arriving volume is not collected by volume counters. Hence, the program assumes a speed (S_A) of 65 mph for the arriving volume. Once shockwave speed is calculated, the queue length at time t_2, $QL(t_2)$ is computed:

$$QL(t_2) = QL(t_1) + u_{AQ} * (t_2 - t_1) \quad (27)$$

The program can estimate the beginning of congestion when the queue length is assumed to be zero. Thereafter, the Equation 27 is used to compute queue length at any time.

E.2 Beginning of Congestion

The beginning of congestion is when demand exceeds capacity. However, direct application of this logic may produce some error due to the nature of the demand data available. The issue is explained using the following simple example for a bottleneck with capacity of 1,250 vehicles/hour.

Table E.1. Volume Data

Interval (hr)	1	2	3	4	5	6	7
Start time	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM
End time	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
Traffic count (veh)	1,100	1,200	1,400	1,300	1,200	1,100	1,000

If it is assumed that the arrival rate is always constant during the interval, the beginning of congestion will coincide with the beginning of the interval when demand exceeds capacity. With this assumption, the beginning of congestion would be the beginning of interval 3 as demand (1400) exceeds capacity (1,250). This assumption poses some drawbacks. It is not possible to find the onset of congestion in the middle of an interval; thus, the average error in the estimated beginning of congestion is half of the interval length, which in this case is 30 minutes. Moreover, it implies that in the beginning of the interval there is a sudden jump in the arrival rate. The instantaneous change in arrival rate may not be reasonable when the difference between the arrival rate of the two consecutive intervals is high. To reduce the possibility of error, the beginning of congestion is estimated, assuming that arrival rate changes linearly, rather than being constant. Let C be the capacity of the work zone in vph, and V_{i-1} and V_i be the arriving volumes for the intervals i – 1 and i, respectively, such that $V_{i-1} < C < V_i$, then the portion of interval i – 1, which is oversaturated, is

$$\theta = \frac{V_i - C}{V_i - V_{i-1}} \tag{28}$$

and

Beginning of congestion = Beginning of interval (i – 1) + (1– θ) * Interval length

For this example, $\theta = \frac{1400-1250}{1400-1200} = 0.75$, and congestion starts approximately at 11:15 AM.

E.3 Boundaries for Shockwave Speed

It is possible that the estimated shockwave speed is much higher than the expected rate in high-volume conditions. This might be due to the curves that are approximated by interpolation or due to the density data, estimated from speed-flow curves rather than field data. Thus, boundaries are established for four cases in this section.

It should be noted that the units of the variables are selected such that the shockwave speed is in feet/second.

1. Backward propagation from the back of queue

This case happens when arriving volume exceeds capacity (see Figure E.2).

Figure E.2. Backward queue propagation

The boundaries are set up as follows:

$$\tilde{u}_{AQ} = \max\{-16, u_{AQ}, \frac{(F_Q - F_A) * d_Q}{interval\ length}\} \tag{29}$$

Where

$\tilde{u}_{AQ}$ = Shockwave speed between arriving volume and queue after imposing the boundaries

d_Q = Spacing in the queue

All the units should be selected such that the three elements in the equation above are in feet/second. This equation ensures that the absolute value of shockwave speed is not more than 16 feet/second, which roughly corresponds to queue length growth when arriving volume is

two vehicles/second and average vehicle length (including trucks) is 32 feet. In addition, this value is roughly the maximum deceleration rate, which can be considered an upper bound for queue length growth in the worst conditions under which vehicles are stopped in the queue. The third term imposes the constraint that queue growth cannot be more than the number of vehicles that will be added to queue multiplied by the spacing in the queue.

2. Queue shrinkage from the back of queue

This happens when demand falls below capacity and the back of the queue moves in the traffic direction. In this case, u_{AQ} is positive and the following equation is used to restrict it:

$$\tilde{u}_{AQ} = \min\{S_Q, u_{AQ}, \frac{(F_Q - F_A) * d_q}{interval\ length}\} \tag{30}$$

The only change with respect to case 1 is the first term implying the recovery shockwave speed cannot be more than speed in the queue, S_Q.

3. Queue propagation from the front

Assume that there is a queuing state, called queue 1, in the work zone. When there is a capacity drop, a new queue state, called queue 2, propagates backward, as shown Figure E.3.

Figure E.3. Queue propagation due to capacity drop.

In this case, shockwave speed is restricted by the following equation:

$$\tilde{u}_{Q_1Q_2} = \max\{-16, u_{Q_1Q_2}, \frac{(F_{Q_2} - F_A + N_{Q_1}) * d_{Q_2}}{interval\ length}\} \tag{31}$$

Where N_{Q_1} is the number of vehicles in queue 1.

Similarly when there are three queues, the boundaries are estimated as follows:

$$\tilde{u}_{Q_2Q_3} = \max\{-16, u_{Q_2Q_3}, \frac{(F_{Q_3} - F_A + N_{Q_1} + N_{Q_2}) * d_{Q_3}}{interval\ length}\} \tag{32}$$

As will be explained in the next section, the program analyzes up to three queues in a given interval.

4. Shrinkage from the front of queue

Capacity increase creates a backward shockwave, increasing traffic speed and queue flow rate. The following bounds are applied to the estimated shockwave speed:

$$\tilde{u}_{Q_1Q_2} = \max\{-32, S_{Q_1Q_2}, \frac{(F_{Q_2} - F_A + N_{Q_1}) * d_{Q_2}}{interval\ length}\} \tag{33}$$

When there are three queues, the boundaries are estimated as follows:

$$\tilde{u}_{Q_2Q_3} = \max\{-32, u_{Q_2Q_3}, \frac{(F_{Q_3} - F_A + N_{Q_1} + N_{Q_2}) * d_{Q_3}}{interval\ length}\} \tag{34}$$

E.4 Maximum Number of Queue States

The program can process up to three queue states in a time interval. However, when the number of queue states exceeds three, the program replaces the existing three states with another queue representing the average condition of the three states. Assume that there are three queuing states in the work zone and due to further capacity drop, a new backward shockwave will be created. Before creation of the new wave, the three states are replaced with an average queue state, as shown in Figure E.4.

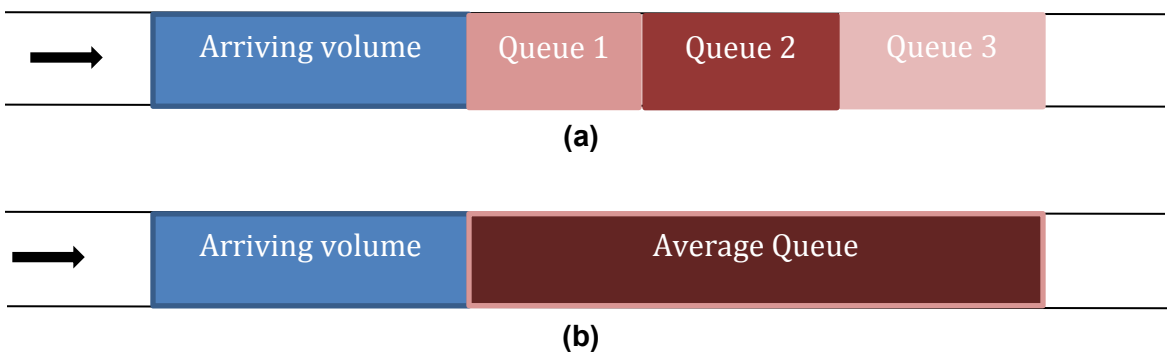

Figure E.4. Program reaches the maximum number of queues: (a) three queue states, (b) queue state representing average condition of the three queues.

Average speed, density, and flow rate are computed as follows:

$$S_Q = \frac{S_{Q_1} * N_{midQ_1} + S_{Q_2} * N_{midQ_2} + S_{Q_3} * N_{midQ_3}}{N_{midQ_1} + N_{midQ_2} + N_{midQ_3}} \tag{35}$$

$$D_Q = \frac{N_{midQ_1} + N_{midQ_2} + N_{midQ_3}}{L_{midQ_1} + L_{midQ_2} + L_{midQ_3}} \tag{36}$$

$$F_Q = S_Q * D_Q \tag{37}$$

Where

S_{Q_i} = speed of queue i

N_{midQ_i} = Number of vehicles in queue i in the middle of the interval

L_{midQ_i} = Length of queue i in the middle of the interval

Then the program creates the new wave due to capacity drop and keeps track of the changes within the interval.

E.5 Average Speed Calculation

The program computes an average speed for each interval, representing the travel speed within the work zone. The algorithm to compute average speed is explained for three cases.

1. Interval is completely in undersaturated conditions

The speed, corresponding to the arriving volume, is read from the speed-flow curve.

2. Interval is completely oversaturated

If there is one queue, the speed corresponding to capacity will be read from the speed-flow curve, but if there is more than one queue due to capacity increase or decrease, the weighted average speed will be computed as shown in Equation 38, where the weights are the number of vehicles in each queue at the middle of the interval

$$S_Q = \frac{S_{Q_1} * N_{midQ_1} + S_{Q_2} * N_{midQ_2} + S_{Q_3} * N_{midQ_3}}{N_{midQ_1} + N_{midQ_2} + N_{midQ_3}} \tag{38}$$

As previously mentioned, the number of queues in a time interval cannot exceed three.

3. Interval is partially oversaturated

Weighted average speed is computed for the queues presented during the interval, as well as for the arriving volume when there is no queue.

$$S_Q = \frac{S_{Q_1} * N_{midQ_1} + S_{Q_2} * N_{midQ_2} + S_{Q_3} * N_{midQ_3} + S_A * N_A}{N_{midQ_1} + N_{midQ_2} + N_{midQ_3} + N_A} \tag{39}$$

where N_A is the number of vehicles that experienced undersaturated conditions only, and S_A is the speed corresponding to the arriving volume, which is read from the speed-flow curve.

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